ANALYSIS AND OPTIMISATION OF MACHINING PARAMETERS FOR LASER DRILLING ON STRUCTURAL CERAMICS USING TAGUCHI METHOD

[1]Joseph Abraham Chacko, [2]Benu Deepsun

[1]Assistant Professor, [2]Assistant Professor
[1 and 2] Department of Mechanical Engineering,
[1 and 2] SRM Institute of Science and Technology, Chennai, India

Abstract. ***Ceramics are becoming most popular in many fields due to its best mechanical and physical properties. Earlier methods to machine brittle and hard materials ae difficult. One among the non-traditional machining methods, laser beam machining. It has emerged as an effective technique for drilling of hard materials as well as ceramics. The aim of the work is to study the drilling process parameters on alumina by CO_2 laser. The study parameters considered in the present experiments are based on the laser beam power and an exposure time for drilling. The final results found by optical observations suggest that ordinary and coated alumina cannot withstand to a contact of the laser beam and crack during the formation of the drilling hole. The minimum power and duration of work were found to be the optimal parameters for drilling the material, after observations with high detail no micro-cracks were present and also we see that the edges of the holes have better quality of surface with best aspects.***

Keywords — Structural Ceramics, Alumina, CO_2 laser drilling, Optimal parameters

I. INTRODUCTION

II. Drilling is the important and best applications of lasers machining. This process using laser emerges as a successful substitute for holes with less than 0.25mm diameter, especially for hard and brittle materials, such as super alloys and ceramics. Laser drilling of metals is used to produce minute holes for cylinder head in engines, nozzles, cooling channels in air turbine blades, etc. For direct hole drilling, the quality of the laser beam, wavelength, intensity, pulse duration, pulse repetition rate are all important parameters.

III. Photon energy is transferred into target material in the form of thermal energy, the materials are removed by transferring high jet and heat beam to the area of machining and melts and blow away. On the other hand, conventional machining processes rely on compression and stresses induced by tools to break the bonds of materials. This will differentiate in material removal mechanism decides the challenges of Laser Machining Process compared with traditional.

IV. Laser drilling produces précised and accurate quality with shorter pulse width and higher peak intensity due to the change in parameters in machining. Reduced pulse laser is helpful to improve the effectiveness of machining even at higher cost.

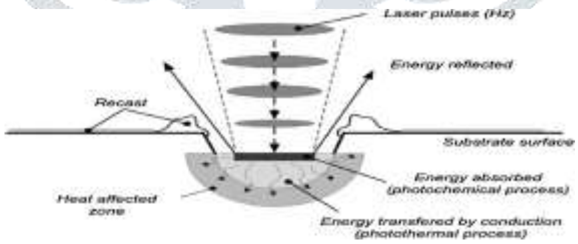


Figure 1.Schematic representation of laser in contact with ceramic.

Auxiliary method using LBM is a appropriate machining way. The obtained results are used to investigate the quality of hole.

ADVANTAGES OF LASER MACHINING

Laser cutting on mechanical cutting reduced contamination and material handling can be done easily. Precision will be better due to nil wear-rate. It also minimized chance of warping the material that is being cut. It can be done with all hard materials with more effective.

Laser cutting for metals is dominating among all other process of being more precise and utilizes less energy during the process. Laser machines operating at maximum power (7000 watts, compared with old machines with less than 1500watts). This machining is cheap compared to all other.

Contact

Laser machining is friction less, wear free and non-contact machining, while traditional machining has direct material. The dimensions in machining are in microns and traditional is in mm. The laser width and frequency on target material is negligible for bulk material.

Delicate Machining

Laser machining can do machining at micron level at précised range, while traditional machining removes material at macro scale. The minimum depth of laser drilling can be done less than one micron with good flexibility. This will reduce scrap rate in material.

Heat Affected Zone

Heat Affected Zone (HAZ) in laser machining is very thin solidified recast layer near to produced holes leads to a distortion in machining.

Surface Finish

LMP will give a high accuracy and predictive level of finish with more precision even for micron holes. Edge cutting can be done effectively using laser machining. High aspect ratio holes can be drilled using lasers.

