An Investigation of CO2 Laser Drilling on SS316

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Abstract—Lasers can be successfully used for machining of materials such as metals, composites, Ceramics and polymers. Nowadays laser based machining processes are finding more applications in various areas like laser drilling is one of the applications used for both metal and non-metal materials. In this study, laser machining was carried out by using nitrogen environment as assistant gas. The experimental planning has been done using Taguchi L9 orthogonal design. Laser power, Gas pressure and Scanning speed are the three input variables with three different levels selected for the present study. The main focus of this article is to find out optimum levels of processing parameters of laser trepanning drilling process. The SS316 material having thickness of 1.2 mm was used for experiment. Response parameters such as entrance circularity, exit circularity, hole taper and heat affected zone thickness were chosen to analyze process. The approach combines the Taguchi based orthogonal array used for design of experiments with ANOVA. The analysis done with ANOVA technique to determine most effective parameters affects output responses.

Index Terms—Drilling, Circularity, Trepanning, HAZ, ANOVA.

I. INTRODUCTION

The transformation of material into goods takes place to satisfy human needs through manufacturing process [1]. Machining is an important area in the field of engineering. To satisfy today's needs of customers or human needs, there is need to use advanced machining processes. Laser machining is one of from machining processes, and now a day's laser based machining processes can be considered as an advanced or non-conventional machining process. The schematic diagram of laser drilling process is shown in Fig. 1.

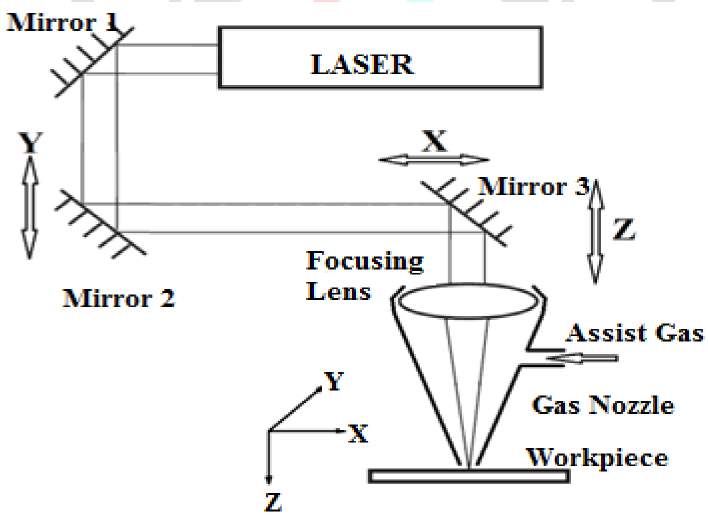

Figure 1 Laser Drilling Process

Circularity at entrance, exit and taper of hole as well as spatter loss and heat affected zone (HAZ) around hole are the main geometric features of laser drilled hole considered after laser drilling process as an quality of end product [2]. Vaporization and melt ejection are the two mechanisms through which material removed from the workpiece during drilling [3]. The desired hole features with high accuracy and less defects can be obtained by controlling the laser beam precisely by means of arrangement of optical setting. Laser drilling is not restricted by the hardness, strength and brittleness of materials. CO2 laser drilling has become one key technologies of the advanced machine field for its high speed, no tool loss, low cost and adapt to group of holes so widely used for different applications like drilling, cutting, forming etc [4]. Initially stainless steel 316 developed for use in paper mills 316 stainless steel is now typically used in: Food processing equipment, Brewery equipment, Chemical and petrochemical equipment, Laboratory benches & equipment, Coastal architectural panelling, Coastal balustrade, Boat fittings, Chemical transportation containers, Heat exchangers, Mining screens, Nuts and bolts, Springs, Medical implants [5].

Bharatish et al. [6] represents the work on CO2 laser drilling of alumina ceramics. They used orthogonal array experimentation and response surface methodology to find out effect of laser parameters on the quality of drilled holes such as Circularity of drilled hole at the entry and exit, heat affected zone and taper in alumina ceramics. Finally they concluded that, both entrance and exit circularities were significantly influenced by hole diameter and laser power, heat affected zone was influenced by frequency and Taper was also significantly influenced by laser power. Brajdic et al. [7] have investigated the effect of laser drilling parameters on hole quality in deep drilling of through holes made on stainless steel with the superposed radiation of two pulsed Nd:YAG lasers. It is found that heat affected zone (HAZ) severely influence the quality of hole. Choudhury et al [8] did the laser trepan drilling on Acrylonitrile butadiene styrene (ABS) and Polymethyle Methacrylate (PMMA) polymer material. Polymeric material having 5mm thickness with laser power, assist gas pressure, cutting speed and standoff distance were four input parameters chosen for different 2mm, 4mm and 6mm diameter of hole. L9 orthogonal array for different 4 factors and 3 levels for each factor were used to perform experiment. From ANOVA analysis, they found that the optimum levels of 4 process variables were different for different hole size and material. Also they found that for ABS polymer circularity of hole at entrance more than that of exit while for PMMA it was opposite. Taguchi's design of experiment (DoE) technique was used by S. Bandyopadhyay et al. [9] to study the effects of the laser process variables on the quality of the drilled holes and to obtain optimum processing conditions.

