

Investigation of Effect of Laser Beam Machining (LBM) Process Parameters on Performance Characteristics of Stainless Steel (SS 304)

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Abstract

This study investigates the influence of Laser Beam Machining (LBM) process parameters on surface roughness and kerf width while machining Stainless Steel (SS 304). Laser Beam Machining (LBM) is a non conventional process in which material removal takes place through melting and vaporization of metal when the laser beam comes in contact with the metal surface. There are so many process parameters which affect the quality of machined surface cut by LBM. But, the laser power, cutting speed, assist gas pressure, nozzle distance, focal length, pulse frequency and pulse width are most important. However, the important performance measures in LBM are Surface Roughness (SR), Material Removal Rate (MRR), kerf width and Heat Affected Zone (HAZ). Experiments are carried out using L₂₇ Orthogonal array by varying laser power, cutting speed and assist gas pressure for stainless steel SS 304 material. The results showed that the assist gas pressure and laser power are the most significant parameters affecting the surface roughness and kerf width respectively, whereas the influence of the cutting speed is much smaller.

Keywords: Laser Beam Machining, Taguchi, ANOVA, SR, S/N Ratio, L-27 orthogonal array, Optimization.

Introduction

Emergence of advanced engineering materials, stringent design requirement, and intricate shape and unusual size of work piece restrict the use of conventional machining methods. Hence, it was realize to develop some nonconventional machining methods known as advanced machining processes. There are many advancement in process are being used in industries such as Electron Beam Machining (EBM), Electro Chemical Machining (ECM), Electrical Discharge Machining (EDM), Ion Beam Machining (IBM), Laser Beam Machining (LBM) and Abrasive Water Jet Machining (AWJM) etc. are increasingly being used as alternative to conventional machining techniques because of it is restricted for advanced engineering materials, stringent design requirements, intricate shape and unusual size of work piece. LBM is one of the advanced machining processes which are used for shaping almost whole range of engineering materials. Major application of laser beam is mainly in cutting of metals and non-metals, soft and Difficult to Machine (DTM) materials [1].

Laser is the acronym for Light Amplification by Stimulated Emission of Radiation. The first laser was invented in 1960. It was an optical pumped laser using a ruby crystal as gain medium. Afterwards the technology has been in constant development. In 1967 laser cutting was demonstrated for the first time. This was done using a focused CO₂ laser and an assist gas jet. It wasn't until 1978 that the first flatbed laser cutting machine was introduced for commercial use. This machine was actually a punch/laser cutting machine, where the cutting head was a stationary unit and the work piece could be moved in the x-y directions using numerical controls. The year after 1979 Trump (German laser machine manufacturer) introduced a 500-700 W CO₂ laser cutting machine. [2] LBM has certain advantageous characteristics, which turns to achieve significant penetration into manufacturing industries.

- high precision
- small heat-affected zone
- low level of noise
- No need of special fixtures for the work piece
- No need of expensive or replaceable tools
- Low waste

The laser beams are widely used for cutting, drilling, marking, welding, sintering and heat treatment. [3, 4] It is normally used for applications, ranging from military weapons to medical instruments, Cutting, Welding, Aerospace, Aeronautical industry. Materials which are cut by LBM are Al alloy, wood, ceramic, rubber, plastic, Brass, Hardox-400, etc.

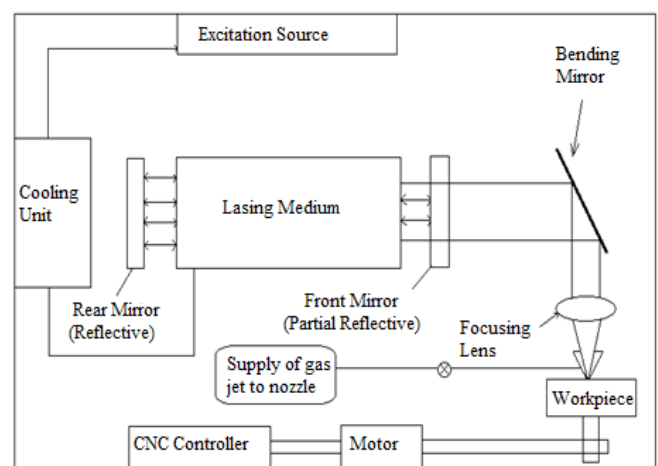


Figure 1: Laser Beam Machine Schematic diagram [2]

