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Process Development of micro-hole by Pulsed Laser

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***Abstract:*-- Laser drilling is a popular non-traditional machining process for the production of large numbers of cooling holes of various sizes (<1mm) and angles in modern aerospace gas turbine components such as turbine blades, nozzle guide vanes, combustion chambers and afterburners. The rate of production of micro-hole (i.e. productivity) is very high but the quality of hole (such as straightness, circularity and HAZ etc.) is very poor due to unique nature of the process. In the present study, first, a set of experiments have been conducted using Taguchi's L9 orthogonal arrays on a medium carbon steel specimen. Subsequently, different quality parameters (i.e. circularity, HAZ, aspect ratio and spatter deposition) of the micro-hole were measured through SEM.**

Index Terms - Pulsed Laser, whole quality, Taguchi method, Process Parameter, SEM analysis.

INTRODUCTION TO COMPOSITE

The word LASER is an acronym for "Light Amplification by Stimulated Emission of Radiations". A laser system or simply a laser is an electro-optical device used to convert electrical energy into electromagnetic energy in the form of a beam of light. At the heart of lasing phenomenon is the ability of photons to stimulate the emission of other photons, each having the same wave length and direction of travel as the original. Since last three decades, lasers have been used as potential tools for materials processing due to the unique properties such as: coherent, monochromatic beam of low divergence and having high energy density

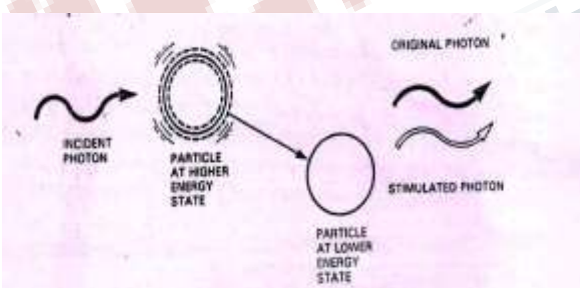

Fig. 1 : Stimulated emission

Among various applications, laser drilling is a popular process for producing large numbers of cooling holes of various sizes and angles [1] in the modern aerospace gas turbine components such as turbine blades, nozzle guide vanes, and combustion chambers and after burners: Besides these applications, it has become a fast growing method in automobile, electronic and pharmaceutical Industries. Laser is an attractive tool because of the following advantages [2] over mechanical methods such as (i) ability to drill ceramics, high strength materials and composites(ii) higher accuracies and smaller dimensions (iii) high productivity (i.e. more than 100 holes/s) without tool changing and (iv) ability to drill inaccessible areas. Generally low to medium power pulsed Nd-YAG laser with Gaussian beam (TEM00) mode is suitable for laser drilling. Further, the position of the work piece should be at focal plane of the lens. It facilitates least beam diameter, high energy density and the holes become straighter compared to other positions. The mechanism of the laser drilling process is explained with the help of the Fig.1.

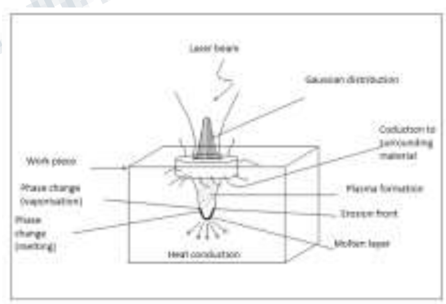

Fig.2 : Mechanism of Laser Drilling.

In laser drilling the significant mechanism of material removal is the melt ejection [3]. Vapourization within the hole creates high pressure gradient as a result of which molten material is expelled out from the hole. Because of melting and vaporization processes [4], the hole becomes tapered and bell shaped at the top. In order to protect the lens and sometimes to accelerate the drilling process, assist gases like air, oxygen, nitrogen or argon is used. Laser drilled holes are associated with the deposition of spatters because, the

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Vol 3, Issue 2, February 2018

ejected materials resolidifies and adheres around the periphery of the holes [5].

It is obvious from the aforesaid discussion that though the process is capable of producing large numbers of fine holes on any hard and brittle material on one hand, the holes become tapered associated with oxide layers and or heat affected zone, spatters deposition on the surface, lack of circularity, presence of crack and shallow depth on the other hand. In view of the above facts, researchers are trying to minimize these defects to make this process more attracting. The main parameters which govern the quality of the hole are: pulse width, pulse frequency, power density, type and flow rate of assist gases. Researchers are trying to obtain the optimum controllable parameters for getting a best quality hole with existing set-up through experiments.
In the present study first a set of experiments have been conducted using Taguchi's L9 orthogonal arrays on a medium carbon steel specimen. Subsequently different quality parameters (i.e circularity, HAZ ,aspect ratio and spatter deposition)of the micro-hole were measured through SEM..