Material Choices

The Laser Machining can be done on most of the materials with unique and dependent optimum parameters. Hard or ceramics materials are suitable for this machining, even though it is difficult in other machines. Ceramic materials are challenging for machining using Laser Machine.

CERAMICS (ALUMINA)

Alumina is the most commonly used ceramic, and is made from aluminium oxide. It can be made via different stages of manufacturing processes - iso-tactic pressing, injection moulding and extrusion. Precision grinding and lapping will give a finish to the process. High ionic inter-atomic bond makes Alumina chemically very stable. It is a good electrical insulator, resistant to wear and corrosion and has a high mechanical strength. The high alumina content is ensured from its raw material which is calcined alumina. The high content of Al_2O_3 makes it perform well in fireproof and refractory applications. Due to these advantages, alumina is mostly used in semiconductor components, pump components, electrical insulations and automotive sensors. The alumina substrate used for the experiments had a thicknesses of 3 mm, length of 50 mm and width of 50 mm. The material has a purity of more than 95%.

Alumina is a ceramic. The primary feature that determines this categorization is the fact that aluminum and oxygen share ionic bonds. This makes the material brittle and electronically insulating.

LASER MACHINING OF PURE ALUMINA

Initially, the alumina substrate was machined with laser directly. Four samples of holes were performed with different parameters. As the parameters were changed the depth also changed. It was came into a conclusion that the required depth was only attained when the frequency rate was increased.

Increase in the speed of beam made it harder to get the essential depth. This was derived while the four holes were machined with the parameters modified each time.

Experimental Table for Pure Aluminia

PARAMETERS	GRAPHITE COATED 1	GRAPHITE COATED 2	SILVER COATED 3	SILVER COATED 4
SPEED (MM/S) (VARIABLE)	230	250	230	260
POWER (%) (VARIABLE)	80	90	85	90
MARK LOOPS (VARIABLE)	10	15	10	15
WATT (W) (VARIABLE)	16	18	17	18
FREQUENCY(KHZ) (NON-VARIABLE)	20	20	20	20

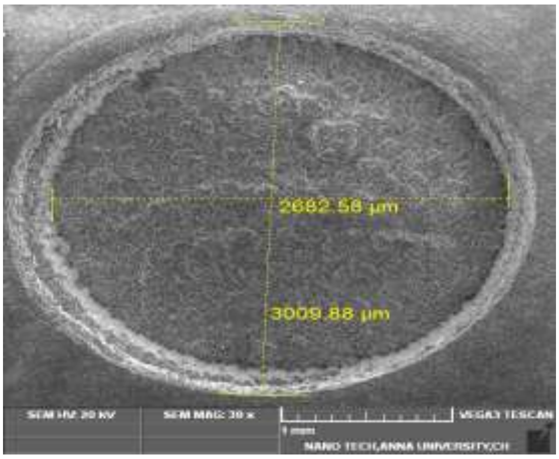


Figure 2 – SEM Analysis of pure Alumina

The following are determined only after the SEM images of the hole were taken. The external diameter was found to be 3009.88µm and the internal diameter was 2682.58µm.Using this the Taper was 272.37µm, which is a high value that is not appreciated.

LASER MACINING OF COATED ALUMINA

After it was found that the external and the internal diameter of the hole were not even close to one another, a coating over the substrate could give a better result was strong-willed. Therefore a strong coating was to be made on the sample. By spin coating, two small samples were coated. One of the sample with Graphite and the other with Conductive silver coated. Graphite coating was done as it increases the thermal conductivity. Thermal conduction in graphite results a better bond between the carbon atoms and it reflects a better machining. Conductive Silver was used for the same reason. The atoms in silver are allowed to move through freely without much resistance.
The below listed are the selected parameters to do the laser machining on graphite and silver coated alumina.
Spin coating was used because of its high effectiveness and long lasting durability. Also, the layer is spread out evenly throughout the surface. Film thickness can be changed by high speed spin or changing to high viscosity. It costs less and operating system is fast.

