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Performance Studies and comparison of Effect of Process Parameters of Laser Beam Cutting on AISI 4130, AISI 310 and AISI 316 Steel Alloys

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Abstract

Background: Laser beam machining (LBM) is an emerging engineering process in the field of microparts manufacturing to fabricate the complex shapes of microproducts.
Objectives: This machining method has been magnificently employed in machining various materials, starting from aluminium, a highly ductile material, to very hard materials like ceramics and Inconel's. Inconel and Ti-based alloys have a treasure trove of wider applications in these present industries.
Methods: In this investigation, an effort is made to study the influence of LBM input parameters such as laser power, machining speed, and gas pressure on AISI 4130, AISI 310 and AISI 316 Steel Alloys., both linear and nonlinear.
Statistical Analysis: Preliminary trials were conducted by changing the process parameters in order to design a process parameter window.
Findings: The design matrix has been developed with L9 experiments, and the corresponding outputs and responses, such as kerf width and surface roughness, were measured and recorded.
Applications: The responses have been used to measure the Ra and kerf values of all the specimens after being cut by LBM.
Improvements: ANOVA identifies the influencing process parameters on machining Inconel 825 output responses, namely kerf width and surface roughness.

Keywords: Laser Beam Cutting, AISI 4130, AISI 310 and AISI 316 Steel Alloys. Kerf Width, ANOVA, Surface profile.

1. Introduction

Metal cutting using lasers is the more trustworthy technology for the fabrication of engineering products. Laser beam machining (LBM) is widely used for producing complex profiles in almost all materials (Sharma & Yadava 2010). The viable application of lasers involves varying fields like medical, industrial, army, and scientific research [1]. The classification of lasing media into solid, liquid, or gaseous categories is determined by their respective wavelengths [2]. The commercially available lasers for material processing in industries encompass a variety of types, including Ruby, Nd-Glass, Diode, He-Ne (Helium-Neon), CO2 (Carbon Dioxide), Nd- YAG (Neodymium-doped Yttrium Aluminium Garnet), Argon Ion, Dye, and Excimer lasers. Each of these laser types is utilized for specific applications, ranging from cutting and welding to precision machining and scientific research. [3]. Among several commercial lasers, CO2 is usually used as one of their great advantages. The CO2 laser is the initial industrialized gas laser capable of manufacturing powers in the range of 0.1 to 50 kw and is electrically more effective in the range of 15–20%. Hence, it is used in industries for processing the material [4]. Having large benefits, the laser is fetched into manufacturing engineering and industrialized applications as well, particularly in the joining of metals. Laser beam machining has both benefits and losses. But advantages and effects dominate over disadvantages. Hence, laser beam machining is widely utilized in metallic working processes in production.

2. Background Study

The literature pertaining to the LBM process is addressed in the following.
Atish Kumar et al. [5] have investigated the state of the art of CO2 LBM on different materials and dealt with the analysis of process parameters that affect the cutting profile quality characteristics and technical/commercial growth.
Milo J. Madic et al. [6] studied the heat-affected zone in CO2 laser cutting of steel. The influence of the laser machining parameters on the width of HAZ during CO2 laser cutting of AISI 304 steel. The investigation was done by developing an ANN model with laser power, assist gas pressure, cutting speed, and focus position as the input parameters.
F. Abedin and Devi K. Kalla [7] have investigated HAZ in laser machining. Laser machining, being a non-contact process, possesses several advantages, such as no tool wear or damage and no contact force-induced problems.
Avanish Kumar Dubey and Vinod Yadava [8] have been reviewing laser beam machining. LBM represents a highly utilized thermal energy-based non-contact machining process applicable across a diverse range of materials. The focused laser beam efficiently melts and vaporizes undesired material from the parent material, making it particularly suitable for intricate profile cutting and the creation of miniature holes in sheet metal.
From the literature, AISI 4130, AISI 310 and AISI 316 Steel Alloys are available in rectangular and circular profiles by using CO2 LBM. Based on the experiment, the influence of input process parameters on output process parameters (kerf width and surface roughness) is analyzed, and the most influenced process parameter is identified by using ANOVA.

3. Experimental Process

The laser is used to cut the rectangular profile and circular profile on AISI 4130, AISI 310 and AISI 316 Steel Alloys. The experiments are conducted according to the combination of process parameters (laser power, machining speed, and gas pressure) in the orthogonal array L9, the experimental process explained in the following.