Experimentation

A) Experimental Set-up and material:

Laser Beam Machining on Stainless Steel (SS 304) material is carried out by using FOM2 3015NT Laser machine with maximum output power of 2.5 KW. Nitrogen was used as an assist gas for cutting with 100% duty cycle. The size of the work piece is 200 mm x 150 mm and 20 mm x 20 mm slot were cut down from the plate of 5 mm thickness for surface roughness measurement and a central linear cut of 10mm was cut down on it to measure the kerf width. Experimental set-up of LBM process is as shown in figure 2.



Figure 2: Experimental setup available at Merasha Shapers Pvt. Ltd., Five Star M.I.D.C., Kagal, Kolhapur, Maharashtra, India.

B) Selection of Process Parameters and Levels:

LBM process is some kind of complicated process, because it consists of various process parameters such as laser power, cutting speed, assist gas pressure, standoff distance and focal length. [5, 6] To achieve higher dimensional accuracy by selection of optimum machining parameter combination is very difficult task. Hence, it requires step by step systematic approach to identify the optimum parametric combination. [7, 8]

In industry, selection of levels of process parameters is largely depending on production engineer's experience. [9] So

number of researchers focused their study to find relationship between process parameters and performance characteristics. Here, process parameters levels are selected by literature survey, experience of production engineer and self initial experiments. [10, 11, 12, 13] From summary of literature survey, we observe that laser power, cutting speed, assist gas pressure plays an important role on performance characteristics hence here we select laser power, cutting speed and assist gas pressure as a process parameters.

Table 1: Process parameters with levels

Parameters	Unit	Level 1	Level 2	Level 3
Laser power	W	2300	2400	2500
Cutting Speed	mm/min	800	900	1000
Assist gas pressure	MPa	0.7	0.8	0.9

C) Selection of Orthogonal Array:

Selection of an appropriate orthogonal array for the experiments is done on the basis of number of process parameters and its levels. As number of parameters is 3 and number of levels are 3, L_{27} orthogonal array is selected. [14, 15]

Table 2: Taguchi L_{27} Orthogonal Array Parametric Combinations

Ex. No.	Laser Power (w)	Cutting speed (mm/min)	Assist gas pressure (MPa)
1	2300	800	0.7
2	2300	800	0.8
3	2300	800	0.9
4	2300	900	0.7
5	2300	900	0.8
6	2300	900	0.9
7	2300	1000	0.7
8	2300	1000	0.8
9	2300	1000	0.9
10	2400	800	0.7
11	2400	800	0.8
12	2400	800	0.9
13	2400	900	0.7
14	2400	900	0.8
15	2400	900	0.9
16	2400	1000	0.7
17	2400	1000	0.8
18	2400	1000	0.9
19	2500	800	0.7
20	2500	800	0.8
21	2500	800	0.9
22	2500	900	0.7
23	2500	900	0.8
24	2500	900	0.9
25	2500	1000	0.7
26	2500	1000	0.8
27	2500	1000	0.9

