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STUDY OF LASER CUTTING MACHINING & OPTIMUM EFFICIENCY PARAMETERS

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Abstract: *This Paper presents an experimental study that is conducted on Laser Cutting machine with Oxygen Gas & Stainless steel 304 as a Material. Stainless Steel Plate 304 is selected as experimental material. Input parameters Like Gas Pressure, Laser Power, Cutting Speed kept variable. Some parameters like Nozzle Diameter, Focus length, Lens Diameter, Standoff Distance are kept fixed. Some Response variables like Surface roughness, Kerf width will be inspected. Using suitable DOE method, Study of Parameters Optimization will be obtain for laser Cutting Using Oxygen as Gas.*

Nitrogen gas laser cutting is mostly chosen for Stainless steel to get better finishing as it doesn't leave burr marks of oxidation as oxygen gas does. So the research work on Stainless steel with combination of oxygen gas Laser cut is rare & its experiment work has not been conducted so far anywhere. That is why this combination of Stainless steel with Oxygen gas has been chosen for this research.

Keywords: O_2 gas Laser Cutting, Cut Quality, Parameters Optimization

Introduction:

Laser cutting depends on an assist gas, which may be active or inert. Oxygen is the standard active assist gas used for laser cutting of mild and carbon steels. It is also referred to as the cutting gas.

When cutting with oxygen, the material is burned and vaporized after being heated up to ignition temperature by the laser beam. The reaction between the oxygen and the metal actually creates additional energy in the form of heat, which supports the cutting process. The liquid iron oxide, which has very low viscosity, is removed from the cut by the shear force of the oxygen jet.

The pressure of the oxygen can be increased in order to improve the melt-shear removal process. This increase is not, however, limited by the cooling effect caused by the gas, but by the increase in sideways burning due to the higher oxygen concentration. This can result in bad cuts with significant dross or no cut at all.

The maximum oxygen pressure depends primarily on the material thickness. For thin sheets up to 2 or 3 mm, oxygen pressure can be as high as 20 bar, where the contribution of the combustion process is insignificant and the melt-shear removal process does all the work. For thick sheets however, the maximum applicable oxygen pressure drops rapidly. At thicknesses above 20 mm, the applied pressure is rarely over 1 bar (gauge).

Sahajanand Brahmastra- Vector 3015 F1.0 Laser Cutting Machine from 2015 was manufactured in India and has a working history of only 4000 production hours. Equipped with a Beckroff control unit, this 1 kW Laser Cutter has mainly worked with stainless steel during the past. A pallet changer and an UPS unit are included as additional equipment.

Material Selection:

Material for the experiment is stainless steel 304. Stainless steel is mostly used for fabrication work. Mild steel is so prone to corrosion but stainless steel has corrosion resist property & has good machinability. Corrosion can affect experiment measurement, so this way corrosion resistive material is good for experiment. Moreover, research on mild steel laser cutting is widely available but stainless steel with Oxygen laser cutting is rarely available.
Type 304 is the most widely used austenitic stainless steel. It is also known as "18/8" stainless steel because of its composition, which includes 18% chromium and 8% nickel. Type 304 stainless steel has good forming and welding properties as well as strong corrosion resistance and strength.

304 Stainless Physical Properties:

- **Density:** 8.03g/cm^3
- **Electrical resistivity:** 72 microhm-cm (20C)
- **Specific Heat:** 500 J/kg °K (0-100°C)
- **Thermal conductivity:** 16.3 W/m-k (100°C)
- **Modulus of Elasticity (MPa):** 193 x 10^3 in tension

Melting Range: 2550-2650°F (1399-1454°C)

PROCESS PARAMETERS

The laser cutting machining considered working parameter as input parameters is laser power, cutting speed, assisted gas pressure, stand of distance and output parameter like surface roughness , material removal rate, heat affected zone and kerf width.

INPUT PARAMETER

1. **Laser power**

Laser power is the total energy emitted in the form of laser light per second while the intensity of the laser beam is the power divided by the area over which the power is concentrated. High beam intensity, obtained by focusing the laser beam to a small spot, is desirable for cutting applications because it causes rapid heating of the kerf leaving little time for the heat to dissipate to the surrounding which results into high cutting speeds and excellent cut quality. Additionally, reflectivity of most metals is high at low beam intensities but much lower at high intensities and cutting of thicker materials requires higher intensities. The optimum incident power is established during procedure development because excessive power results in a wide kerf width, a thicker recast later and an increase in dross while insufficient power cannot initiate cutting. High power beams can be achieved both in pulsed and continuous modes;

however, high power lasers do not automatically deliver high intensity beams. Therefore, the focus ability of the laser beam is an important factor to be considered.
The laser cutting power we opting for experiment will be 500W, 550W & 600 W in variation.

2. **Cutting speed**

The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided into two parts namely; energy used in generating a cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken. Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. A reduction in cutting speed when cutting thicker materials leads to an increase in the wasted energy and the process becomes less efficient. The levels of conductive loss, which is the most substantial thermal loss from the cut zone for most metals, rise rapidly with increasing material thickness coupled with the reduction in cutting speed. The cutting speed must be balanced with the gas flow rate and the power. As cutting speed increases, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When oxygen is applied in mild steel cutting, too low cutting speed results in excessive burning of the cut edge, which degrades the edge quality and increases the width of the heat affected zone (HAZ). In general, the cutting speed for a material is inversely proportional to its thickness. The speed must be reduced when cutting sharp corners with a corresponding reduction in beam power to avoid burning.
The cutting speed will be chosen as 550 mm/min , 600 mm/min & 650 mm/min in variation.

