Experimental Study in the Process Parameters in Laser Percussion Drilling

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Abstract— In order to service and grow in the present day of global competition, every manufacturing concern focuses mostly on two factors i.e. productivity and quality. Laser drilling is a popular non-traditional machining technique for producing large numbers of cooling holes of various sizes (less than mm diameter) and angles in modern aerotech components such as turbine blades, injector nozzles, and combustion chambers. Although the productivity of microhole in very high, the quality of hole (straightness, circularity, aspect ratio, heat affected zone, micro-crack spatter rate etc.) is poor due to unique nature of the process. In the present paper experimental investigation has been carried out using Taguchi's L9 orthogonal array technique to optimize the main laser and process parameters to get a quality hole in case of in plane carbon steel specimen. Pulsed Nd: YAG laser beam has great ability for micro-machining of plane carbon steel materials because of high laser beam intensity at low mean beam power, good focusing characteristics due to very small pulse duration and less heat effected zones. The quality characteristics such as aspect ratio (depth / diameter), heat affected zone, spatter deposition, hole circularity are studied though scanning electron micro-scope (SEM). The specific advantages of this Taguchi's technique of optimization are that with a very less number of experiments, optimization is possible.

Index Terms*:* Aspect ratio, Drilling rate Hole circularity, HAZ, Laser drilling ,Optimization, , Taguchi's technique,

1 Introduction

The automobile, modern aerospace manufacturing units has been using Laser drilling to produce cooling holes of various sizes in turbine blades, nozzles guide vanes, combustion chamber etc. The high intensity laser beam falls on a very small area, the target materials gets heated, melted and vaporized due to the pressure of assist gas, the mechanism of material removal involves both vaporization and melt ejection resulting in conical hole with lot of spatter deposition on the hole periphery at the top surface. The word laser is an acronym for 'Light Amplification by Stimulated Emission of Radiation'. It has the capability to deliver the energy in order of 10^6 W/cm^2, and can be varied over a wide range of temporal and spatial distribution. Moreover, the laser light is highly coherent and monochromatic in nature. Materials processing makes the use of the thermal and photonic effect associated with the interaction of laser beam with various engineering materials. Being a noncontact, inertia less tool, laser has tremendous potential in improving the processing speed.

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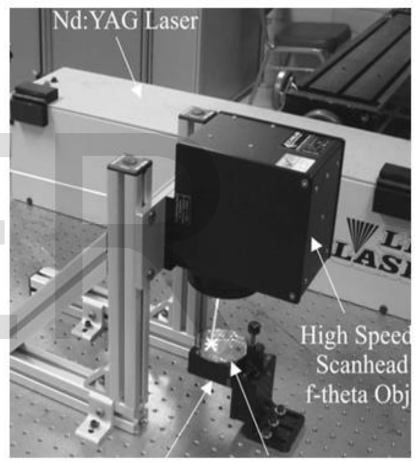


Fig.1. Laser drilling set-up.

The laser machining is based on the interaction of laser light with the outer most atoms of solid matter (opaque). Because of complex process, a small amount of material is removed from the surface of the solid. In both the cases, short to ultra short laser pulses when applied to the solid body, a small amount of material is removed in a controlled way. Keeping in view of the potentiality of the laser drilling process, the present work has been planned in this area. Low et al [1] studied the Characteristics of spatter formation under the effect of different laser parameters during laser drilling. Guo et al [2] developed spatter free laser drilling of alumina ceramics based on gel casting technology and new laser micromachining technique using a mixed mode ablation. Wang et al [3] experimentally studied the effect of assist gases such as oxygen, argon and nitrogen on the speceman. Schoonderbeek et al [4] micro structures of recast layer and reported that these are independent studied the influence of pulse width on the quality of hole using a excimer laser. Nedialkov et al [6] investigated "Laser drilling of AlN ceramics using nanosecond pulses, also similar type of work are found in [5] N.N Nedialkov et al.