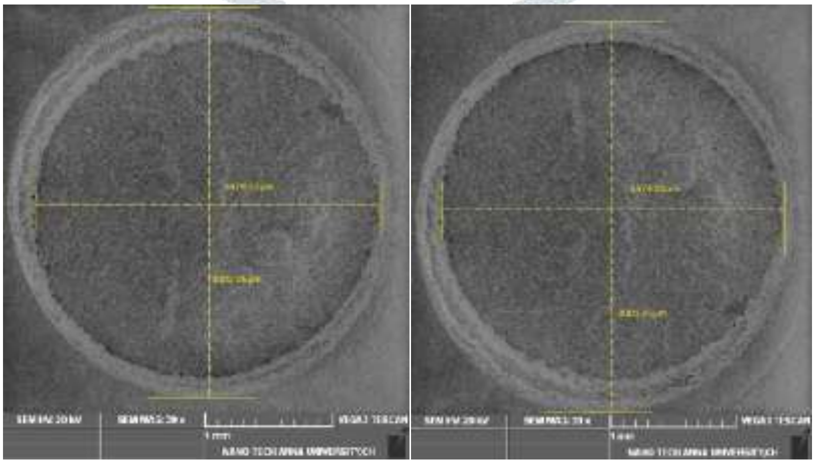
Firstly the graphite coated sample was machined with the previously attained optimal parameters. After high detail observations, it was found that there were not much of changes as expected. Also, the time taken for machining was higher which was not expected at all.

Conductive silver coated sample was later machined which gave a better result. Time taken was optimal, which was an advantage compared to the previous coating. After SEM observations the diameter changes were minimal. This result gave a positive note than the Graphite Coated sample.

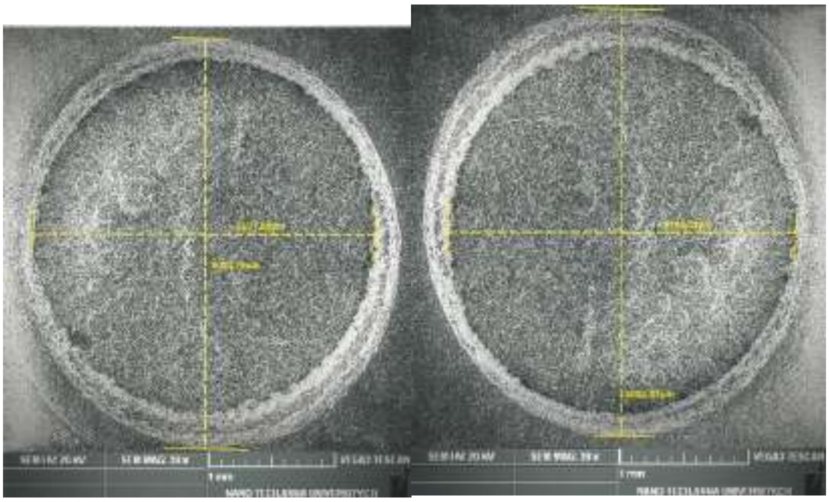
SEM ANALYSIS

SEM – Scanning Electron Microscopy gives detailed high resolution images of the work piece by raster a focused electron beam across the surface and detecting secondary or backscattered electron signal.

SEM analysis was mainly done to give a detailed approach for our research. These images above give the external and internal diameters for the machined holes. It is ideal for characterizing ceramic and composite materials. It will analysis the critical grain size and size distribution.



