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Parametric Investigation of Laser Cutting and Plasma Cutting of Mild Steel E350 Material - A Comparative Study

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Abstract: *The main objective of this paper is to select the best technology for cutting Mild Steel E350 grade material by using Laser Cutting and Plasma Cutting machines; they are non contact and non conventional machining process. To study the effect of laser and plasma cutting process by choosing laser power, gas pressure and cutting speed as input parameters, surface roughness, taper kerfs and heat affected zone as output parameters. The experiment was designed according to Taguchi L_{27} orthogonal array with three different levels for each input parameter. For interpretation, Analysis of Variance (ANOVA) was conducted and optimum parameter is selected on the basis of signal to noise ratio which confirms the experiment results*

***Key Words**: Laser Cutting, Plasma Cutting, Mild Steel E350 material and Taguchi Method.*

I. Introduction

Laser beam machining generates the intense light beam, which quickly heats up the work piece and melts the material. The assist gas is applied to protect and cool the focusing lens and to remove the molten metal from the cut kerfs at the same time. Due to high accuracy of cutting, narrow kerfs width, higher production rate, intricate shape, hard to cut material proves laser beam machining a good choice for industrial application .There are many parameters for LBM process to be selected and optimize to achieve desired response. For processing parameters Many researchers have chosen input parameters like laser power, cutting speed, assist gas pressure, nozzle diameter, stand of Distance, varying thickness of work piece, focus length and focal point etc. to determine output parameters such as surface roughness, kerfs width, taper angle, material removal rate ,heat affected zone, dross inclusion, dross height and operating cost etc. Because of the multiple parameters, they require fine setting to get better result of LBM.

Plasma arc cutting is a non-conventional manufacturing process capable of processing a variety of electrically conducting materials. Stainless steel manganese steel, titanium alloys, copper magnesium aluminum and its alloys and cast iron can be processed. The plasma process for cutting was developed approximately thirty years ago for metals difficult to be machined through conventional processes. It uses a high energy stream of dissociated ionized gas known as plasma, as the heat source Plasma cutting process is characterized by an electric arc established between an electrode and the work piece. The electrode acts as the cathode, and the work piece Material acts as the anode. In order to achieve higher cutting thickness without losing the quality of the cut, many parameters must be taken into consideration. Investigations on plasma cutting process on various materials have identified as dominant process parameters such as Cutting Speed, Cutting Current, Cutting Height or standoff distance maintained between the torch and work piece after piercing and while cutting, Pressure and flow of the plasma gas.

II. Literature Review

K. SalonitisaS.Vatousianosb: Investigated the quality of the cut has been monitored by measuring the kerfs, taper angle, the edge roughness and the size of the heat-affected zone. Parameters such as the cutting power, scanning speed, cutting height and plasma gas pressure. By using design of experiment and analysis of variance, it was found that the surface roughness and the kerf are mainly affected by the cutting height where as the heat affected zone is mainly influenced by the cutting current.

B. D. Prajapati1, R. J. Patel2, B. C. Khatri: Investigated laser machine processing parameters such as laser power, gas pressure, cutting speed and thickness effect on measured response such as surface roughness. The experiment was designed according to Taguchi L27 orthogonal array with three different levels of each input parameter. The results conclude that Laser Power had less effect for surface roughness might be due to small variation in their level. Gas pressure had higher effect for cutting of Mild Steel and for Hardox- 400 had less effect.

III. Objectives of The Study

1. To study about the influence of Laser and Plasma Cutting Parameters on Mild Steel E350 material
2. To select a best technology for cutting a Mild Steel E350 Grade material with 5mm thickness by using Laser and plasma cutting machines, with respect to Edge Surface Roughness, Kerf, Taper and Heat Affected Zone as output Parameters and Power, Cutting Speed and Gas Pressure as input parameters.
3. To make a comparative study of these two techniques by highlighting the difference between them.