Campbell et al [7] analyzed the ultra short pulse laser micromachining parameters for optimization of shallow hole drilling. Naeem, et al [8] developed "Laser percussion drilling of aerospace materials using high peck power fiber delivered 1 Amp – Pumped pulsed Nd – YAG Laser. Ghoreishi et al [9] analyzed "Optimization of effective factors in geometrical specifications of laser percussion drilled hole. The present paper deals with experimental investigation of laser and process parameters using SEM analysis for quality optimizations such as hole circularities, heat affected zone and aspect ratio, spatter deposition on a medium carbon steel specimen. G. Taguchi, [10] "Introduced Quality Engineering the appropriate S/N ratio for these quality characteristics (circularity) is "smaller the better" and" higher the better.

2 EXPERIMENTAL DETAILS:

A steel plates of 50 mm long, 15 mm wide and 5 mm thick were used for the drilling operation. The main factors (air flow rate, pulse frequency, pulse width) are considered to characterize laser-drilled hole. The specimen was mounted on the platform with the arrangement to regulate the flow of assist gas and the laser beam was focused with a lens of focal plane as shown in Fig.1. A set of holes were drilled on one longitudinal surface of the specimen following Taguchi's L_9 orthogonal array. Three controllable parameters such as pulse width, pulse frequency and air flow rate were varied as presented in Table 1.

Sl. No	Parameters	Unit	Low level	Medium level	High level
1	Pulse width	µs	500	700	900
2	Pulse frequency	s^{-1}	1	2	3
3	Air flow rate	lit/min	5	15	25

When a laser beam is focused in to the work piece surface, a portion of the beam is absorbed on the surface and some part is reflected back which depends upon the nature of surface finish and wave length of laser beam. The photons of absorbed laser beam interact with the outer most atom of the work piece surface and heat is developed. Because of the focused and high energy density of the incident laser beam, a portion of the work piece material gets melted and vaporized. In principle, laser drilling is governed by an energy balance between the irradiating energy from the laser beam and the conduc tion of heat into the work piece, the energy losses to the environment and the energy required for phase change in the work piece. The mechanism of the laser drill- ing process is explained with the help of the Fig.1(a).

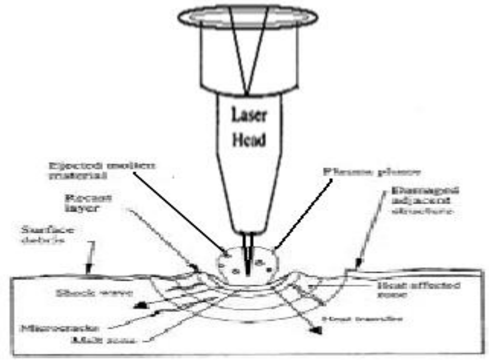
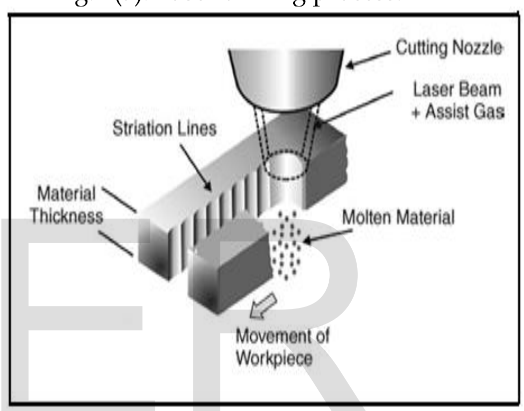


Fig.1 (a). Laser drilling process.



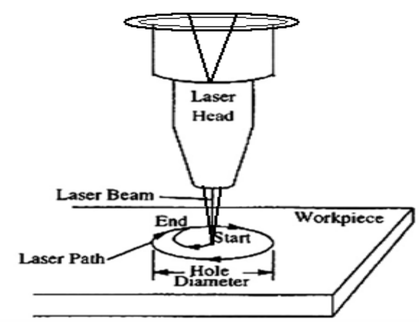


Fig.2. Mechanism of Laser Drilling.