3. **Process Gas & Gas pressure**

The process gas has five principle functions during laser cutting. An inert gas such as nitrogen expels molten material without allowing drops to solidify on the underside (dross) while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting thick sections with high beam intensities and focusing optics are protected from spatter by the gas flow. The cut edge is cooled by the gas flow thus restricting the width of the HAZ. The choice of process gas has a significant effect on the productivity and quality of the laser cutting process. The commonly used gases are oxygen (active gas) and nitrogen (inert gas) with each having its own advantages and potential disadvantages. Although nitrogen is not purely inert, it is the most commonly used gas for inert gas cutting because it is relatively cheap. Purely inert gases, argon and helium, are common choices when cutting titanium since they prevent the formation of oxides or brittle titanium nitrides. Nitrogen gas is the preferred gas for the cutting of stainless steel, high-alloyed steels, aluminium and nickel alloys and it requires higher gas pressures to remove the molten material from the cut kerf. The high gas pressure provides an extra mechanical force to blow out the molten material from the cut kerf. When high-pressure nitrogen cutting is used to cut stainless steel, it produces a bright, oxide free cut edge but the processing speeds are lower than in oxygen assisted cutting. The main problem associated with the inert gas cutting is the formation of burrs of resolidified material on the underside of the kerf. Burr-free cutting conditions are achieved by optimization of the principle processing parameters; nozzle diameter, focal position and gas pressure. The nitrogen pressure lies in the range of 10-20 bar and the pressure requirement increases with increasing material thickness. Nitrogen gas purity should be above 99.8%. Oxygen is normally used for cutting of mild steel and low-alloyed steels. Use of oxygen causes an exothermic reaction, which contributes to the cutting energy resulting into high cutting speeds and the ability to cut thick sections up to 12mm. However, oxygen cutting leads to oxidized cut edges and requires careful control of process parameters to minimize dross adherence and edge roughness. The oxygen gas nozzle pressure usually lies in the range of 0.5-5 bar. The oxygen pressure is reduced as plate thickness is increased to avoid burning effects and the nozzle diameter is increased. High gas purity is important – mild steel of 1mm thickness can be cut up to 30% more quickly using 99.9% or 99.99% purity oxygen in comparison with the standard oxygen purity of 99.7%.

So, The Oxygen gas will be used for the laser cutting experiment & in the variation of 5 bar, 6 bar & 7 bar gauge pressure.

4. **Stand-of-distance**

The stand-off distance is the distance between the nozzle and the workpiece. This distance influences the flow patterns in the gas, which have a direct bearing on the cutting performance and cut quality. Large variations in pressure can occur if the stand-off distance is greater than about 1mm. A stand-off distance smaller than the nozzle diameter is recommended because larger standoff distances result in turbulence and large pressure changes in the gap between the nozzle and work piece. With a short standoff distance, the kerf acts as a nozzle and the nozzle geometry is not so critical. In this experiment stand of distance will be constant at 700 microns.

5. **Focus length & nozzle diameter**

The nozzle delivers the cutting gas to the cutting front ensuring that the gas is coaxial with the laser beam and stabilizes the pressure on the workpiece surface to minimize turbulence in the melt pool. The nozzle design, particularly the design of the orifice, determines the shape of the cutting gas jet and hence the quality of the cut. The diameter of the nozzle, which ranges from 0.8 mm and 3 mm, is selected according to the material and plate thickness. Due to the small size of the focused laser beam, the cut kerf created during laser cutting is often smaller than the diameter of the nozzle. Consequently, only a portion of the gas jet formed by the nozzle penetrates the kerf, which necessitates the use of a high gas pressure.
In this experiment nozzle Diameter is fixed at 1.5mm, focus length is (-ve)7 mm & lens diameter is 125mm respectively.

OUTPUT PARAMETER /RESPONSE VARIABLE

1. **Surface roughness**

Surface Roughness is an output parameter. Minimal roughness and the visual appearance of the cut edge are key quality requirements when laser cutting sheet metal. The optimal cutting parameters are being determined in an extensive series of experiments. Up to now fluctuations in the process parameters, such as laser output, have been regarded as the sole cause of surface roughness. Surface Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The standard which is utilized in the United States is the Roughness Average (Ra). This is defined as the arithmetic average of all departures of the roughness profile from the centre line of the evaluation length. It is also known as the arithmetic average (AA) and the centre line average (CLA). The finest surface finishes will be of the order of Ra 0.10 (μm), and the visual effect is almost like a mirror finish the parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut off length. Cut-off length is the length that the stylus is dragged across the surface; a longer cut off length will give a more average value, and a shorter cut-off length might give a less accurate result over a shorter stretch of surface.

2. Kerf Width

The laser beam burns away a portion of material when it cuts through which is known as the laser kerf and ranges from 0.08mm – 1mm or even more depending on the material type and other conditional factors.. Any areas in design where cut lines come closer than 0.5mm together could burn away entirely. Any details narrower than 1mm are likely to be very fragile and in some cases can cause the material to warp whilst cutting. Laser power and oxygen pressure had significant influence on the percentage of kerf width variations. Increasing of the laser power and the oxygen pressure provided high oxidation rate and hence deepened the melt zone. Consequently, the depth of stria increased drastically. Low cutting speed and low oxygen gas pressure lead to premature formation of the dross.