IV. Experimental Setup

AMADA Japan 3015NT CNC Laser Cutting machine with 4.0KWin continuous mode is used for experimental work .Lens of 7.5" focal length is used with oxygen as assist gas for cutting selected material with 1.2 Nozzle diameter. Plasma Messer Germany Kjellbert cutting machine with 35- 130AMPS and 1.2 Nozzle diameter is also used for experimentation. The size of the work piece (172mmx100mm) Mild Steel E350 Grade material with 5mm thickness was selected for measurement of surface roughness, Taper, Kerfs and Heat effected zone. The surface roughness was measured by using portable Profilometer of Mitutoyo model and Taper, Kerfs by using Digital Vernier Scales. Heat affected zone was measured by using Digital Microscope.

Table: 1 Mechanical Properties of Mild Steel

MECHANICAL PROPERTIES OF MILD STEEL - E350 GRADE		
Yield Strength(MPA)	**Tensile Strength (MPA)**	**Elongation %**
240	450	25

Table: 2 Process Parameters, Laser Machine Control Factors and their Levels

Levels	Factors		
	Power(w)	**Cutting Speed (mm/min)**	**Gas Pressure (Bar)**
1	1200	900	0.4
2	1400	1100	0.5
3	1600	1500	0.6

Table: 3 Plasma Machine Control Factors and Levels

FACTORS/ LEVELS	POWER(A)	CUTTING SPEED(mm/min)	GAS PRESSURE (BAR)
1	60	1800	8
2	90	2500	9
3	130	2800	10

V. Results And Discussion For Mild Steel- E350 Grade

An experiment was conducted to fulfill the above objective and the results obtained furnished in the following tabular form for further analysis using Minitab Software.

Table: 4 Laser Cutting Results

S.NO	Laser Power	Cutting Speed	Gas Pressure	Taper	Surface Roughness	Kerf	S/N ratio		
	(W)	mm/min	bar	µm	µm	µm	Taper	RA	kerfs
1	1200	900	0.4	**103**	**1.0**	512	-40.2567	0	-54.1854
2	1200	900	0.5	110	1.06	528	-40.8279	-0.5061	-54.4527
3	1200	900	0.6	115	1.1	554	-41.214	-0.8278	-54.8702
4	1200	1100	0.4	123	1.02	**506**	-41.7981	-0.172	-54.083
5	1200	1100	0.5	121	1.19	518	-41.6557	-1.5109	-54.2866
6	1200	1100	0.6	135	1.18	531	-42.6067	-1.4376	-54.5019
7	1200	1500	0.4	142	1.12	521	-43.0458	-.09843	-54.3368
8	1200	1500	0.5	150	1.15	586	-43.5218	-1.2139	-55.358
9	1200	1500	0.6	162	1.17	609	-44.1903	-1.3637	-55.6923
10	1400	900	0.4	125	1.11	603	-41.9382	-0.9064	-55.6063
11	1400	900	0.5	116	1.14	668	-41.2892	-1.1381	-56.4955
12	1400	900	0.6	131	1.16	686	-42.3454	-1.2891	-56.7265
13	1400	1100	0.4	148	1.22	678	-43.4052	-1.7272	-56.6246
14	1400	1100	0.5	157	1.26	721	-43.918	-2.0074	-57.1587

15	1400	1100	0.6	145	1.34	736	-43.2274	-2.5421	-57.3376
16	1400	1500	0.4	159	1.42	743	-44.0279	-3.0457	-57.4198
17	1400	1500	0.5	174	1.68	811	-44.811	-4.5061	-58.1804
18	1400	1500	0.6	187	1.64	821	-45.4368	-4.2968	-58.2869
19	1600	900	0.4	192	1.81	817	-45.666	-5.1535	-58.2444
20	1600	900	0.5	205	2.1	889	-46.2351	-6.4443	-58.978
21	1600	900	0.6	211	2.08	921	-46.4856	-6.3612	-59.2852
22	1600	1100	0.4	203	2.1	903	-46.1499	-6.4443	-59.1138
23	1600	1100	0.5	215	2.19	945	-46.6488	-6.8088	-59.5086
24	1600	1100	0.6	226	2.18	1121	-47.0822	-6.7691	-60.9921
25	1600	1500	0.4	221	1.89	1132	-46.8878	-5.5292	-61.0769
26	1600	1500	0.5	246	2.26	1178	-47.8187	-7.0821	-61.4229
27	1600	1500	0.6	278	2.23	1194	-48.8809	-6.9661	-61.5401

