EXPERIMENTAL INVESTIGATION AND PERFORMANCE CHARACTERIZATION OF MACHINING PARAMETER INAJM PROCESS USING ANALYTICAL METHOD

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ABSTRACT

The present investigates the performance characteristics of the process parameters in Abrasive Jet Machining using Taguchi orthogonal design matrix. The mixture of high pressure air with aluminium oxide (as abrasive particle) is used for machining of glass material. The nozzle is used to maximize the flow of abrasive particle. The machine automation was done by using the controller and driver circuit. The study established the optimum condition for the effect of over cut (OC) and material removal rate (MRR) of the said work piece. Individual optimal settings of parameters are carried out to minimize the OC and Maximize the MRR.

KEYWORDS: Abrasive Jet Machining, MRR, OC, Taguchi Orthogonal Array.

For rising of hard and brittle material, which is very difficult-to-machine, is found to be unsuitable for machinig with conventional machining. The surface finish may not be smooth or may be the tool or workpiece damaged by using above process.Besides, machining of these materials into complex shapes is thorny, time consuming and sometimes unfeasible.Advanced materials such as hastalloy, waspalloy, nitralloy, carbides, nimonics, heat resisting steels ,stainless steel and many other high-strength-temperature resistant (HSTR) alloys find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resisting properties.Considering the importance of the difficulty, Merchant in 1960's highlighted the need for the development of newer ideas in metal machining. As a result, non-traditional machining processes have appeared to triumph over these difficulties. These non-traditional technologies do not utilize a conventional or traditional tool for metal removal, as a substitute they directly make use of some form of energy for metal machining. The classification of the machining processes, based upon the type of energy used, the mechanism of metal removal in the process, the source of energy, and the medium for transfer of those energies. Material removal may occur with chip formation or even no chip formation. In some cases microscopic size chip formation occurs.

Abrasive jet machining (AJM) is one of the non-traditional methods employed for machining process in which mechanical form of energy is used. The basic mechanism of metal removal process occurs due to erosion and the transfer media is the high velocity particles. Pneumatic / hydraulic pressure happens to be the energy source.

The AJM process was started a few decades ago, till today experimental and theoretical studies have been investigated throughout the world by many researchers to develop the most efficient method. Burzynski and papini [1] implemented the narrow band level set method (LSM) on AJM for find out the surface evolution on inclined masked micro-channel in poly-methyl-methacrylate (PMMA) and glass. The result profile of glass have round bottom and curved wall and the resulting profile of PMMA have straight walls and rectangular bottoms. Ghobeity et.al [2] presented a analytical models on AJMM in which the target is oscillated transversely to the overall scan direction, by which they predicted the shape, sidewall slope, and depth of machined planar areas and transitional slopes in glass Wakuda et.al [3] compared the machinability between AJM process and the solid particle erosion model. They concluded from the test result that the relative hardness of the abrasive against the target material is critical in the micro-machining process but it is not taken into consideration. In conventional erosion process radial crack do not propagate downwards as a result of particle impact due to no strength degradation occurs for the AJM surface. Gradeena et. al [4] used a cryogenic abrasive jet machining apparatus for solid particle erosion of polydimethylsiloxane (PDMS) using aluminum oxide as an abrasive at a temperature range between -178^{0}C to 17^{0}C and observed that optimum machining of PDMS occurred at temperature approximately at -178^{0}C and also concluded that PDMS can be machined above its glass transition temperature. Ally et. al [5] observed that the optimum erosion rate occurred at impact angles between 200 and 300 when machining the aluminum 6061-T6, 316L stainless steel and Ti-6Al-4V alloy and taking the 50 μmAl_2O_3 as

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abrasive powder and found that AJM etch rate in metal was minimum when compared with the glass and polymer.

By going through many of the papers the overall conclusion drawn was that electro chemical machining and electro discharge machining are limited to the application of conductive materials which also makes high initial cost and operation cost. Similarly chemical etching requires high technical knowledge, electron beam machining laser beam machining etc. requires high investment and operating cost. Much more difficulties were faced for machining of glass, ceramic and brittle material. The above drawback motivate towards fabrication of a new AJM machine. The new AJM machine was designed, fabricated in NIT, Rourkela. The working model involved the use of a high speed stream of aluminum oxide as abrasive particles which are carried by a high pressure of air through nozzle for drill on glass as the work piece. The main objected was to minimize the over cut at the same time to maximize the material removal rate. Taguchi analysis was carried out to establish the optimum condition.

METHODOLOGY

The AJM was put into action for designing a feasible working model. The model was designed by using CATIA software. The fabrication of the model was completed by utilizing some of the waste product also fabricating some new components.