II. EXPERIMENT

CO2 laser drilling machine of Yawei HLB-1530 series was used for performing the experiments on SS 316. This machine was provided by "Power Control Electro Systems Private Limited, Kupwad M.I.D.C". The CO_2 Laser system was used to make drilled holes in given material. The machine has maximum 2 kW power capacities. Laser trepanning process was used to drill hole in given material. In trepanning process, firstly a hole is quickly pierced to drill the hole into the material, and then drilling laser beam is moved around the perimeter of the desired hole. Basically this type of drilling process used to make large diameter of hole.

Selection of process parameters and their level

It is more important to choose process parameters and their level for getting better result. The most affecting process parameters of laser system and their level selected for experiment were based on literature review and from trial experiment. The process parameters and their levels are as shown in Table 1.

Table 1 Process parameters and their Levels for Final Experiments on SS 316

Sr. No.	Process parameters	Units	Parameter	Level 1	Level 2	Level 3
1	Laser power	Watt	A	800	1200	1600
2	Feed	mm/min	B	100	200	300
3	Gas pressure	Bar	C	2	4	6

Design of experiment for laser drilling

The quality of laser drilled hole affected by number of parameters, but it is not possible to vary some of parameters. Therefore, depending on the parameters which are able to change, the particular orthogonal array was selected for doing experiment. So that the parameters which are able to change easily are laser power, gas pressure and scanning speed were chose. Depending upon number of levels of a factor, a 2 or a 3 level Orthogonal Array (OA) can be selected. For all 3 parameters 3 levels were selected. Depending on the number of parameters that is 3 and their 3 levels the L9 and L27 orthogonal array is available, for this study L_9 array was used as shown in Table 2. Material selected is as per the application of CO2 laser drilling process, stainless steel of 1.2mm thickness for experiment. The 2kW capacity of CO2 laser machine was used. In this study Laser trepanning is one of type of laser drilling was used to make holes. Based on the preliminary experiments, the range of laser power, scanning speed and gas pressure were selected as 800–1600 W, 100-300 mm/min and 2-6 bar respectively.

Table 2 L_9 Orthogonal Array

Expt. No.	Laser Power (W)	Gas Pressure (Bar)	Scanning Speed (mm/min)
1	800	2	100
2	800	4	200
3	800	6	300
4	1200	2	200
5	1200	4	300
6	1200	6	100
7	1600	2	300
8	1600	4	100
9	1600	6	200

Measurement of responses

To get accurate response values, the each trial was carried out for three times and then average value of the responses for each trial was taken for analysis. The responses such as circularity at entrance and exit were measured using following equation (1) and (2) respectively [10],

$$\text{Cent} = \frac{\text{Dmin}}{\text{Dmax}} \quad (1)$$

$$\text{Cext} = \frac{\text{dmin}}{\text{dmax}} \quad (2)$$

Here, Dmax is the required diameter of hole and Dmin is available diameter of hole at entrance after experiment and similarly dmax and dmin are required and available diameter after experiment at exit side of hole respectively. Considering 't' is the thickness of material, the taper angle was calculated by using Equation (3), where Dent and Dext are diameter at entrance and exit of hole respectively [10],

$$\text{Taper Angle } (\theta) = \tan^{-1}\left(\frac{(\text{Dent} - \text{Dext})}{2t}\right) \quad (3)$$

The Heat affected Zone (HAZ) is measured by measuring the micro hardness change in material. To get HAZ firstly the polishing with 400, 800 and 1200 grit size polishing paper and then with velvet cloth final polishing of experiment piece was done. Then Specimens were kept on Vickers micro- hardness testing machine to measure the change in hardness of material outside of hole to measure HAZ thickness. Table 3 shows the experiment results on MS sheet of 1.2mm thickness.