From among 27 experiments Optimum values of taper (103µm) and Surface Roughness (1.0µm) obtained at a given Laser Power of 1200W, Cutting Speed of 900 mm/min and Gas pressure of 0.4 bar. Optimum values of Kerf(506µm) obtained at a given Laser Power of 1200W, Cutting Speed of 1100 mm/min and Gas pressure of 0.4 bar.

Table: 5 General Linear Models for Taper

S.NO	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	**POWER**	**2**	**42988**	**21494.1**	**275.25**	**0.000**
2	**CUTTING SPEED**	**2**	**9506**	**4753.0**	**60.87**	**0.000**
3	**GAS PRESSURE**	**2**	**1688**	**844.0**	**10.81**	**0.001**
4	**Error**	**20**	**1562**	**78.1**		
5	**Total**	**26**	**55744**			
6	**S :8.83679**	**R-sq:97.20%**	**R-sq(adj): 96.36%**	**R-sq(pred): 94.89%**		

From Table-5, it is observed that R^2 (adjusted) value is 96.36% and R^2 (predicted) value is 94.89%, which indicates that there is no much variation between them. Hence, the model used for analysis is appropriate. Since p value is less than 0.05, which indicates that all the parameters are significant for Taper.

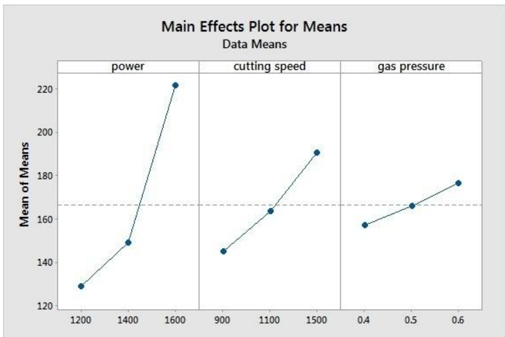


Fig: 1 Main effect plots for E350

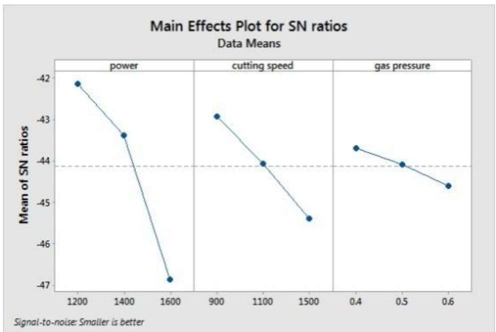


Fig: 2 Main effect plots S/N ratio for E350

Figure:2 represents the results of Analysis of mean ANOVA response plot. The level of parameter with the highest S/N ratio is the optimal level

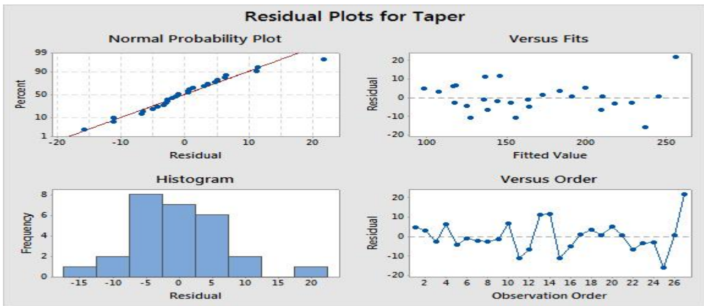


Fig: 3 Residual plots for Taper

From Figure: 3 the Normal Probability Plot indicates that the residual follows a straight line and there are no unusual patterns or outliers. Therefore, the assumptions regarding the residuals were not violated and the residuals are normally distributed.