[a] **[b]**



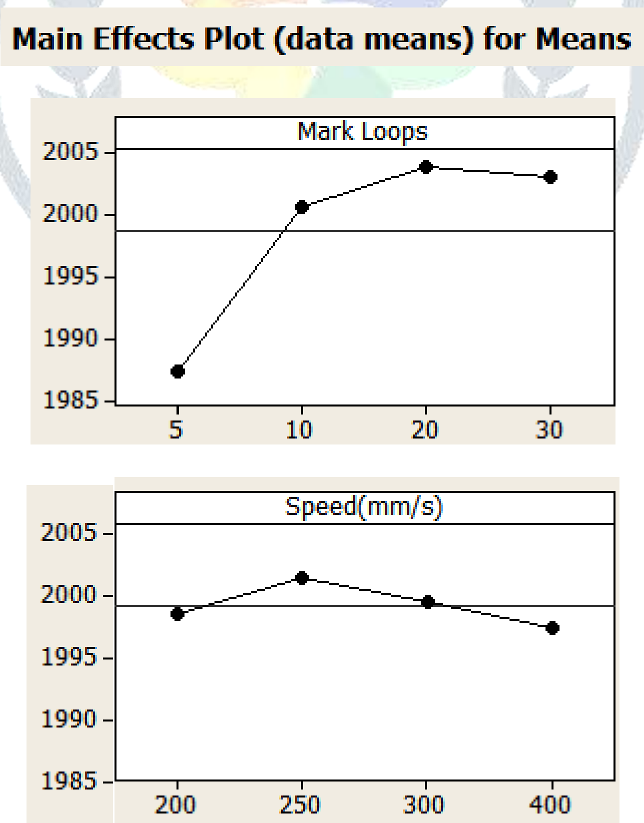
[c] **[d]**

Figure 3 - SEM Analysis
[a and b] Conductive Silver coated Alumina
[c and d] Graphite coated Alumina

DOE OPTIMISATION

The parameters in the SEM analysis are fed in the MINITAB software in order to get the desired optimal results. The taguchi method in DOE was applied in order to obtain the optimal values. The 3 level method of taguchi was used has we had only 3 input parameters changed majorly. These 3 input parameters were mark loops, speed(mm/s) and power(%). The standard deviations and SN ratios graph were needed to obtain the required optimal values. Separate graphs for each parameter were obtained so as detailed approach for the result would be possible. The output parameters for the process were External diameter, Internal diameter and Taper.in µm. The values that were obtained during the SEM analysis were the outputs. The input parameters entered were the machining parameters which were used while drilling the substrate.

Obtained graphs show that the time duration required for machining a hole was quite high for pure alumina compared to coated alumina. It also showed that frequency rate of the laser beam maintained at a constant level was preferable. Increase in power intensity of the laser beam did not give that much of a change. Number of passes of the laser beam implied an important role for obtaining an optimal result. The following shows the generated results provided by MINITAB:-



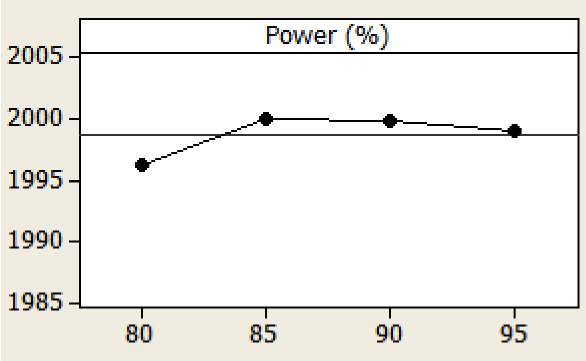


Figure 4 - Mean Effective Graphs of Pure Alumina

CONCLUSION

After thorough analysis of the microscopic images, it has been interpreted that coated alumina has given favorable results. Pure Alumina didn't have the précised finishing that the coated alumina had produced. Graphite coated alumina had a higher taper compared to Conductive silver sample because of its low conductivity compared to Silver. Reduced taper was effectively achieved by coating alumina. Surface Indifference was found to be the least in conductive silver coated sample and regular for the graphite coated substrate while pure alumina had the roughest surface finish and the uneven surface of all. When higher power (450kW) was passed onto the material it was found to give a better surface finish. This shows the high strength holding capacity of Alumina. Alumina was enhanced with better machining capabilities when coated with conductive silver. The above statements give clear evidence of the augmentation and this gives better machinability and wider range of applications in various fields.

PARAMETERS	Graphite coated (Optimized)
SPEED (MM/S) (VARIABLE)	230
POWER (%) (VARIABLE)	85
MARK LOOPS (VARIABLE)	10
WATT (W) (VARIABLE)	17
FREQUENCY(KHZ) (NON-VARIABLE)	20

Table 02 - Optimised Parameter Readings

With the help of generated values using Taguchi method validation of the parameters became simpler. Material enhancement with the help of coating has arrived as a situation to develop abundant applications.

Optimized results for machining of alumina were derived. Optimized parameters to machine the Sample, Optimized SEM image of the machined hole are given below. The experiments are carried out according to Design of Experiment (DoE). After experiments, the required measurement was 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.

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