Table 3 Experimental Results

Measured Responses	Experiment Number								
	1	2	3	4	5	6	7	8	9
Entrance Circularity	0.851	0.832	0.847	0.872	0.863	0.876	0.879	0.888	0.871
Exit Circularity	0.793	0.817	0.826	0.825	0.843	0.849	0.851	0.867	0.855
Hole Taper angle (Degree)	2.743	0.716	1.026	2.243	0.931	1.313	1.337	1.003	0.764
HAZ Thickness (mm)	0.235	0.205	0.180	0.305	0.235	0.280	0.350	0.380	0.310

III. ANOVA OF EXPERIMENT

ANOVA was used to find out most affecting parameter on responses, the results are shown in Table 4, Table 5, Table 6 and Table 7. The assessment of result was done using F and P distribution. Also the main effects plot for entrance circularity, exit circularity, hole taper and for HAZ thickness shown in Fig. 2, 3, 4 and 5 respectively.

Table 4 ANOVA of Entrance Circularity

Factor	DF	Entrance Circularity					
		SSq	Adj SS	Adj MS	F	P	% C
Laser Power (W)	2	0.215	0.215	0.1075	21.76	0.044	82.87
Gas Pressure (bar)	2	0.0066	0.0066	0.0033	0.67	0.6	2.55
Scanning Speed (mm/min)	2	0.0279	0.0279	0.014	2.83	0.261	10.78
Error	2	0.0099	0.0099	0.005			3.8
Total	8	0.2593	S = 0.07027 R-Sq = 96.2% R-Sq(adj) = 84.8%				

Table 5 ANOVA of Exit Circularity

Factor	DF	Exit Circularity					
		SSq	Adj SS	Adj MS	F	P	% C
Laser Power (W)	2	0.3446	0.3446	0.1723	19.24	0.049	74.94
Gas Pressure (bar)	2	0.0873	0.0873	0.0437	4.88	0.17	19.01
Scanning Speed (mm/min)	2	0.0098	0.0098	0.0049	0.55	0.647	2.14
Error	2	0.0179	0.0179	0.009			3.9
Total	8	0.4596	S = 0.09462 R-Sq = 96.1% R-Sq(adj) = 84.4%				

Table 6 ANOVA of Hole Taper

Factor	DF	Hole Taper (Degree)					
		SSq	Adj SS	Adj MS	F	P	% C
Laser Power (W)	2	12.754	12.754	6.377	2.57	0.28	10.01
Gas Pressure (bar)	2	90.581	90.581	45.291	18.28	0.052	71.26
Scanning Speed (mm/min)	2	18.850	18.850	9.425	3.80	0.208	14.82
Error	2	4.954	4.954	2.477			3.9
Total	8	127.14	S = 1.574 R-Sq = 96.1% R-Sq(adj) = 84.4%				

Table 7 ANOVA of Heat Affected Zone thickness

Factor	DF	Heat Affected Zone thickness (mm)					
		SSq	Adj SS	Adj MS	F	P	% C
Laser Power (W)	2	30.626	30.626	15.313	55.27	0.018	81.53
Gas Pressure (bar)	2	2.9221	2.9221	1.461	5.27	0.159	7.77
Scanning Speed (mm/min)	2	3.4544	3.4544	1.7272	6.23	0.138	9.19
Error	2	0.5541	0.5541	0.2771			1.5
Total	8	37.556	S = 0.5264 R-Sq = 98.5% R-Sq(adj) = 94.1%				