Table:6 General Linear Model For kerf

S.NO	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	POWER	2	1016086	508043	154.16	0.000
2	CUTTING SPEED	2	115383	57692	17.51	0.000
3	GAS PRESSURE	2	32105	16053	4.87	0.019
4	Error	20	65913	3296		
5	Total	26	1229487			
6	S :57.4076	R-sq: 94.64%	R-sq(adj): 93.03%	R-sq(pred): 90.23%		

From Table- 6, it is observed that R^2 (adjusted) value is 93.03% and R^2 (predicted) value is 90.23%, which indicates that there is no much variation between them. Hence, the model used for analysis is appropriate. Since p value is less than 0.05, which indicates that all the parameters are significant for kerf.

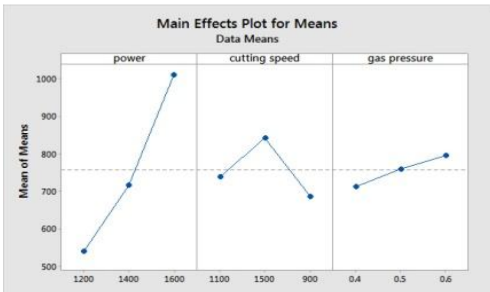


Fig:4 Main effect plots for E350

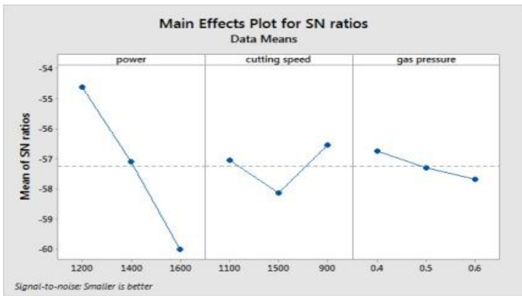


Fig: 5 Main effect plots forS/N ratio for E350

Fig: 5 represent the results of Analysis of mean ANOVA response plot. The level of parameter with the highest S/N ratio is the optimal level

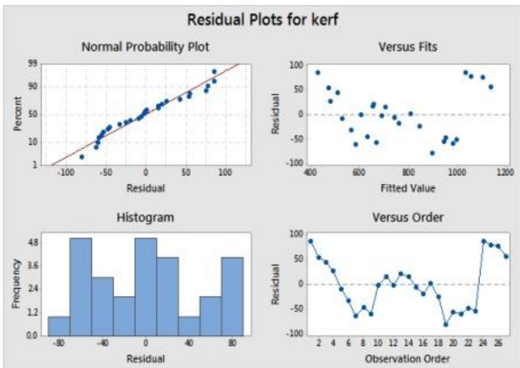


Fig: 6 Residual plots for E350

From Figure: 6 The Normal Probability Plot indicates that the residual follows a straight line and there are no unusual patterns or outliers. Therefore, the assumptions regarding the residuals were not violated and the residuals are normally distributed.

Table: 7 General Linear Models for Surface Roughness

S.NO	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	**POWER**	**2**	**4.7941**	**2.39703**	**217.56**	**0.00**
2	**CUTTING SPEED**	**2**	**0.2233**	**0.11164**	**10.13**	**0.001**
3	**GAS PRESSURE**	**2**	**0.1382**	**0.06908**	**6.27**	**0.008**
4	**Error**	**20**	**0.2204**	**0.01102**		
5	**Total**	**26**	**5.3759**			
6	**S :0.104966**	**R-sq:95.90%**	**R-sq(adj): 94.67%**	**R-sq(pred):92.53%**		

From Table: 7 ,It is observed that R^2 (adjusted) value is 94.67% and R^2 (predicted) value is 92.53% ,which indicates that there is no much variation between them. Hence, the model used for analysis is appropriate. Since p value is less than 0.05, which indicates that all the parameters are significant for surface roughness.