The same optimum result can also be obtained by only 9 set of experiments following Taguchi's L_9 orthogonal array. The Taguchi's method requires both analysis of mean response (output value) and analysis of variance using appropriately chosen "signal to noise (S/N) ratio" derived from a quadratic loss function. In the present experimental work, three output parameters i.e. hole circularity; aspect ratio and drilling rate were studied. The error of hole circularity is decided by the difference of radial distance between the minimum and maximum inscribing circles. That means smaller the difference, better will be the circularity. Therefore, the appropriate S/N ratio for these quality characteristics (circularity) is "smaller the better" and is given by:

$$\eta_{LB} = -10\log_{10}\left(\frac{1}{r}\sum_{i=1}^{r} y_i^2\right)$$

For a better quality hole, the aspect ratio (depth/diameter) should be as high as possible. Similarly for higher productivity, the drilling rate should be higher. Therefore, the appropriate S/N ratios for these two quality characteristics are "higher the better" and is given by:

$$\eta_{HB} = -10\log_{10}\left(\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right)$$

The various steps in this technique are:

- The output parameters to be optimized.
- The levels of controllable and uncontrollable parameters are idetified.
- The orthogonal array matrix is prepared.
- Experiments are performed as per orthogonal array matrix.
- Using the experimental observation, average output parameters for each set of process parameters and appropriate (S/N) signal to noise ratios are determined.
- The data are analyzed through a set of graphs to obtain the optimum level combination of parameters.

3. Results and Discussion.

The present study involved investigation of various characteristic associated with pulsed Nd-YAG laser drilling using processing of the metal. After the drilling operation, micrographs of the top surface of the holes were taken using scanning electron microscope (SEM) to show the circularity, heat affected zone .A transverse section is made near the diametral plane of the micro-hole after polishing the cut surface of the micro hole, the different parameters such as hole diameter, thickness of Heat affected zone, approximate depth etc. were measured under a scanning electron microscope. The side view of few micro holes is also presented. The measured parameters are presented in Table.2 and average values of output parameters such as aspect ratio (depth/diameter) thickness of heat affected zone and corresponding S/N ratio are calculated and presented.

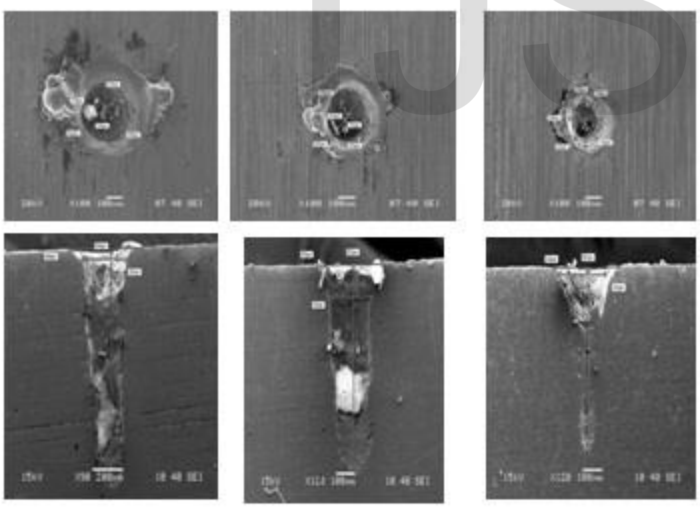


Fig. 3: SEM photograph at process parameters

Pulse width = 500 μs,
Number of pulse per second =3, average power = 1.7 W,
Air flow rate =5 lit/min, time = 20 sec.

Pulse width = 700 μs,
Number of pulse per second = 3,average power = 2 W,
Airflow rate = 15 lit/min, time = 20 sec

Pulse width = 900 μs,
Number of pulse per second = 3, average power = 3 W,
Airflow rate = 25 lit/min, time = 20 sec.