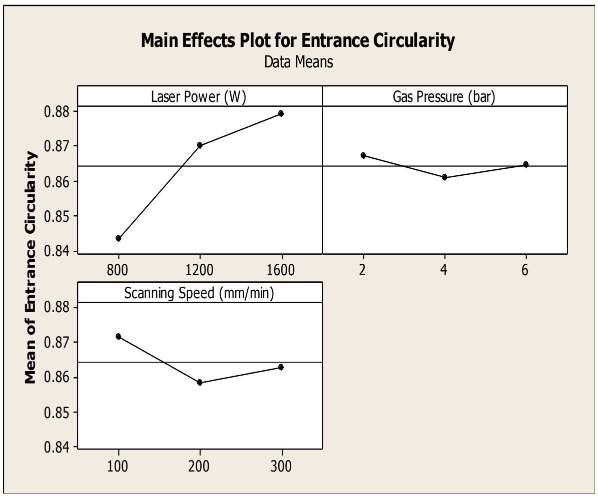

Figure 2 Main effect plot for Entrance Circularity

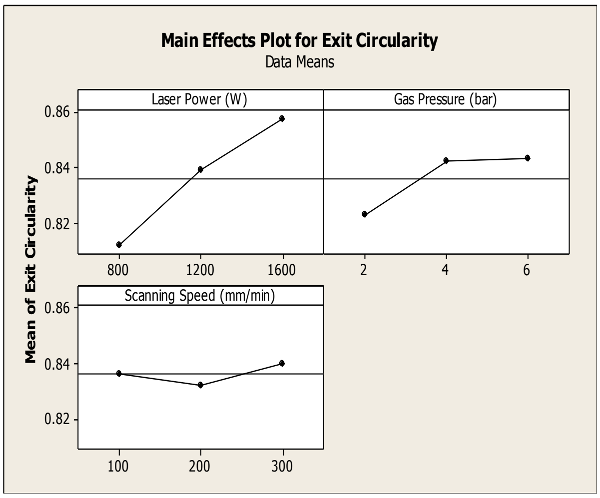

Figure 3 Main effect plot for Exit Circularity

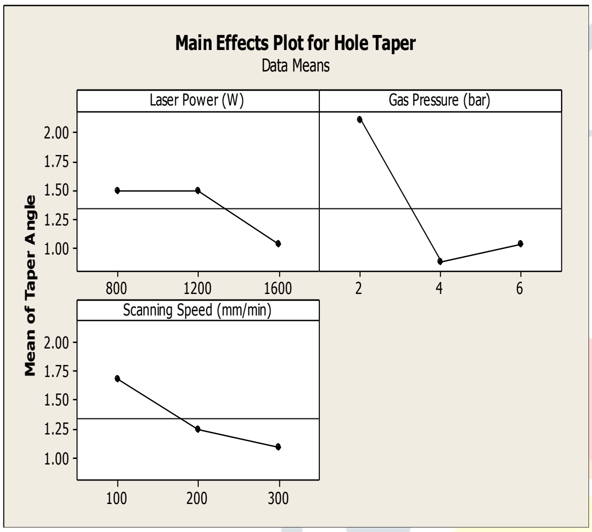

Figure 4 Main effect plot for Hole Taper

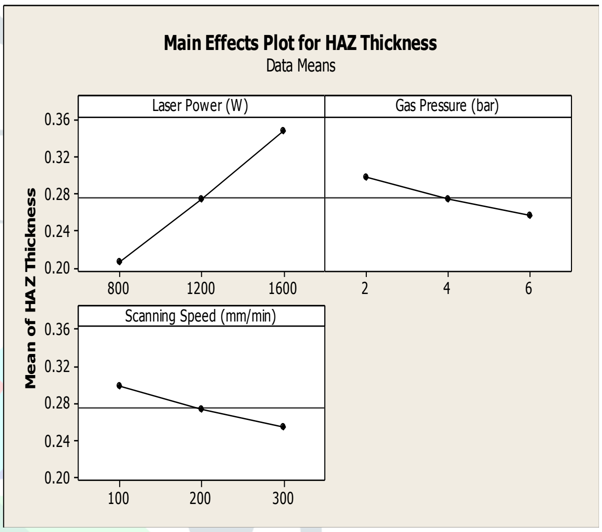

Figure 5 Main effect plot for HAZ Thickness

IV. RESULTS AND DISCUSSION

The experiments were carried out according to Design of Experiment (DoE). After experiments, the required measurements were taken to do the analysis. Analysis of the measured values was done with ANOVA technique to get the optimum values of input parameter for correct geometry characteristics of hole.

ANOVA of entrance and exit circularity

ANOVA result for entrance and exit circularity presented in Table 4 and 5 respectively. The result shows that, both entrance circularity and exit circularity are mainly influenced by Laser Power. As laser power increases, both entrance and exit circularity increases. Because of high thermal energy of laser beam does not allow molten material to accumulate, so that circularity increases. Ng and Li [11] investigates that entrance circularity is sensitive at higher laser power and with increase in hole diameter it gradually decreases.

Fig. 2 and Fig. 3 shows up to certain power limit circularity at entrance and exit increases, but as power increases beyond that limit circularity decreases. Because of high thermal energy of laser beam, melting of material increases, that results in diameter of hole increase. But the effect of gas pressure and scanning speed at entrance side less as compared to laser power. Whereas considering exit circularity as gas pressure increases the removal of molten metal increases this result in circularity of hole at exit increases but up to a certain pressure limit i.e. after 4 bar pressure the effect of gas pressure on exit circularity remains constant.

ANOVA of Taper

Table 6 presents the ANOVA result of hole taper, it can be conclude that taper of hole is mostly influenced mostly by gas pressure and later by scanning speed and laser power. Minimum value of taper is preferred for good quality of drilled hole. As gas pressure increases the energy available with gas also increases, which results in removal molten metal at exit as well as at entrance side that gives less taper. Fig. 4 shows the effect of gas pressure. Also material removal rate increases as laser power increases this is because of direct evaporation of metal taken place which results in it gives better hole circularity at exit as well as entrance side which will also decreases taper. With increase in peak power the taper decreased reported by Ghorieshi et al. [12]. When the high energy of laser beam strikes on the material gives larger entrance diameter is produced, at the same time beam produces larger exit diameter because greater energy per pulse has more effect on the hole exit than that at the entrance. This results in lower values of taper.