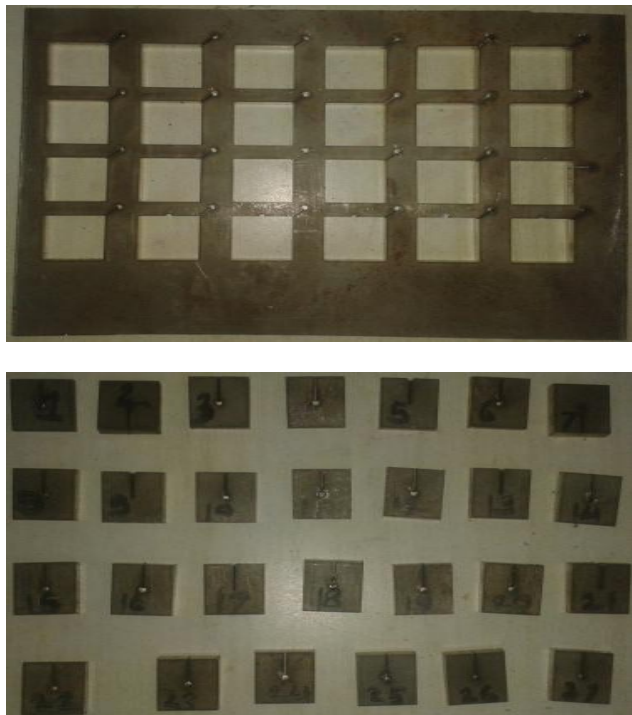


Figure 3: SS 304 Specimen after cut

Table 3: Experimental Results for SR and kerf width

Ex. No.	Laser Power (w)	Cutting speed (mm/min)	Assist gas pressure (MPa)	SR (μm)	Kerf Width (mm)
1	2300	800	0.7	3.02	0.389
2	2300	800	0.8	3.08	0.393
3	2300	800	0.9	2.99	0.381
4	2300	900	0.7	3.10	0.379
5	2300	900	0.8	2.88	0.377
6	2300	900	0.9	2.95	0.394
7	2300	1000	0.7	3.15	0.378
8	2300	1000	0.8	2.89	0.391
9	2300	1000	0.9	3.01	0.380
10	2400	800	0.7	3.12	0.392
11	2400	800	0.8	2.97	0.397
12	2400	800	0.9	3.14	0.382
13	2400	900	0.7	3.07	0.384
14	2400	900	0.8	2.91	0.395
15	2400	900	0.9	2.94	0.388
16	2400	1000	0.7	3.01	0.383
17	2400	1000	0.8	2.96	0.398
18	2400	1000	0.9	2.90	0.385
19	2500	800	0.7	3.09	0.396
20	2500	800	0.8	2.92	0.390
21	2500	800	0.9	3.13	0.393
22	2500	900	0.7	3.03	0.399
23	2500	900	0.8	2.93	0.402
24	2500	900	0.9	3.17	0.386
25	2500	1000	0.7	2.98	0.391
26	2500	1000	0.8	3.16	0.401
27	2500	1000	0.9	3.00	0.387

Results and Discussion

A) Analysis of Variance (ANOVA):

The purpose of ANOVA experimentation is to reduce and control the variation of a process; subsequently decisions can be made concerning which parameters affect the performance of the process. ANOVA [16, 17, 18] is the statistical method used to interpret experimental data to make the necessary decisions. Through ANOVA, the parameters can be categorized into significant and insignificant machining parameters and the p-value was used to determine the significance of the factors or their combinations. [19] Here, in this analysis 95% confidence level is used ANOVA analysis carried out in Minitab software and the results are shown here.

B) Signal to noise ratio (S/N Ratio):

According to Taguchi method, the S/N ratio is the ratio of signal to noise where signal represents the desirable value (i.e., the mean for the output characteristics), and noise represents the undesirable value (i.e., the square deviation for the output characteristics). Therefore, the S/N ratio is the ratio of mean to square deviation. It is denoted by ' η ' with a unit of dB. Depending on the criterion for the quality characteristic to be optimized, different S/N ratios [20] can be chosen: smaller-the-better, larger-the-better, and nominal-the-best. Regardless of the category of the performance characteristic, the larger algebraic value of S/N ratio corresponds to the better performance characteristic, and hence the optimal level of the parameter is the level with the highest S/N. [21]

Table 4: Response Table for S/N Ratios for Surface Roughness (smaller is better)

Levels	Laser Power (LP)	Cutting speed (CS)	Assist gas pressure (AGP)
1	-9.56129	-9.68657	-9.72257
2	-9.54550	-9.53183	-9.44160
3	-9.66951	-9.55790	-9.61213
Delta	0.12401	0.15474	0.28097
Rank	3	2	1

Main effect plots for S/N ratios (SR)