Surface roughness & Kerf width will be measured by inspection

Input Parameters

- Factor A - Laser Power (watt)
- Factor B - Cutting Speed (mm/min)
- Factor C - Gas Pressure (bar)

1. Factors

These are variables that have direct influence on the performance of the product or process under investigation.

2. Levels

This is the values or descriptions that define the condition of the factor held while performing the experiments.

Sr. no	Input Parameters	Level-1	Level-2	Level-3
1	Laser Power	500 W	550 W	600 W
2	Cutting speed	550 mm/min	600 mm/min	650 mm/min
3	Gas Pressure	5 bar	6 bar	7 bar

(Input Variable)

Sr. no	Fixed parameter	Set value
1	Nozzle dia.	1.5mm
2	Focus length	-7 mm
3	Standoff height	700 microns
4	Lens dia.	125 mm

(Fixed Variable)

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. Experimental design is an effective tool for maximizing desirable effect and minimizing undesirable effect. In factorial design, only one factor is changing at a one time and investigates effect of many other factors. A full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. Experimental design is the process of planning a study to meet specified objectives. Planning an experiment properly is very important in order to ensure that the right type of data and a sufficient Assessment and power are available to answer the research questions of interest as clearly and efficiently as possible.

Features:

- Total experiments conducted are 27 cycles with variation in parameters.
- Each experiment cut rectangular block of 80x80 mm
- Additional 25mm cut for kerf Measurement
- Raw material used is Stainless Steel 304
- Initial dimension of raw material is 1500x100 mm
- Thickness chosen of material is 6 mm
- Experiment conducted at normal room temperature
- Power, cutting speed & gas pressure changed sequential
- Nozzle dia, focus length, standoff height kept constant
- Each work piece was given specific experimental number
- Power capacity of Laser cutting Machine is 1 KW
- Oxygen as a Gas is used
- Raw material was cleaned before conducting the Trial
- Safety equipment used while conducting the experiment
- Workpiece will be taken for inspection

introductions

Design of experiments is a powerful analysis tool for modelling and analysing the influence of control factors on performance output. The traditional experimental design is difficult to be used especially when dealing with large number of experiments and when the number of machining parameter is increasing . The most important stage in the design of experiment lies in the selection of the control factors . Therefore, the Taguchi_method, which is developed by Dr. Genichi Taguchi, is introduced as an experimental technique which provides the reduction of experimental number by using orthogonal arrays and minimizing the effects out of control factors . Taguchi is a method which includes a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analysis data in order to obtain the information about behaviour of the given process. Besides that, it is a set of methodologies that took into account of the inherent variability of materials and manufacturing process during the design stage . It is almost similar to the design of experiment (DOE) but the Taguchi design's balanced (orthogonal) experimental combination offers more effective technique than the fractional factorial design. This technique has been applied in the manufacturing processes to solve the most confusing problems especially to observe the degree of influence of the control factors and in the determination of optimal set of conditions .

In the Taguchi definition, the quality of a product is defined in terms of the loss imparted by the product to the society from the time it is shipped to the customer . The losses due to the functional variation are known as losses due to the deviation of the product's functional characteristics from its desired target value. Besides that, the noise factors are the uncontrollable factors which cause the functional characteristics of a product that do not achieve its targeted values . The noise factors can be classified as the external factors (temperature and human errors), manufacturing imperfections and product deterioration. The main purpose of quality engineering is to make sure that the product can be robust with the respect of all possible noise factors . So, the Taguchi method could decrease the experimental or product cycle time, reduce the cost while increasing the profit and determines the significant factors in a shorter time period as it can ensure the quality in the design phase .

The procedure of Taguchi's design as shown in can be categorized into three stages viz. system design, parameter design and tolerance design . Parameter design, considered as the most important stage, can determine the factors affecting quality characteristics in the manufacturing process. The first step in Taguchi's parameter design is selecting the proper orthogonal array (OA) according to the controllable factors (parameters). Then, experiments are run according to the OA set earlier and the experimental data are analysed to identify the optimum condition. Once the optimum conditions are identified, then confirmation runs are conducted with the identified optimum levels of all the parameters .

Sr. no	Input Parameters	Level-1	Level-2	Level-3
1	Laser Power	500 W	550 W	600 W
2	Cutting speed	550 mm/min	600 mm/min	650 mm/min
3	Gas Pressure	5 bar	6 bar	7 bar

Sr. no	Fixed parameter	Set value
1	Nozzle dia.	1.5mm
2	Focus length	-7 mm
3	Standoff height	700 microns
4	Lens dia.	125 mm

(Fixed Variable)