Material Selection

The work piece materials, AISI 4130, AISI 310 and AISI 316 Steel Alloys, ,were considered. The work piece's chemical composition is shown in Table 1. The AISI 4130, AISI 310 and AISI 316 Steel Alloys work piece before the LBM process.

Process Parameters

The process parameters Laser Power (LP), Machining Speed (MS), and Gas Pressure (GP) are selected for machining. The process parameter combination is considered L9. The selected process parameters and levels are shown in Table 2. Similarly, the experimental process parameter combination is shown in Table 3.

Table 1. AISI 4130, AISI 310 and AISI 316 Chemical Composition

S. No.	ELEMENT (W %)	AISI 4130	AISI 310	AISI 316
1	C_{Max}	0.28	0.054	0.019
2	Si_{Max}	0.21	0.39	0.54
3	Mn_{Max}	0.47	0.41	1.81
4	Cr	0.84	25.01	17.94
5	Ni	-	19.05	10.53
6	P_{Max}	0.016	0.027	0.033
7	S_{Max}	<0.005	<0.005	<0.005
8	Mo	0.16	-	0.31

Figure 1. AISI 4130, AISI 310 and AISI 316 Steel Alloys Work Pieces Before LBC Operation

Process Parameters

The process parameters Laser Power (LP), Machining Speed (MS), and Gas Pressure (GP) are selected for machining. The process parameter combination is considered L9. The selected process parameters and levels are shown in Table 2. Similarly, the experimental process parameter combination is shown in Table 3.

Table 2. The Parameters and their Levels

	Laser Power (LP) (W)	Machining Speed (MS) (m/min)	Gas Pressure (GP) (bar)
Level -1	5000.00	08.00	07.00
Level -2	5500.00	09.00	08.00
Level -3	6000.00	10.00	09.00

Experimentation

The experiment is conducted on Inconel 825 material with a combination of laser power (LP), machining speed (MS), and gas pressure (GP). The experimentation process is shown in Figure 2. The Inconel 825 work piece after LBM operation is shown in Figure 3.

Table 3. L_9 Orthogonal Array

S. No	LP	MS	GP
1	5000.00	08.00	07.00
2	5000.00	09.00	08.00
3	5000.00	10.00	09.00
4	5500.00	08.00	08.00
5	5500.00	09.00	09.00
6	5500.00	10.00	07.00
7	6000.00	08.00	09.00
8	6000.00	09.00	07.00
9	6000.00	10.00	08.00

Figure 2. Experiment Work

Figure 3. AISI 4130, AISI 310 and AISI 316 Steel Alloys. Work Pieces After LBC Operation

Output Responses

Laser Beam Machining process on AISI 4130, AISI 310 and AISI 316 Steel Alloys. material output responses Surface roughness was measured. The measuring output process is explained in the following. Kerf Width

Kerf Width

It is the amount of wobble created during cutting and the amount of material pulled out of the sides of the cut. We know the required width of the workpiece, which feeds into the program for cutting. After machining, the obtained width is measured by an optical microscope. Kerf width is calculated as the difference between the programmed width and the obtained width, and it is expressed in mm.

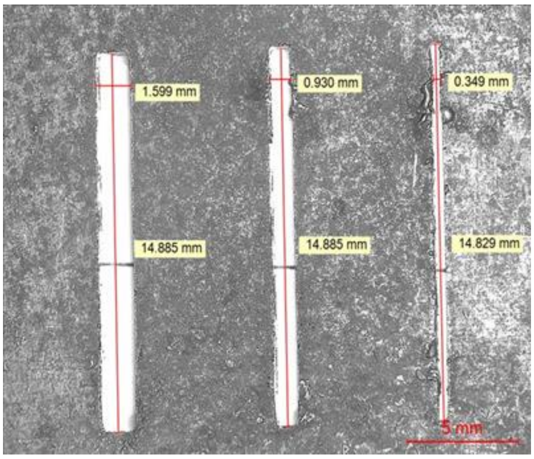

Figure 4. Microscope Captured Images

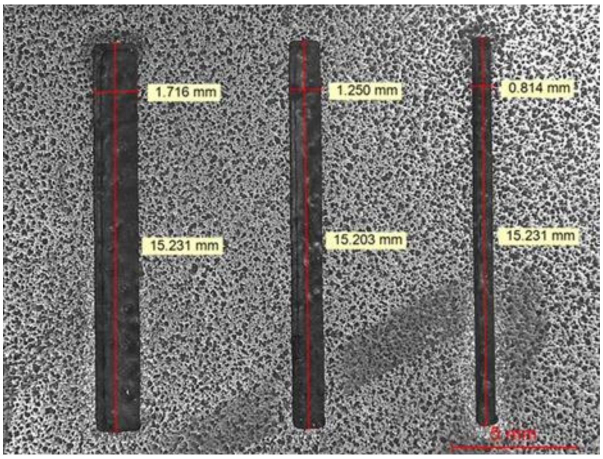

Figure 5. Measuring the Width of the Width (mm)