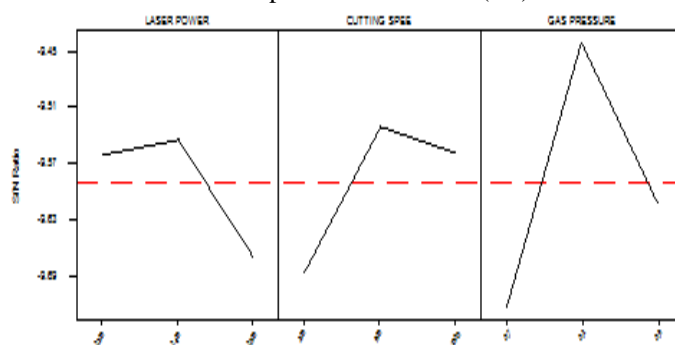


Figure 4: Graph showing S/N ratio for SR

Table 5: Analysis of Variance (ANOVA) for SR

Source	D F	Seq. SS	Adj. SS	Adj. MS	F	P
L.P.	2	0.010007	0.010007	0.005004	0.68	0.518
C.S.	2	0.014696	0.014696	0.007348	1.00	0.386
A.G.P.	2	0.042719	0.042719	0.021359	2.90	0.078
Error	20	0.147119	0.147119	0.007356		
Total	26	0.214541				

Table 7: Analysis of Variance (ANOVA) for Kerf Width

Source	D F	Seq. SS	Adj. SS	Adj. MS	F	p
L.P.	2	0.0003827	0.0003827	0.0001914	5.64	0.011
C.S.	2	0.0000201	0.0000201	0.0000100	0.30	0.747
A.G.P.	2	0.0002836	0.0002836	0.0001418	4.18	0.031
Error	20	0.0006792	0.0006792	0.0000340		
Total	26	0.0013656				

The graph (Fig. 4) shows that SR is minimum in the case of Laser Power at level 2 (2400), in case of Cutting Speed at level 2 (900) and in case of Assist gas Pressure SR will be minimum at level 2 (0.8). Analysis of variance [22] is performed to find out the significant parameter which affects the surface roughness. With help ANOVA table 5, significant process parameters for particular response are identified. Assist gas pressure has maximum effect on SR.

Table 6: Response Table for S/N Ratios for Kerf Width (smaller is better)

Levels	Laser Power (LP)	Cutting speed (CS)	Assist gas pressure (AGP)
1	8.29956	8.17209	8.22724
2	8.19457	8.19550	8.09641
3	8.09340	8.21994	8.26389
Delta	0.20617	0.04785	0.16748
Rank	1	3	2

Main effect plots for S/N ratios (Kerf Width)

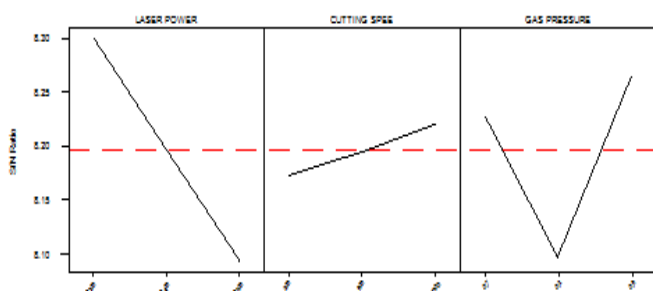


Figure 5: Graph showing S/N ratio for Kerf Width

The graph (Fig. 5) shows that Kerf Width is minimum in the case of Laser Power at level 1 (2300), in case of Cutting Speed at level 3 (1000) and in case of Assist gas Pressure kerf width will be minimum at level 3 (0.9). Analysis of variance is performed to find out the significant parameter which affects the surface roughness. With help ANOVA table 7, significant process parameters for particular response are identified. Laser power has maximum effect on kerf width.

Conclusion

This paper presents analysis of various process parameters and on the basis of experimental results, analysis of variance (ANOVA), F-test and S/N Ratio.

The following conclusions can be drawn for effective machining of Stainless steel (SS 304) by LBM process as follows:

Assist gas pressure is the most significant factor for SR during LBM. Meanwhile Laser power and Cutting speed are sub significant in influencing. The parametric combination for optimum surface roughness is LP2-CS2-AGP2. The optimal parameter setting for the SR found (2400-900-0.8). Similarly Laser power is the most significant factor for kerf width during LBM. Meanwhile Assist gas pressure and Cutting speed are sub significant in influencing. The parametric combination for optimum kerf width is LP1-CS3-AGP3. The optimal parameter setting for the kerf width found (2300-1000-0.9).

It is concluded that the Assist gas pressure and Laser power plays a significant role in governing low SR and low Kerf width. The confirmation experiments were conducted using the optimum combinations of the machining parameters obtained from Taguchi analysis. As a result, optimization of the performance characteristics of the LBM such as SR and Kerf width are improved together by using the method proposed by this study.

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