Sr. no	Laser Power (W)	Cutting speed(mm/min)	Gas Pressure(bar)	Surface roughness(µm)	Kerf(mm)
1	500	550	5	1.892	0.43
2	500	550	6	1.683	0.40
3	500	550	7	1.703	0.45
4	500	600	5	1.705	0.39
5	500	600	6	1.587	0.38
6	500	600	7	1.787	0.40
7	500	650	5	1.402	0.39
8	500	650	6	1.519	0.43
9	500	650	7	1.684	0.41
10	550	550	5	1.958	0.42
11	550	550	6	1.770	0.41
12	550	550	7	1.738	0.40
13	550	600	5	1.968	0.43
14	550	600	6	1.666	0.43
15	550	600	7	1.973	0.39
16	550	650	5	1.947	0.41
17	550	650	6	1.932	0.42
18	550	650	7	1.823	0.40
19	600	550	5	1.942	0.40
20	600	550	6	1.797	0.42
21	600	550	7	1.684	0.42
22	600	600	5	1.724	0.43
23	600	600	6	1.895	0.43
24	600	600	7	1.380	0.43
25	600	650	5	1.584	0.43
26	600	650	6	1.577	0.43
27	600	650	7	1.384	0.44

(Experimental measurement)

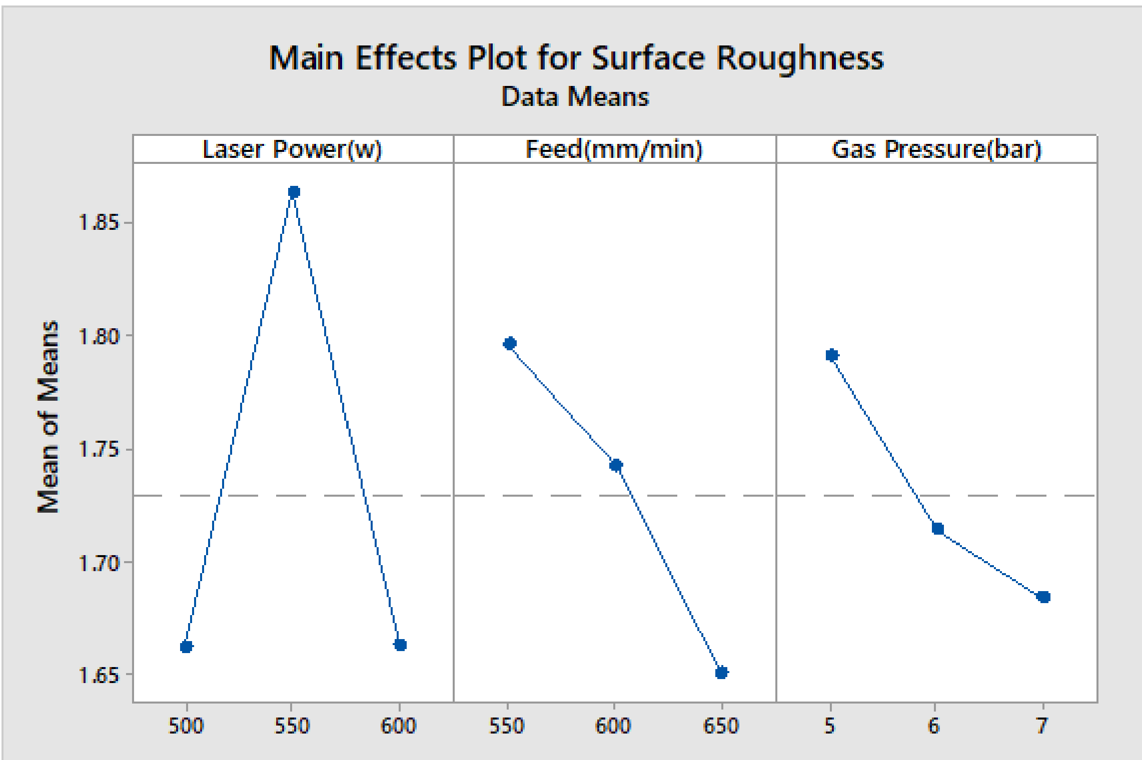
Design Summary

Taguchi Array	L27(3^3)
Factors:	3
Runs:	27

Response Table for Means

Level	Laser Power(w)	feed (mm/min)	Gas Pressure(bar)
1	1.662	1.796	1.791
2	1.864	1.743	1.714
3	1.663	1.650	1.684
Delta	0.201	0.146	0.107
Rank	1	2	3

(Response table for means)



(Main effect plot for surface Roughness)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.147911	0.049304	1.63	0.210
Laser Power(w)	1	0.000001	0.000001	0.00	0.995
feed (mm/min)	1	0.096068	0.096068	3.18	0.088
Gas Pressure(bar)	1	0.051842	0.051842	1.71	0.203
Error	23	0.695543	0.030241		
Total	26	0.843455			

Regression Equation

surface roughness = 2.925 + 0.000006 Laser Power(w) - 0.001461 feed (mm/min) - 0.0537 Gas Pressure(bar)