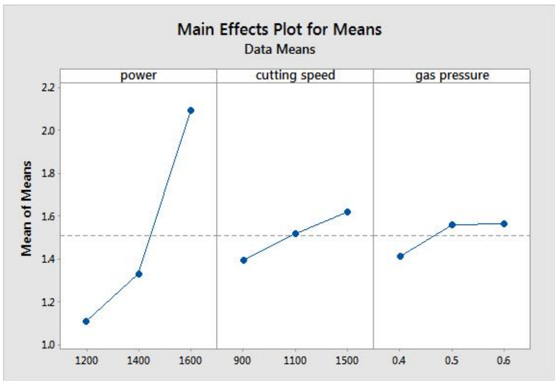


Fig: 7 Main effect plots for E350

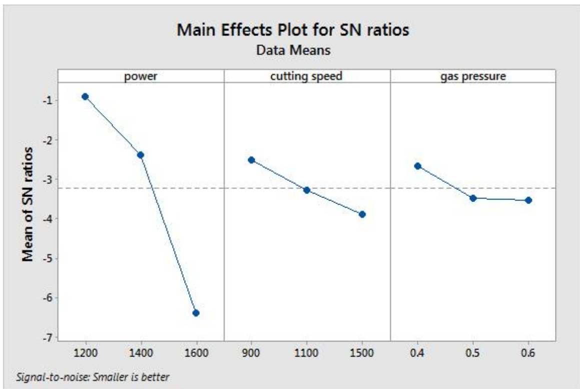


Fig: 8 Main effect plots for S/N ratio for E350

Fig: 8 represent the results of Analysis of mean ANOVA response plot. The level of parameter with the highest S/N ratio is the optimal level

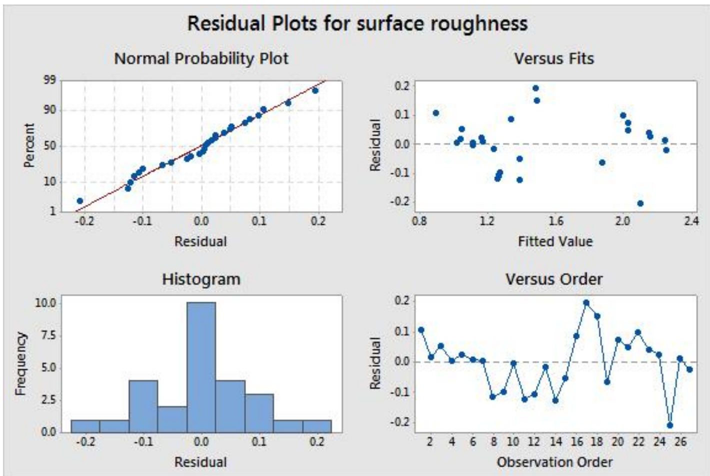


Fig: 9 Residual plots for E350

In Figure: 9, the Normal Probability Plot indicates that the residual follows a straight line and there are no unusual patterns or outliers. Therefore, the assumptions regarding the residuals were not violated and the residuals are normally distributed.

Table-8 Plasma Cutting Results

S.NO	power	cutting Speed	gas pressure	Taper	kerfs	S/N ratio	
	(A)	mm/min	bar	μm	μm	TAPER	KERF
1	60	1800	8	**810**	1913	-58.1697	-65.6343
2	60	1800	9	824	1931	-58.3185	-65.7156
3	60	1800	10	844	**1895**	-58.5268	-65.5522
4	60	2500	8	813	2062	-58.2018	-66.2858
5	60	2500	9	872	2104	-58.8103	-66.4609
6	60	2500	10	882	2145	-58.9094	-66.6285
7	60	2800	8	890	2112	-58.9878	-66.4939
8	60	2800	9	928	2185	-59.351	-66.789
9	60	2800	10	944	2175	-59.4994	-66.7492
10	90	1800	8	1265	2312	-62.0418	-67.2798
11	90	1800	9	1328	2551	-62.464	-68.1342
12	90	1800	10	1364	2812	-62.6963	-68.9803
13	90	2500	8	1512	2745	-63.591	-68.7708
14	90	2500	9	1640	3183	-64.2969	-70.0567
15	90	2500	10	1648	3221	-64.3391	-70.1598
16	90	2800	8	1551	3245	-63.8122	-70.2243
17	90	2800	9	1640	3451	-64.2969	-70.7589
18	90	2800	10	1840	3277	-65.2964	-70.3095
19	130	1800	8	1612	2746	-64.1473	-68.774
20	130	1800	9	1724	3126	-64.7307	-69.8998
21	130	1800	10	1700	3106	-64.609	-69.844
22	130	2500	8	1714	3112	-64.6802	-69.8608
23	130	2500	9	1860	3325	-65.3903	-70.4358
24	130	2500	10	1832	3399	-65.2585	-70.627
25	130	2800	8	1784	3120	-65.0279	-69.8831
26	130	2800	9	1884	3323	-65.5016	-70.4306
27	130	2800	10	1844	3155	-65.3152	-69.98