Table 4. Kerf Width of Linear cutting AISI 4130, AISI 310 and AISI 316 steels

S. No.	LP (W)	MS (M/min)	GD (mm)	Results - Optioned dimension		
				AISI 4130	AISI 310	AISI 316
1	5000	8	0.5	0.109	0.140	0.314
2	5000	9	1.0	0.132	0.163	0.221
3	5000	10	1.5	0.075	0.157	0.215
4	5500	8	1.0	0.099	0.163	0.279
5	5500	9	1.5	0.075	0.157	0.187
6	5500	10	0.5	0.092	0.256	0.314
7	6000	8	1.5	0.099	0.216	0.244
8	6000	9	0.5	0.151	0.314	0.285
9	6000	10	1.0	0.070	0.250	0.25

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Table 5. Kerf width of Non-Linear cutting AISI 4130, AISI 310 and AISI 316 steels

S. No.	LP (W)	MS (M/min)	GP (bar)	Results - Optioned dimension		
				AISI 4130	AISI 310	AISI 316
1	5000	8	0.5	0.175	0.183	0.213
2	5000	9	1.0	0.100	0.189	0.232
3	5000	10	1.5	0.133	0.192	0.228
4	5500	8	1.0	0.082	0.189	0.226
5	5500	9	1.5	0.151	0.192	0.213
6	5500	10	0.5	0.147	0.200	0.229
7	6000	8	1.5	0.052	0.190	0.229
8	6000	9	0.5	0.143	0.196	0.204
9	6000	10	1.0	0.108	0.197	0.238

4. Results and Discussions

ANOVA Results of Linear cutting kerf width for AISI 4130 Steel

ANOVA for the Kerf width results of the AISI 4130 steel LBM Linear Cutting is shown in Table – 5.1. Input parameters are shown in column (1), followed by Degrees of Freedom (DF) shown in column (2), Sum of Squares (SS) in column (3); Adj SS in column (4), Adj MS in column (5), F-value in column (6); P-value in column (7) and percentage of contribution in column (8). Similarly, the columns show to represent the variables in the other ANOVA Tables.

Table 6. ANOVA of Kerf Width of AISI 4130 linear cutting

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	% C
Laser Power	2	0.000604	0.000604	0.000302	0.55	0.644	10.19
Machining Speed	2	0.002460	0.002460	0.001230	2.26	0.307	41.54
Geometrical Dimension	2	0.001768	0.001768	0.000884	1.62	0.381	29.85
Residual Error	2	0.001090	0.001090	0.000545			
Total	8	0.005922					
S = 0.02334 R-Sq = 81.6% R-Sq(adj) = 26.4%							

Experimental F- Value is greater than F table = 19.00 @ (2,2) and P-Values are less than 5%. The process parameters have significant effect on the weld joints at 95% confidence level. From the Table – 5.1, the percentage of contribution results shows that the Machining Speed has contribution of 41.54% on Kerf Width, followed by Geometrical Dimension 29.85% and Laser Power 10.19%. R2 81.6% confirms the reliability of the model. Hence, it is observed that the Machining Speed has a greater influence on Kerf Width on AISI 4130 linear cutting by using LBM. The influence of AISI 4130 Linear Cutting by using LBM input process parameters on Machining Speed as shown fig. 6.