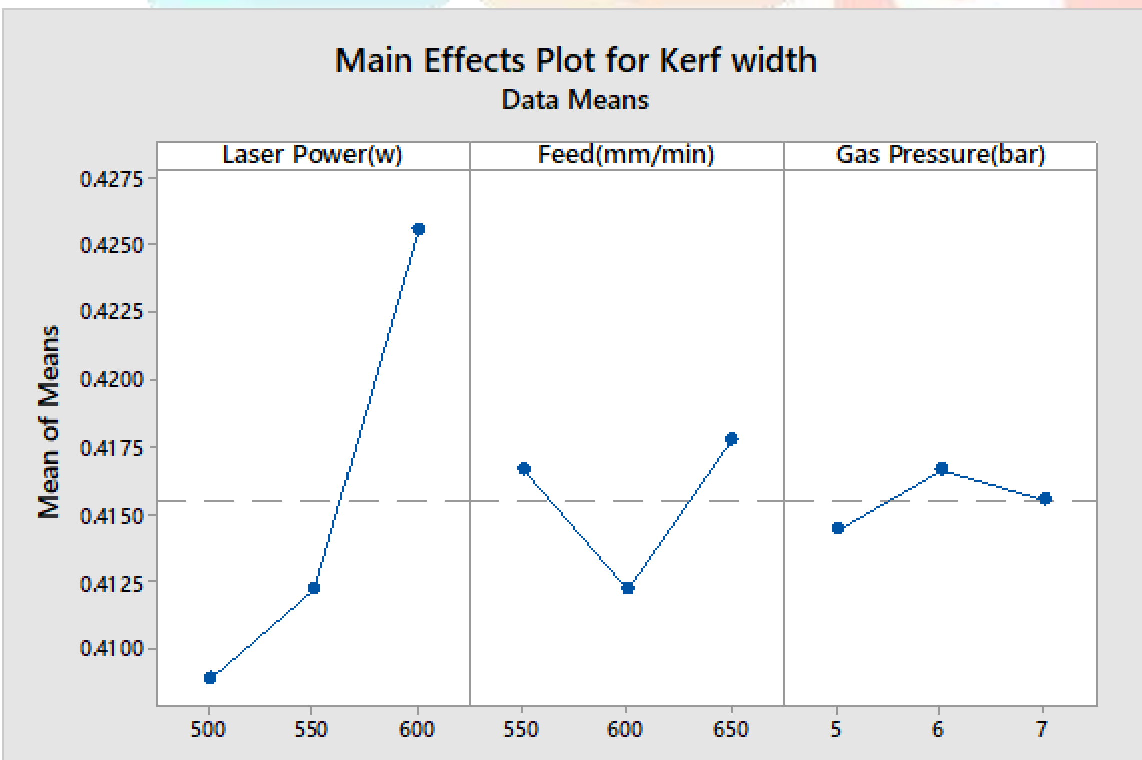
taguchi for Kerf width

There are total 27 runs of experiment, with 3 input factors.

Response Table for Means

Level	Laser Power(w)	feed (mm/min)	Gas Pressure(bar)
1	0.4089	0.4167	0.4144
2	0.4122	0.4122	0.4167
3	0.4256	0.4178	0.4156
Delta	0.0167	0.0056	0.0022
Rank	1	2	3

(Response table for means)



(Main effect plot for kerf width)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.001261	0.000420	1.38	0.274
Laser Power(w)	1	0.001250	0.001250	4.10	0.055
feed (mm/min)	1	0.000006	0.000006	0.02	0.894
Gas Pressure(bar)	1	0.000006	0.000006	0.02	0.894
Error	23	0.007006	0.000305		
Total	26	0.008267			

Regression Equation

kerf width(mm) = 0.3139 + 0.000167 Laser Power(w) + 0.000011 feed (mm/min) + 0.00056 Gas Pressure(bar)

GREY RELATIONAL ANALYSIS

Through the grey relational analysis, a grey relational grade can be obtained to evaluate the multiple performance characteristic. As a result, optimization of the complicated multiple performance characteristic can be converted into the optimization of a single grey relation grade. For multiple performance characteristic optimizations using GRA, following steps are followed:

Process Steps for Multi Response Optimization

The basic process steps for multi-response optimization are given below.

a) Normalization of experimental results for all performance characteristics.
b) Calculation of grey relational coefficient (GRC).
c) Calculation of grey relational grade (GRG) using weighing factor for performance characteristics.
d) Analysis of experimental results using GRG.
e) Selection of optimal levels of process parameters.
f) Conducting confirmation experiment to verify optimal process parameter settings.

NORMALIZATION OF S/N RATIO FOR RESPONSE PARAMETERS

In the grey relational analysis, a data pre-processing is first performed in order to normalize the raw data for analysis. Normalization is a transformation performed on a single data input to distributed the data evenly and scale it into an acceptable range for further analysis. In this study, a linear normalization of the response parameters are normalized for further analysis using following equations. In Grey relational generation, the normalized corresponding to the smaller-the-better (SB) criterion for SR which can be expressed as:

$$Xi(k) = \frac{\max yi(\quad) - yi(k)}{\max yi(k) - \min yi(k)} \qquad \text{---------(1)}$$

The normalized kerf width corresponding to the smaller-the-better (SB) criterion which can be expressed as:

$$Xi(k) = \frac{\max yi(\ \ ) - yi(k)}{\max yi(k) - \min yi(k)}$$ ---------(2)

Where, Xi (k) is the value after the Grey relational generation for the SB criteria.

Min yi(k) is the smallest value of yi(k) and for the kth response.

Max yi(k) is the largest value of yi(k) for the kth response.

An ideal sequence is Xi (k) (k=1, 2,.. m) for the responses.

The definition of the Grey relational grade in the course of the Grey relational analysis is to reveal the degree of relation between the 8 sequences [x0(k) and xi(k), k = 1,2,…,m and i = 1,2,…,9].

CALCULATION OF GREY RELATIONAL COEFFICIENT

Grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Grey relation coefficient and grey relational grade are calculated from normalized S/N ratio using following equations.

$$\gamma\ (yo\ (k),\ yj(k)) = \frac{\Delta \min + £\Delta max}{\Delta f(k) - £\Delta max}$$ ---------(3)

j=1, 2… n; k=1,2…m. where n is the number of experiment data and m is the number of Responses.

$$\Delta 0i = |Y0\ (k) - Yj(k)|$$ ---------(4)

Y0 (k) is the reference sequence (yo (k) =1, 2…m);

Yj(k) is the specific compression sequence.