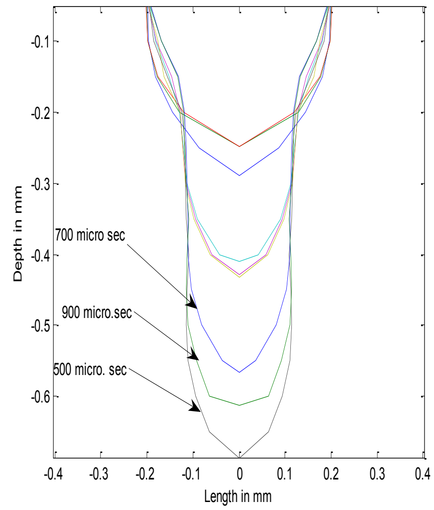


Fig 4 .Super imposition of 9 different predicted hole contours for comparision .

Fig.4 shows the different isotherm by changing parameters and all the 9 isotherm in a single graph respectively.

Table – 2: Process parameters and corresponding output with S/N values.

Sl.No. (Test No.)	Pulse width (µs)	Pulse Freq. (No.of Pulse(s))	Air flow rate (lit /min)	Average power (W)	Drilling time (s)	Error in hole circularity (%)	S/N ratio for error of hole circularity (db)	Depth of hole (µm)	Drilling rate (µm/s)	S/N ratio for drilling rate (db)	Average hole diameter (µm)	Aspect ratio (depth/dia)	S/N ratio for aspect ratio (db)
1	500	1	5	0.8	20	11.18	-20.9	940	47.0	33.44	265	3.547	11.0
2	500	2	15	1.1	20	57.565	-35.20	632	31.6	29.99	300	2.107	6.47
3	500	3	25	1.7	20	5.426	-14.69	567	28.350	29.05	155	3.658	11.26
4	700	1	15	1.6	20	74.528	-37.45	938	46.9	33.42	130	7.215	17.16
5	700	2	25	1.8	20	43.878	-32.84	808	40.4	32.13	150	5.387	14.63
6	700	3	5	2.0	20	3.093	-9.81	707	35.35	30.97	150	4.713	13.47
7	900	1	25	1.5	20	59.043	-35.42	618	30.9	29.80	110	5.618	14.99
8	900	2	5	2.5	20	61.49	-35.78	754	37.7	31.53	170	4.435	12.94
9	900	3	15	3.0	20	30.986	-29.82	939	46.95	33.43	225	4.173	12.41

It clearly shows from the table-2 that hole of high aspect ratio is possible for a pulse width of 500µs(lowest), pulse frequency of 3(highest) and with average power of 1.7 W. A good quality hole is simply represented by higest aspect ratio. That means micro hole having less diameter with higher depth. It is observed from the Taguchi's parametric optimization technic that a deper and narrow hole can be possible by lesser pulse width and higher pulse frequency. The reason is obvious because, lesser pulse width does not allow much time for the heat to diffuse into the neighbouring metal matrix, and higher pulse frequency frequency favours higher vapoization/ melting rate compared to lower pulse frequency.

4 CONCLUSIONS

The following conclusions are obtained from this experimental work:

- To obtain a best circular shaped hole, the optimum combination of process parameters is: pulse width, 500 µs; pulse frequency, 3; and assist gas flow rate, 5 lit/min.
- High productivity and high quality cannot be obtained simultaneously. One has to make a compromise between these two.
- The optimum combination of process parameters for high drilling rate and high aspect ratio is: pulse width; 700 µs, pulse frequency; 1 and assist gas flow rate; 15 lit/min.
- The hole taper varies widely which is obvious from the wide variations of aspect ratios. (i.e. from 2.107 to 7.215) Taguchi's parametric optimization technique is a simple and economic tool to decide the optimum combination of process parameters for obtaining best results from any experiment or process.

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