2 EXPERIMENTATION

2.1 Descriptions of Experiment

A pulsed Nd-YAG laser system was used for the experimental work with the following specifications.(i) Rated average power = 100W, (ii)Rated maximum pulse energy = 2 joules (iii)Wave length = 1.06 µm,(iv) Pulse width = 300µs to 1000µs, (v)Pulse frequency = 1, 2, 3 pulses/sec.

Arrangement was made to regulate the flow of assist gas. A specimen was prepared from medium carbon steel with dimension 100mm x 10mm x 8mm. During the process of drilling it was kept on a platform positioned at the focal plane of the lens. The surface of interest was ground with a surface grinding machine with surface roughness (Ra) of 2µm. A set of 9 different 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.

Table 1: Details of three levels

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.	Assist gas flow rate	lit/min	5	15	25

2.2 Experimental Results

After the drilling operation was over, the different parameters such as hole diameter, thickness of heat affected zone, approximate depth etc. were measured under a scanning electron microscope. The top views of few micro-holes are presented in Figures 2 to 4.

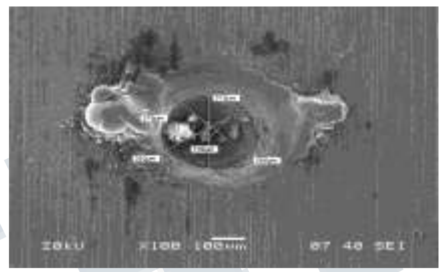

Fig. 2 : SEM photograph at process parameters Pw = 500 µs, Pf =3, P_{av}. = 1.7 W, air flow rate = 25 lit/min, time = 20 sec.

Fig. 3: SEM photograph at process parameters: Pw = 700 µs, Pf = 3, P_{av}.= 2 W, air flow rate = 5 lit/min, time = 20 sec.

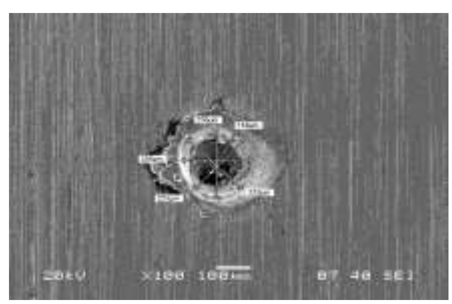

Fig. 4: SEM photograph at process parameters : Pw = 900 µs, Pf = 3, P_{av}.= 3 W, air flow rate = 15 lit/min, time = 20 sec.

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

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corresponding S/N ratio (6) values are calculated and presented in Table 3.

Table 2 Measured hole parameters.

Sl.No.	Pulse width, µs	No. of pulses/s	Air flow rate lit/min	Average beam power, W.	Time, s	Average hole diameter µm.	Error in circularity, µm	Thickness of HAZ, µm	Approximate depth, µm
1	500	1	5	0.8	20	322	18	59.25	1360
2	500	2	15	1.1	20	321	78	24.50	1860
3	500	3	25	1.7	20	258	07	24.25	1110
4	700	1	15	1.6	20	212	79	72.00	1310
5	700	2	25	1.8	20	146	43	82.25	853
6	700	3	5	2.0	20	194	03	33.00	110
7	900	1	25	1.5	20	188.5	56	42.50	1160
8	900	2	5	2.5	20	161.5	50	26.00	847
9	900	3	15	3.0	20	142	22	31.00	1070

Table 3 Calculated hole parameters.

Sl.No.	Pulse width, µs	No. of Pulses/s pulses/s	Air flow rate lit/min	Average beam power, W.	Time, s	Thickness of HAZ, µm	S/N for HAZ, db	Aspect ratio	S/N for aspect ratio, db
1	500	1	5	0.8	20	59.25	-35.487	4.2	12.46
2	500	2	15	1.1	20	24.50	-28.036	5.79	15.25
3	500	3	25	1.7	20	24.25	-27.857	4.30	12.67
4	700	1	15	1.6	20	72	-37.8	6.18	15.82
5	700	2	25	1.8	20	82.25	-38.440	5.84	14.29
6	700	3	5	2.0	20	33	-30.436	5.67	15.07
7	900	1	25	1.5	20	42.50	-36.160	6.15	15.78
8	900	2	5	2.5	20	26.00	-30.358	5.25	14.40
9	900	3	15	3.0	20	31.00	-29.987	7.54	08.77

3DISCUSSIONS

Using the above results graphs were plotted as shown in Fig. 5 and 6. It is observed from the set of figures 5 that the maximum aspect ratio (depth/average hole diameter) was obtained at high value of pulse width (900□s) and minimum pulse frequency (1pulse/sec) and medium air flow rate. At high pulse width, the heat diffusion in the depth directions is higher compared to radial (lateral) direction. Minimum pulse frequency reduces the heat diffusion in the lateral directions and hence diameter is less resulting in high aspect ratio.