From among 27 experiments Optimum values of taper (810μm) and kerf (1895μm) obtained at a given Power of 60Amp, Cutting Speed of 1800 mm/min and Gas pressure of 8 and 10bar respectively.

Table-9 General Linear Model for Kerf

S.NO	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	POWER	2	6255406	3127703	120.56	0.000
2	CUTTING SPEED	2	826705	413352	15.93	0.000
3	GAS PRESSURE	2	244019	122009	4.70	0.021
4	Error	20	518880	25944		
5	Total	26	7845009			
6	S :174.748	R-sq: 93.39%	R-sq(adj): 91.40%	R-sqpred 87.95%		

From Table-9, it is observed that R^2 (adjusted) value is 91.40% and R^2 (predicted) value is 87.95%, which indicates that there is no much variation between them. Hence, the model used for analysis is appropriate. Since p value is less than 0.05, which indicates that all the parameters are significant for kerf.

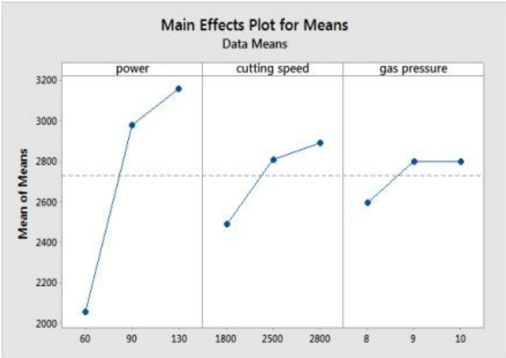


Fig: 10 Main effect plots for E350

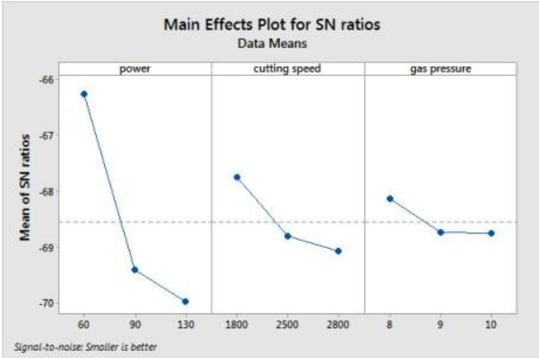


Fig: 11 Main effect plots for s/n ratio E350

Fig: 11 represent the results of Analysis of mean ANOVA response plot. The level of parameter with the highest S/N ratio is the optimal level

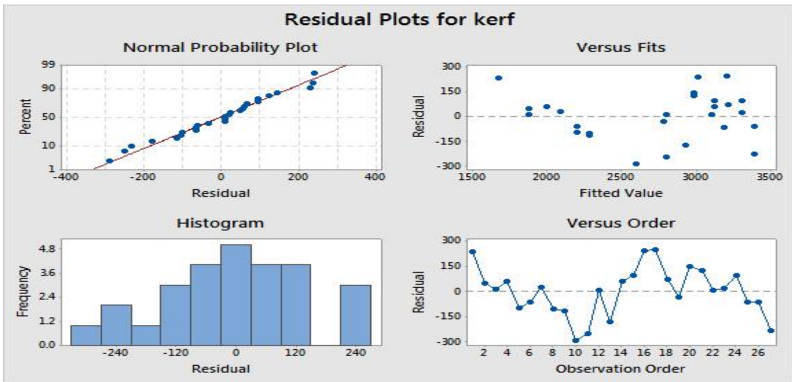


Fig: 12 Residual plots for E350

Figure: 12 The Normal Probability Plot indicates that the residual follows a straight line and there are no unusual patterns or outliers. Therefore, the assumptions regarding the residuals were not violated and the residuals are normally distributed.