Components for AJM

The main components used for fabrication of AJM are; working chamber, mixing chamber, FRL unit, nozzle, air compressor, control unit etc.

Different components of the work chamber are enclosure, work holding devices, opening and closing system and drainage system. The specification of the different material of working chamber is given in Table1.

Table 1: Specification of raw material of working chamber

Sl. No.	Raw Material	Specification
1	Mild steel sheet	880mmx440mmx1.5mm
2	Stainless steel sheet	480mmx280mmx0.5mm
3	Glass fibre sheet	760mmx760mmx5mm
4	Allen bolts with nut and washer	6mm
5	Mild steel hinges	1.5 inches

The enclosure was fabricated air tight to prevent the mixing of abrasive particle with air. The enclosure is of mild steel rectangular box of 1 mm thickness. Transparent glass fibre sheet was fitted to the box with the help of Allen bolt. The work holding device is of L-shaped to hold the work piece. The maximum size it can accommodate is 380 x 180mm. Hinge joint were used for closing and opening of the working chamber. For safe disposal of abrasive particle drainage system is provided to the enclosure. The drainage system is fabricated by Stainless steel of size (480mm x280mmx0.5mm). The model view and working model is shown in figure 1.

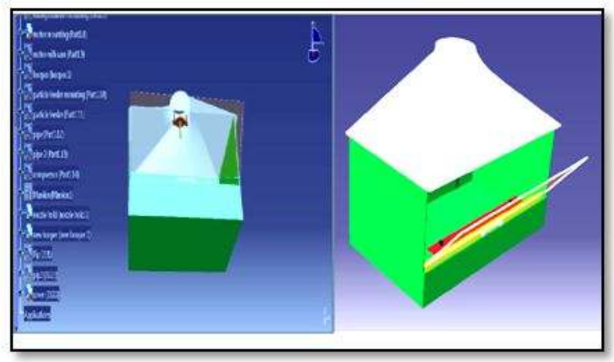

Figure 1: Model view and working model of AJM.

A reciprocating air compressor of capacity 21 kgf/cm2 was used for compressing the air. Filter regulator and lubricator (FRL) was used for filtering the air and regulating the air pressure and lubrication of component. By rotating the top screw of FRL unit, pressure is controlled with in the safe limit. The mixing chamber contains three parts i.e. mixing cylinder, cam and rotor. It is used for mixing of abrasive powder and compressed air. The cam mechanism is used for inserting the abrasive particle. The mixing cylinder was made up of mild steel, has three port. First port is used for inserting the abrasive particle and the second port is used for inserting the compressed air inside the cylinder, while third one is used for outlet of mixing of abrasive and air particle. The mixing chamber is shown in figure 2.To hold the nozzle a nozzle holder was designed and fabricated which is made up of stainless steel.

Figure 2: Mixing Chamber

Machine Automation

The AJM was automated by using controller, driver circuit and a stepper motor. The controller generates the electronic pulses and fed to the driver board. The driver board converts electronic pulse into motion control for motor [6]. A 4-axis controller device is used to control the movement of X, Y and Z axis controller. A software called CNC USB CONTROLLER was installed for these purposes. By using the controller, machine can move in 3-axis direction and by using different types of programming complicated shape can also be machined. Three stepper motor was used for 3-axis movement. The motor specification is given in Table 2.

Table 2: Motor specification

Sl. No.	Parameter	Values
1	Voltage	2.9 V
2	Current	3.1 amps
3	Steps	200 steps/Rev

The whole machine is mounted on the X-Y table. The travel of X-Y table is 290 x 170 mm. The upper table is used for x- movement and the travelling distance is 290mm, while that of y motion the lower table is used and the travelling distance is 170mm.Finally the assembly of the AJM was carried out by using the above component and referring to the model assembly shown in Figure 3.

Figure 3: Working model of AJM

Experimentation

Air is used as a carrier gas in the air compressor. The properties of glass which is used as a work piece and the properties of abrasive powder is shown in Table 3 and Table 4 respectively.