Using the above results graphs were plotted as shown in Fig. 5.

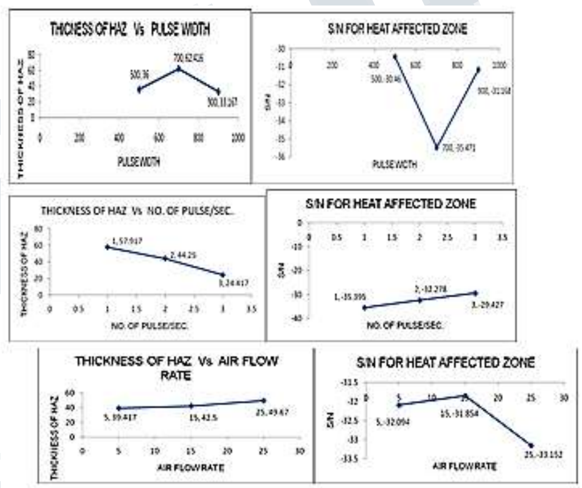

Fig. 5 A set of graphs for optimum HAZ.

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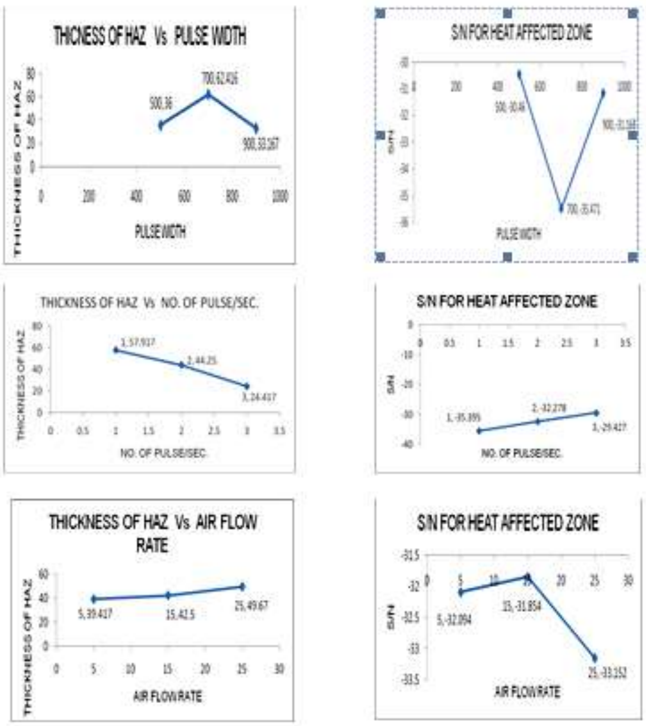

Fig. 6 A set of graphs for optimum HAZ.

Similarly it is observed from figure 6 that the thickness of heat affected zone is minimum for high pulse width (900□s) and high pulse frequency with low air flow rate. The reason for low heat affected zone at high pulse width is stated above. At high pulse frequency, the heat cannot get more time to diffuse in the lateral directions due to obstruction made by ejection of vapour and molten metal coming out of the hole. At low air flow rate, the oxidizing effect is low as a result of which lateral damage is also low.

4 CONCLUSIONS

The following conclusions are obtained from the present study:-

A pulse width of 900 µs is suitable for getting a micro-hole with least heat affected zone and with high aspect ratio. A pulse frequency of 3 per second is suitable for getting least heat affected zone whereas; pulse frequency of 1 is suitable for getting high aspect ratio. The amount of air flow has negligible effect on the value of HAZ and aspect ratio but low to medium rate of air flow is suitable for laser drilling as observed from the experimental results. Best circular hole is obtained at a pulse width of 700 µs, with pulse frequency of 3 per second and at low air flow rate. From the SEM photographs it was found that for a pulse width of 700 µs and pulse frequency of 3 per second and with low air flow rate the deposition of spatter is minimum. High aspect ratio with minimum heat affected zone cannot be achieved simultaneously as observed from these experiments. Therefore, a compromise has to be made between these two parameters. Optimum parameters are reported by conducting only 9 experiments using Taguchi's technique where both costs and times are saved.

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