Table: 10 General Linear Models for Taper

S.NO	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	POWER	2	3956945	1978473	377.27	0.000
2	CUTTING SPEED	2	197844	98922	18.86	0.000
3	GAS PRESSURE	2	55445	27722	5.29	0.014
4	Error	20	104883	5244		
5	Total	26	4315118			
6	S :72.4166	R-sq: 97.57%	R-sq(adj): 96.84%	R-sqpred 95.57%		

From Table-10 it is observed that R^2 (adjusted) value is 96.84% and R^2 (predicted) value is 95.57%, which indicates that there is no much variation between them. Hence, the model used for analysis is appropriate. Since p value is less than 0.05, which indicates that all the parameters are significant for taper.

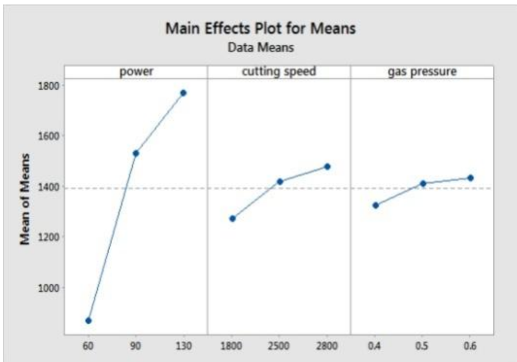


Fig: 12 Main effect plots for E350

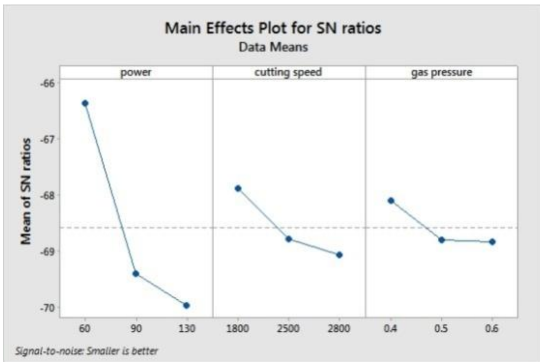


Fig: 13 Main effect plots for s/n ratio for E350

Fig: 13 represent the results of Analysis of mean ANOVA response plot. The level of parameter with the highest S/N ratio is the optimal level

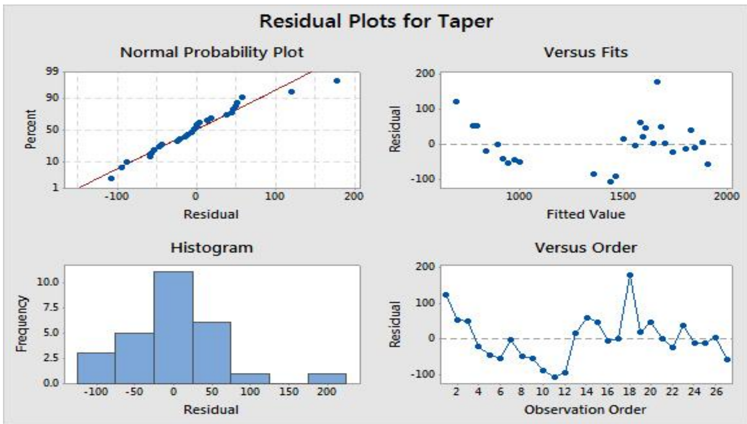


Fig: 14 Residual plots for E350

Figure: 14 The Normal Probability Plot indicates that the residual follows a straight line and there are no unusual patterns or outliers. Therefore, the assumptions regarding the residuals were not violated and the residuals are normally distributed.