Table 3: Properties of glass

Chemical Composition	SiO_2 (74%), Na2O (13%), CaO (10.5%), Al_2O_3 (1.3%), K_2O (0.3%), SO3 (0.2%), MgO (0.2%), TiO_2 (0.01%), Fe_2O_3 (0.04%)
Glass transition temperature	573^0C
Density	2400 kg/m^3
Refractive index	1.518

Table 4: Properties of abrasive materials

Composition	Al_2O_3
Appearance	White solid
Odor	odorless
Size	50 µ
Density	3.95-4.1 gm/cm^3
Solubility	Insoluble in water

Conduct of Experiment

The nozzle diameter of 2mm and abrasive particle size of 50 µ is kept constant. The variable factors or the machining parameters are the Stand of Distance (SOD) and pressure (p). After conducting the experiment (drill hole) the measurement of drill hole was done by tool maker microscope and optical microscope. The final diameter of the drill hole is considered as the mean diameter of both the data of the microscopes. Also initial weight and final weight of the work piece electronic balance weight machine is used whose capacity is of 300 gram weight and 0.001 gram accuracy. Material Removal Rate (MRR) is calculated by Equation (1)

$$\mathrm{MRR} = \frac{W_b - W_a}{t \times \rho} \, \mathrm{m^3/min} \qquad (1)$$

Where,

W_b = Weight of the work piece before machining, kg

W_a= Weight of the work piece after machining, kg

t = Machining time, min

ρ = Density of work piece, kg/m^3

In this experiment, t= 1 minute and ρ=2400 kg/m^3

Optimal Performance Parameter

The selection of controllable parameters is a most important factor in Taguchi optimization process in order to obtain the best results. The two control parameters selected were Stand of Distance (SOD) in mm and Pressure (p) in bar which have influence on the response [8]. The two selected control parameters at three levels indicates L9 i.e. nine trials of experiments to be conducted, with the level of each parameter for each trial run as indicated on the array. Design parameters are shown in TABLE – 5. L9 Orthogonal Array is shown in TABLE -6.

Table 5: Control parameters and levels

Control Parameters	Level		
	Level 1	Level 2	Level 3
Stand Of Distance (mm)	0.7	0.8	0.9
Pressure (bar)	4	5	6

Table 6: Orthogonal Arrays

Run Number	SOD	p
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

The next step is to determine optimal conditions for the control parameters to give the optimum responses. The response variable to be optimized was MRR for maximum value, OC with the least as much as possible. The signal optimum settings of the parameters were achieved from the signal to noise ratio(S/N) which help in data analysis and prediction of the optimum result.

RESULTS AND DISCUSSION

Drilled cavity on work piece as per run number is shown in Figure 4.

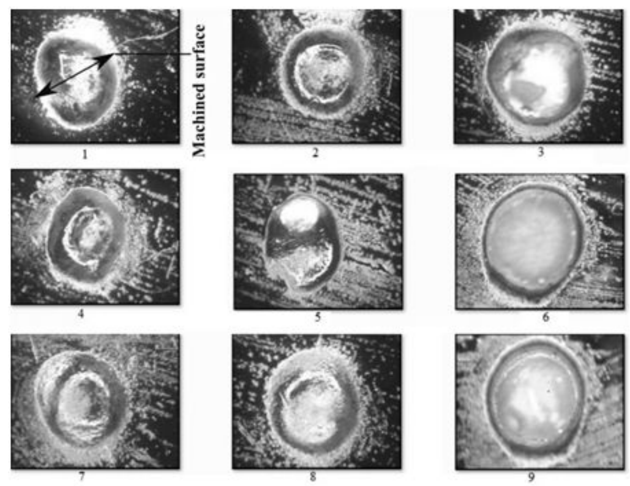

Figure 4: Drilled cavity on work piece as per run number

Experimental data are shown in Table 7 and Table 8.

Table 7: MRR versus SOD, P

Run No.	SOD(mm)	P (bar)	MRR (mm^3/min)
1	0.7	4	4.583
2	0.7	5	5.789
3	0.7	6	8.832
4	0.8	4	5.933
5	0.8	5	7.732
6	0.8	6	10.42
7	0.9	4	6.223
8	0.9	5	7.432
9	0.9	6	9.326

Table 8: OC versus SOD, P

Run No.	SOD(mm)	P (bar)	OC(mm)
1	0.7	4	0.2250
2	0.7	5	0.2976
3	0.7	6	0.4875
4	0.8	4	0.3065
5	0.8	5	0.3675
6	0.8	6	0.5075
7	0.9	4	0.2633
8	0.9	5	0.3278
9	0.9	6	0.4532

By applying the experimental data of Table 7 and Table 8 the Signal to noise (S/N) ratio graphs is shown in Figure 7 and Figure 8.