ANOVA of HAZ

Table 7 shows ANOVA of HAZ thickness, from table it was investigated that laser power is a major contributing factor having percentage contribution 81.53%, followed by scanning speed having contribution 9.19% and then laser power which is 7.77%. Fig. 5 shows the main effect plot for HAZ thickness. There is large variation in HAZ thickness as laser power increases compared to scanning speed and gas pressure. This is because as name HAZ indicates that it is related to heat, so as power increases the heat available with laser also increases which results in increase in HAZ thickness. Considering gas pressure, as gas pressure increases the heat removal also increases. So as gas pressure increase the HAZ thickness decreases. From Fig. 5 it can be say that as scanning speed increases the HAZ thickness decreases because interaction of laser will be decreases as scanning speed increases.

V. CONCLUSION

In the present research, CO2 laser trepanning drilling of 1.2 mm Stainless Steel of 316 grade plates were taken out to examine the effect of laser parameters such as laser power, gas pressure and scanning speed on entrance circularity, exit circularity, HAZ and taper. It was found that both entrance and exit circularities were significantly influenced by laser power and gas pressure. HAZ mainly influenced by laser power as well as scanning speed and gas pressure but less as compared to laser power, also taper was significantly influenced by laser power. Both entrance and exit circularities largely influenced by laser power and increased with increase in laser power. Also it was found that as laser power increases the taper produced was decreased. The HAZ increased with increase in power but it decreased with increase in scanning speed.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] George Chryssolouris, Laser Machining Theory and Practice, Mechanical Engineering Series Book, Springer Publication, Verlag New York, 1991.

[2] Bekir Sami Yilbas, Laser Drilling Practical applications, Manufacturing and surface engineering, Springer Publication, Springer Heidelberg New York Dordrecht London, 2013.

[3] Jeb Collins and Pierre Gremaud, “A Simple Model for Laser Drilling,” Mathematics and Computers in Simulation, 81 (2011) 1541-1552.

[4] M. Boutinguiza, J. Poua, F. Lusquinosa, F. Quinteroa, R. Sotoa, M. Perez-Amora, K. Watkinsb and W.M. Steen, "CO2 laser Cutting of Slate," Optics and Lasers Engineering, (2002) 15-25.

[5] http://www.farnell.com/datasheets/26035.pdf cited on Wednesday, May 18, 2015, 4:21 pm.

[6] A. Bharatish, H.N. Narasimha Murthy, B. Anand, C.D. Madhusoodana, G.S. Praveena and M. Krishna, “Characterization of hole circularity and heat affected zone in pulsed CO2 laser drilling of alumina ceramics,” Optics & Laser Technology , (2013) 22–32.

[7] Brajdic M., Walther K., and Eppelt U., “Analysis of laser drilled deep holes in stainless steel by superposed pulsed Nd: YAG laser radiation,” Optics and lasers in engineering, 46(9) (2008) 648-655.

[8] I.A. Choudhury, W.C. Chong and G. Vahid, “Hole qualities in laser trepanning of polymeric materials,” Optics and Lasers in Engineering, 50 (2012) 1297–1305.

[9] S. Bandyopadhyay, Hina Gokhale, J.K. Sarin Sundar, G. Sundararajan and S.V. Joshi, “A statistical approach to determine process parameter impact in Nd:YAG laser drilling of IN718 and Ti-6Al-4V sheets,” Optics and Lasers in Engineering, 43 (2005) 163–182.

[10] A. Bharatish, H.N. Narasimha Murthy, B. Anand, C.D. Madhusoodana, G.S. Praveena and M. Krishna, “Characterization of hole circularity and heat affected zone in pulsed CO2 laser drilling of alumina ceramics,” Optics & Laser Technology, pp. 22–32, 2013.

[11] G.K.L. Ng and L. Li, “The Effect of Laser Peak Power and Pulse Width on the Hole Geometry Repeatability in Laser Percussion Drilling,” Optics & Laser Technology, vol. 33, pp. 393–402, 2001.

[12] Ghoreishi M, Low DKY, Li L., “Comparative statistical analysis of hole taper and circularity in laser percussion drilling,” International Journal of Machine Tools and Manufacture, vol. 42(9), pp. 985–95, 2009.