Table 7. Kerf Width Response Table for Means

Level	Power	Speed	Geometrical Dimension
1	19.78	19.81	18.80
2	21.10	18.84	20.26
3	19.87	22.11	21.69
Delta	1.32	3.27	2.90
Rank	3	1	2

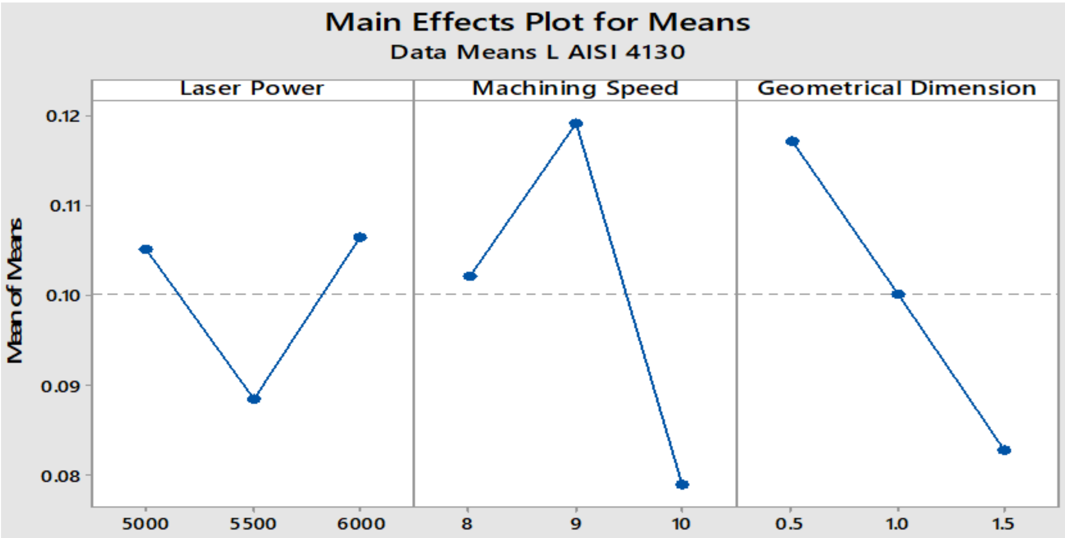

Figure 6. Mean effects plot on Kerf width of AISI 4130 steel linear cutting

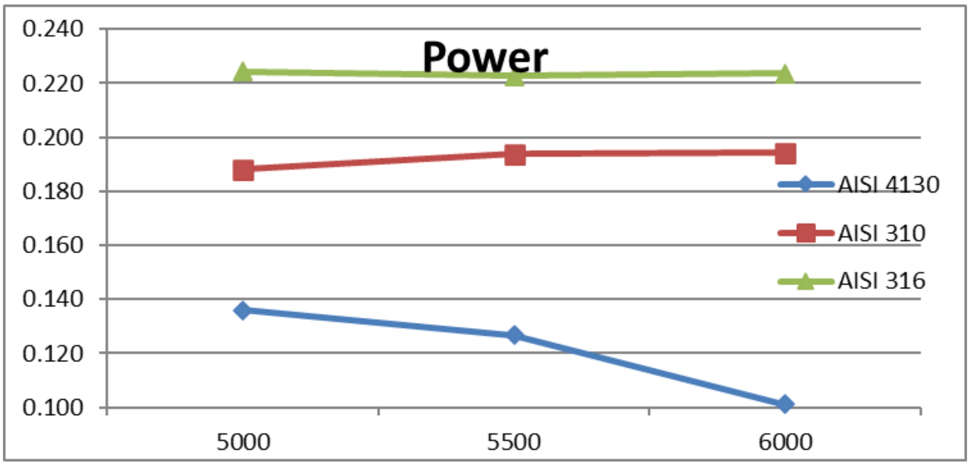

Figure 7. Non - linear metal cutting of Laser Power Vs Kerf Width

Laser Power is varying 5000 W to 6000 W on laser cutting of AISI 413, AISI 310 and AISI 316. In the linear cutting processes, the power is increasing based on that Kerf Width is also increasing between 5000W to 6000W. Similarly, in the non-linear cutting process the power is increasing based on that Kerf Width is decreasing and minimum value at 6000 W of Laser Power.

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5. Conclusion

In the present work, machining of Inconel 825 in linear profile cutting by LBM according to Taguchi DOE has been done. The input parameters are combination L9 using the Taguchi technique. Based on the experimental results and discussions, the following conclusions are made.

From the ANOVA, the influence of process parameters on the AISI 4130, AISI 310 and AISI 316 Steel Alloys. LBM.

From the ANOVA, the influence of process parameters on the AISI 4130, AISI 310 and AISI 316 LBM for Kerf Width

1. Most influenced process parameter is laser power of max percentage of contribution in analysis of variance for means.
2. From response mean table rankings for variance are laser power, gas pressure & cutting speed.
3. From mean effect plot graph, better process parameter are observed at laser power at 5000(w), cutting speed at 8 (m/min) and gas pressure at 7 (bar).

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