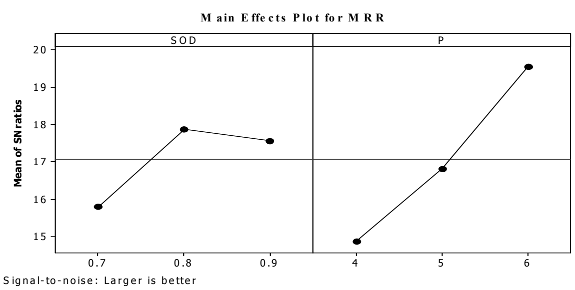

Figure 5: Main effect plot means for MRR

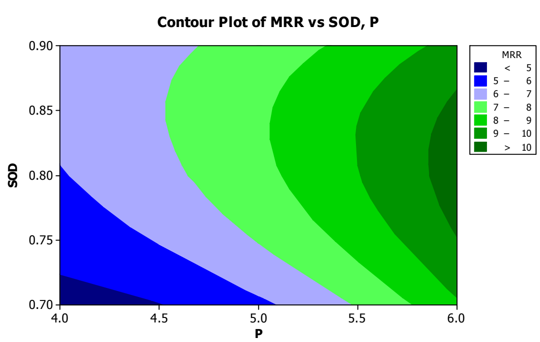

Figure 6: Contour plot for MRR

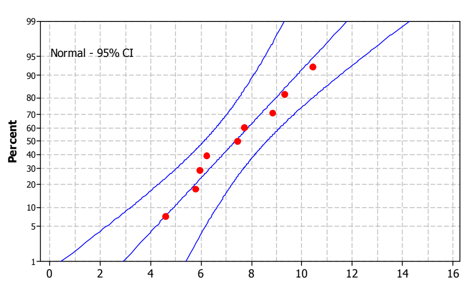

Figure7: Probability plot for MRR

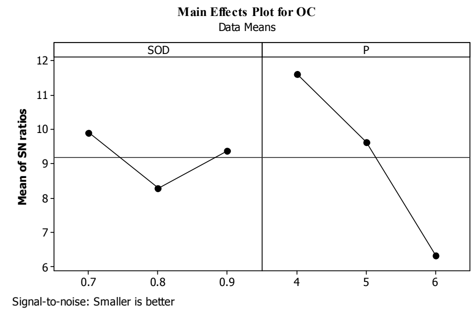

Figure 8: Main effect plot means for OC

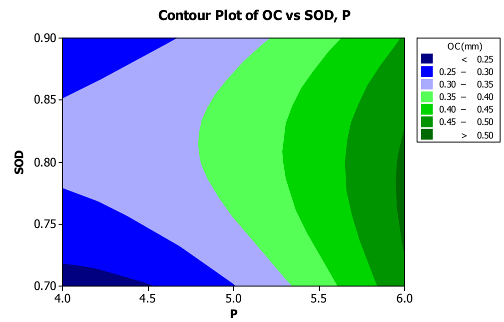

Figure 9: Contour plot for OC

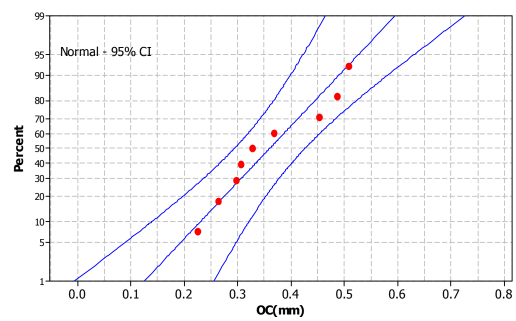

Figure 10: Probability plot for OC

From Table 7 it is observed that the pressure is directly proportional to MRR in the range of 4 to 6 bar. This is expected because an increase pressure produces strong kinetic energy which produces the higher temperature, causing more material to erode from the work piece. The other factor SOD does not influence much as compared to pressure.

To calculate MRR, the S/N ratio with a higher the better characteristics was used. Fig. 7 indicates that at SOD 0.8 mm the MRR is maximum. It decreases with increase in SOD and also decrease with decrease in SOD. From the graph it was observed that the optimization of AZM was found to be SOD =0.8mm at p= 5 bar.

From Fig. 8 indicate that the SOD =0.7mm, the OC is minimum. It increases with SOD up to some level after that it decreases. It has also been observed that with minimum pressure the OC is found to be minimum. It further increases with increase in pressure.

CONCLUSION

Design of the working model was carried out in CATIA software by considering the optimum use of available material and space.

Working chamber, nozzle holder arrangement, work holding device were fabricated in the lab as per the specification.

The AJM machine can be used for drilling and milling of glass plates or other brittle materials.

Various complicated shape can also be machined as per the programming on controller.

SOD and pressure are considered as machine parameter to study the MRR and OC.

For MRR, SOD and pressure are significant factor while pressure is significant for OC.

MRR increases with increase in pressure, but for increase in SOD, MRR increases up to some extent and then it remain constant after that it decreases.

OC increases with increases in pressure, but for increase in SOD, OC increases up to some extent only and a decrease trend is observed.

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