This is the absolute value of the difference between Y0 (k) and Yj (k).

$\triangle$ Min = min. min ‖Y0 (k) − Yj (k) ‖ is the smallest value of Yj (k) -------- (5)

$\triangle$ Max = max. max‖Y0 (k) − Yj (k) ‖ is the largest value of Yj (k) -------- (6)

Where, £ is the distinguishing coefficient, which is defined in the range of 0 to 1.

PRE-NORMALIZATION DATA OF EXPERIMENTAL RESULTS

Sr. no	Machining Characteristic	Quality Characteristic
1	Surface roughness	Minimum
2	Kerf width	Minimum

In table, shows value of the pre-normalization data for the surface roughness and kerf width for this research work. This data has been got after calculate the pre normalization value by using equation no 1 and 2

exp no.	Data pre-normalization	
	Surface roughness	Kerf width
1	0.136594	0.285714
2	0.489039	0.714286
3	0.455312	0.000000
4	0.451939	0.857143
5	0.650927	1.000000
6	0.313659	0.714286
7	0.962901	0.857143
8	0.765599	0.285714
9	0.487352	0.571429
10	0.025295	0.428571
11	0.342327	0.571429
12	0.396290	0.714286
13	0.008432	0.285714
14	0.517707	0.285714
15	0.000000	0.857143
16	0.043845	0.571429
17	0.069140	0.428571
18	0.252951	0.714286
19	0.052277	0.714286
20	0.296796	0.428571
21	0.487352	0.428571
22	0.419899	0.285714
23	0.131535	0.285714
24	1.000000	0.285714
25	0.655987	0.285714
26	0.667791	0.285714
27	0.993255	0.142857

(Data pre-normalization)

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. According to performed experiment design, it is clearly observed from Table No.10.2 that the 'Laser beam machining process parameters' setting of experiment no. 07 has the highest grey relation grade. Thus, the Experiment 07 has the best multiple performance characteristic among 27 experiments, because it has the highest grey relation grade shown in table matrix.

The higher the value of the grey relational grade, the closer the corresponding factor combination is to optimal. A higher grey relational grade implies better machining quality.

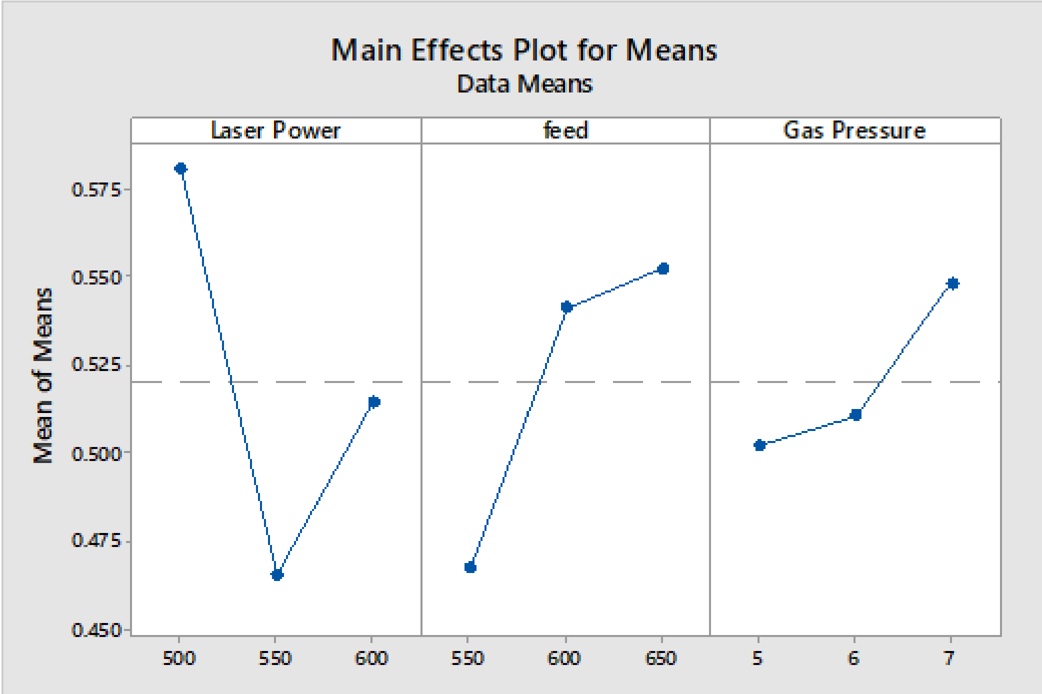
Following table shows the value of the grey relation co-efficient and Grey Relation grade.