Table-11 Comparative study of optimization parameters of Laser and Plasma Cutting

Laser Cutting Results		Plasma Cutting Results	
Taper	**Kerf**	**Taper**	**Kerf**
103	**506**	**810**	**1895**

Table-11 indicates a Comparative Study of optimization parameters of Laser & Plasma Cutting, which visualizes that the optimum/minimum values of the parameters obtained for laser cutting rather than Plasma arc cutting with respect to Taper and Kerf.

Table 12: Results obtained for Laser Cutting with respect to optimum output parameters

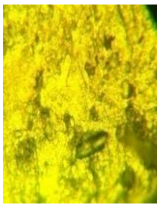
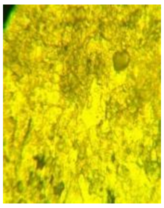
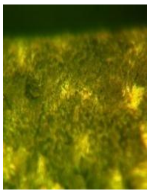
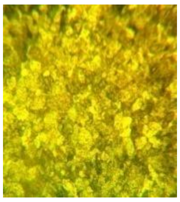
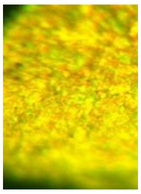
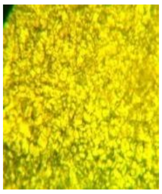
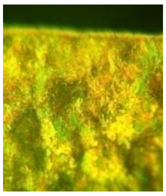
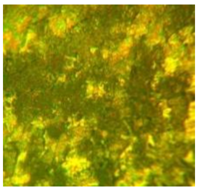
Experiment Number(EXP)	Laser Power	Cutting Speed	Gas Pressure	Taper	Surface Roughness	Kerf
EXP-1	1200	900	0.4	**103**	**1.0**	512
EXP-4	1200	1100	0.4	123	1.02	**506**

Table 13: Results obtained for Plasma Cutting with respect to optimum output Parameters

Experiment Number(EXP)	Laser Power	Cutting Speed	Gas Pressure	Taper	Kerf
EXP-1	60	1800	8	**810**	1913
EXP-3	60	1800	10	844	**1895**

As there is no much variation in the results of the heat affected zone for all the experiments, only those experiments have taken into consideration (Laser Cutting Exp-1&4 and Plasma Cutting Exp-1 & 3) with respect to the optimum output parameters for the purpose of analysis. Heat affected Zone is very less and not affected much with respect to Laser Cutting. Whereas in Plasma Cutting Heat affected Zone is more, which affects the micro structure. However, from the Table :14, it is observed that there is no change in the micro structure of E350 Mild Steel material at the edges for both Laser and Plasma cutting.

Table: 14 Structures of Heat Affected Zone of Laser and Plasma Cutting

Experiment Number(EXP)	Laser cutting	Plasma Cutting
EXP-1	 Edge  Middle	 Edge  Middle
Exp-4 (Laser) & EXP-3 plasma cutting	 Edge  Middle	 Edge  Middle

VI. Conclusion

This paper presents the Taguchi method for optimization of edge surface roughness, taper, kerf in laser cutting and plasma cutting of Mild Steel E350 material, using oxygen as assist gas. Three laser and plasma cutting parameters such as cutting speed, power and assist gas pressure were considered in the experiment that was planned according to the Taguchi's experimental design by using L_{27} orthogonal array. From the experimental results, the following conclusions were made

- The cutting performance of laser cutting is better than the plasma cutting
- The cutting speed and power are the most significant parameters effecting the surface roughness, taper and kerf where gas pressure is much smaller
- It was observed that the cutting speed and power should be kept in low level and gas pressure should be in intermediate level.
- In plasma cutting, It was observed that the cutting speed and power should be kept in low level and gas pressure should be in intermediate level.
- Plasma Cutting machines have a significant advantage over laser machines in terms of acquisition cost, maintenance and productivity
- The confirmation experiments have shown that Taguchi parameter design can successfully verify the optimum cutting parameters. The validation experiment confirmed that predicted model is adequate for determining the optimum quality characteristic at 95%confidence level

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