no	Grey relation co-efficient		Grey Relation Grade	Orders
	Surface roughness	Kerf width		
1	0.366729	0.411765	0.389247	25
2	0.494579	0.636364	0.565471	6
3	0.478612	0.333333	0.405973	23
4	0.477072	0.777778	0.627425	5
5	0.588878	1	0.794439	2
6	0.421464	0.636364	0.528914	10
7	0.930926	0.777778	0.854352	1
8	0.680827	0.411765	0.546296	8
9	0.493755	0.538462	0.516108	12
10	0.339051	0.466667	0.402859	24
11	0.431901	0.538462	0.485181	16
12	0.453018	0.636364	0.544691	9
13	0.335218	0.411765	0.373491	27
14	0.509013	0.411765	0.460389	18
15	0.333333	0.777778	0.555556	7
16	0.34337	0.538462	0.440916	20
17	0.34944	0.466667	0.408053	22
18	0.400947	0.636364	0.518655	11
19	0.34537	0.636364	0.490867	15
20	0.415557	0.466667	0.441112	19
21	0.493755	0.466667	0.480211	17
22	0.46292	0.411765	0.437342	21
23	0.365373	0.411765	0.388569	26
24	1	0.411765	0.705882	3
25	0.592408	0.411765	0.502086	14
26	0.600811	0.411765	0.506288	13
27	0.986689	0.368421	0.677555	4

(grey coefficient and ranking)

Main effect of factors on grey relation grade

The mean of grey relational grade for each level of the machining parameters is summarized and shown in table. The higher the value of the grey relational grade, the closer the corresponding factor combination is to optimal. A higher grey relational grade implies better machining quality.



(Main effect plot for mean)

(Response Table for Means)

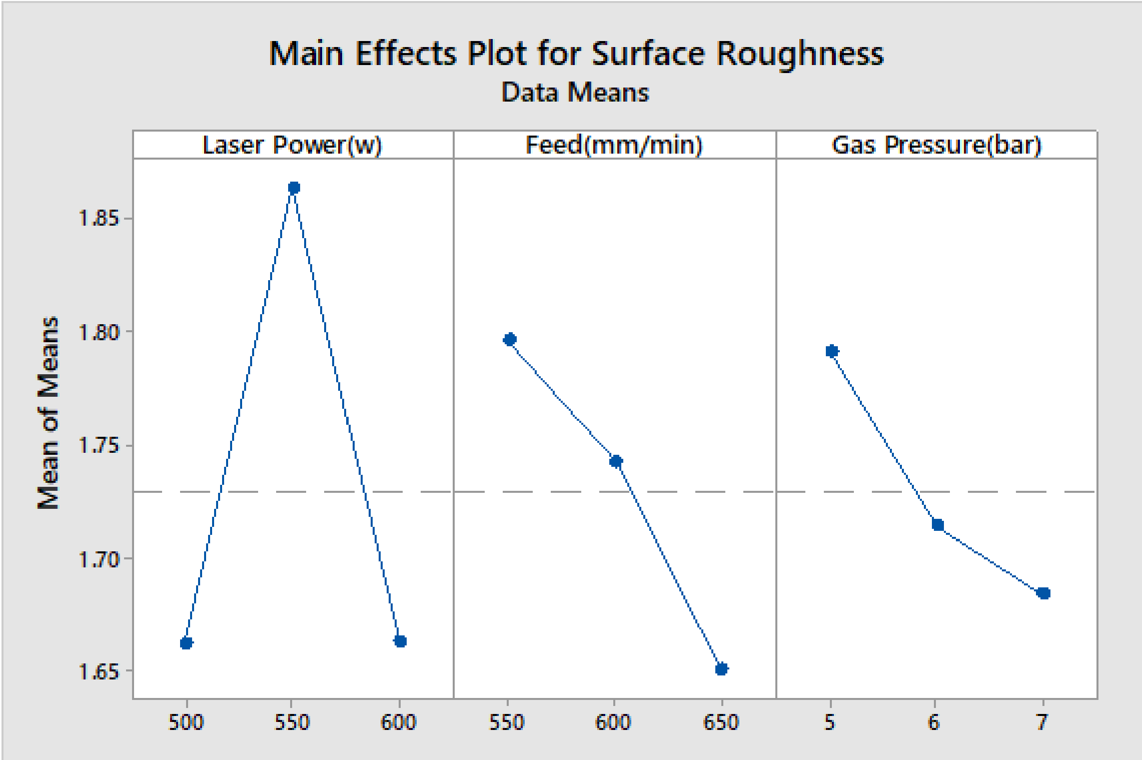
Level	Laser Power	feed	Gas Pressure
1	0.5809	0.4673	0.5021
2	0.4655	0.5413	0.5106
3	0.5144	0.5523	0.5482
Delta	0.1154	0.0850	0.0461
Rank	1	2	3

Symbol	Level-1	Level-2	Level-3
A	**0.5809**	0.4655	0.5144
B	0.4673	0.5413	**0.5523**
C	0.5021	0.5106	**0.5482**

According to Grey reational analysis method calculated value for the grey relational grade from each factor level is shown in above table. Higher value of greyrelation grade is the optimum value for a particular input level of factor which is indicated with bold in table. From this table it is conclude that the optimum parameter level for Laser power and cutting speed is respectively **(500w),(650mm/min),(7 bar)**

RESULT AND DISCUSSION

Performing all the experiments for this thesis work optimization of process parameter on performance of laser beam cutting machining (LBM) on stainless steel ASI304 material as per designed Taguchi method and measuring the output response parameters like, Surface roughness, Kerf width whatever results generated from Minitab software for 27 experiments are discussed in this chapter.

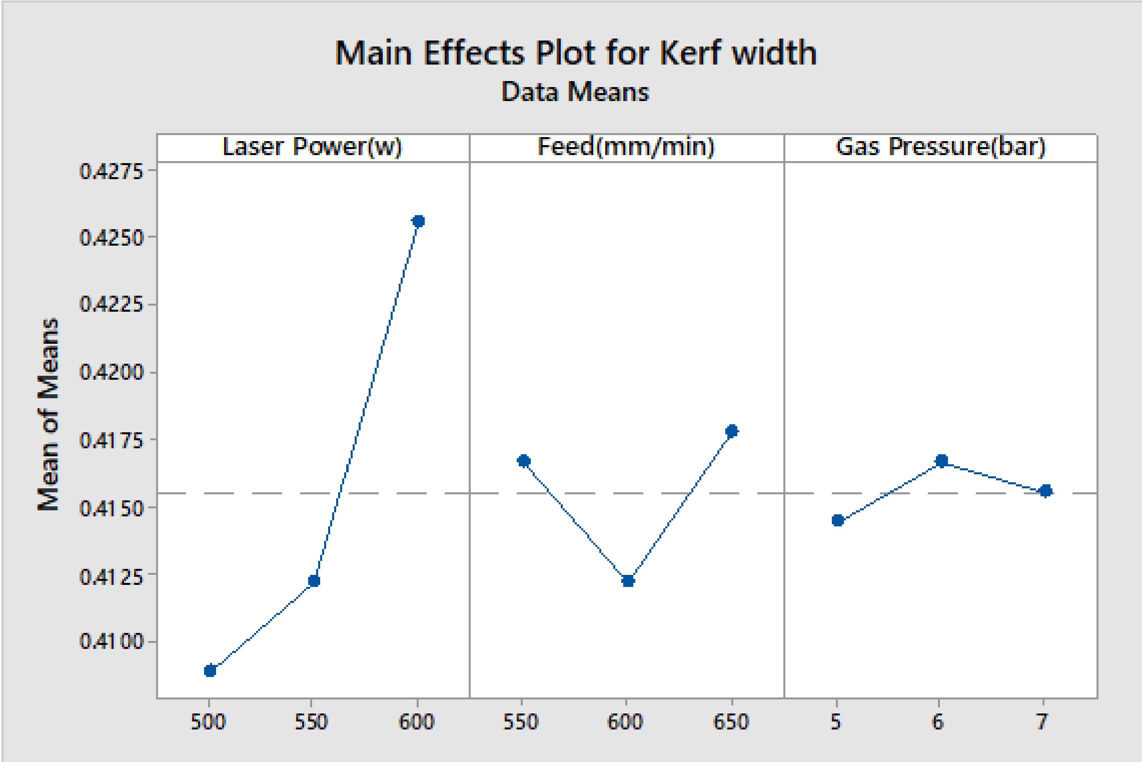


(Main effect plot for surface roughness)

1st graph shows the laser power of laser beam machining process increase from (500 W) to (550 W) the ouput parameter surface roughness is increase. Further laser power increase from (550W) to (600W) the surface roughness decreases. so from performed experimental measured and generated graph can say that in LBM process for Stainless Steel material process parameter (500 W) has good sufface finish as compared with other two variables.

In 2nd graph, its clearly shows that when the cutting speed laser beam cutting machining process increases from (550 mm/min) to (600 mm/min) the surface roughness is decreases. further cutting speed increase from (600 W) to (650 W) the surface roughness is decereases. so the process parameter (650 mm/min) has good surface finish compare with other two variable.

In 3rd graph shows that when Gas pressure increases from (5 bar) to (6 bar) the surface roughness decreases. further Gas Pressure is increased from (6 bar) to (7 bar) the output parameter surface roughness decrease. so the process parameter (7 bar) has good surface finish compare with other two.



(main effect plot for kerf width)

1st graph shows the laser power of laser beam machining process increase from (500 W) to (550 W) the ouput parameter kerf width is increase. Further laser power increase from (550W) to (600W) the kerf width increases. so from performed experimental measured and generated graph can say that in LBM process for Stainless Steel material process parameter (500 W) has good kerf width as compared with other two variables.
In 2nd graph, it's clearly shows that when the cutting speed laser beam cutting machining process increases from (550 mm/min) to (600 mm/min) the kerf width is decreases. further cutting speed increase from (600 W) to (650 W) the kerf width is increases. so the process parameter (600 mm/min) has kerf width compare with other two variables.
In 3rd graph shows that when Gas pressure increases from (5 bar) to (6 bar) the kerf width increases. Further Gas Pressure is increased from (6 bar) to (7 bar) the output parameter kerf width decreases. so the process parameter (5 bar) has good kerf width compare with other two.

Conclusion

In the presented work, experiments are carried out for surface roughness and kerf width with variables as laser power, feed rate and Gas pressure. There are 27 experimental readings taken for all variables to conduct the parametric study. Finally it can be concluded.

- Taguchi analysis is conducted to know the effect of the input parameters. Results indicate that by increasing value of Laser power the value of surface roughness first increase and then decreases, kerf width increases.
- By increasing value of feed the surface roughness decreases, kerf width first decreases and then increase.
- By increasing value of Gas pressure the surface roughness decreases, kerf width first increases and then decreases.
- Grey Relational analysis is done to find out optimal parameter levels. After grey relational analysis, it is found that optimal parameter levels,

1. Laser power at level- (500w)
2. Cutting speed at level- (650 mm/min)
3. Gas pressure- (7bar)