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Optimization and effect of controlling parameters on AJM using Taguchi technique

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ABSTRACT
Abrasive Jet Machining (AJM) is a non-conventional machining process where a high-pressure air stream with small abrasive particles to impinge the work surface through a nozzle. A model of AJM was designed by using CATIA. This model was implemented to design a workable AJM. In this paper drilling experiment was done on glass as the work piece and aluminum oxide (Al2O3) as abrasive powder on AJM. The air pressure and stand-off-distance (SOD) are considering control parameter. The effect of Overcut (OC) and Material Removal Rate (MRR) of glass material was finding by using L9 Orthogonal Array (OA) based on Taguchi design. And the influence of these controlling parameters is analyzed. Individual main effect of air pressure and SOD are plotted and optimized. Analysis of variance (ANOVA) results were performed implementing Taguchi technique.
Keywords - Abrasive jet machining, Abrasive powder, Analysis of variance, Glass material, Taguchi method

I. INTRODUCTION

Abrasive jet machining is a nonconventional machining process that carried a high-pressure air stream with small abrasive particles to impinge the work surface through a nozzle for material removal of the work piece. It is also named as abrasive micro blasting. Here material removal occurs by the erosive action of the abrasive particles striking the work piece surface. It is as an effective machining method for hard and brittle materials.

The AJM process was started a few decades ago, till today experimental and theoretical study on the Abrasive Jet machining process occurs. Most of the study based upon experiment. Some of the study based upon modeling and analysis. Ke et.al [1] has designed a novel hybrid method, called flexible magnetic abrasive jet machining, for investigating the machining characteristics of the self-made magnetic abrasive in abrasive jet machining. According to Taguchi method conclusion was derived that flexible magnetic abrasive particle gives better MRR and surface roughness than traditional abrasive. Gradeena et.al [2] used a cryogenic abrasive jet machining apparatus for solid particle erosion of polydimethylsiloxane (PDMS) using aluminum oxide as an abrasive ata temperature range between -178^{0}C to 17^{0}C. He observed that optimum machining of PDMS occurred at temperature approximately at -178^{0}C and the attacking angle in between 30^0 to 60^0.They were also found that PDMS can be machined above its glass transition temperature. Ally et.al [3] demonstrated the surface evolution model during the machining process of metal(aluminum 6061-T6, 316L stainless steel and Ti–6Al–4V alloy) which was originally developed for ductile polymer using 50 µm AL_2O_3 abrasive powder and found that in AJM, MRR was minimum when compared with the glass and polymer. Dehnadfar et.al [4] has finding out the micro machined surface by applying a jet of particle passed through narrow mask opening in abrasive jet micromachining (AJM). The structure of micro machined feature depends on mass flux and particle velocity.

Wakuda et.al [5] 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. Park et.al [6] described that the performance of MAJM in the micro-grooving of glass. They takes the diameter of the hole-type and the width of the line-type groove are 80 µm. according to the experimental result they concluded that the size of machined groove increased about 2–4 µm. Jianxin [7] studied the erosion wear behavior of boron carbide nozzles, using the silica, silicon carbide and alumina powder as abrasive, on abrasive jet machining. Conclusion was derived that the hardness of abrasive particle was played an important role on wear behavior boron carbide nozzle.

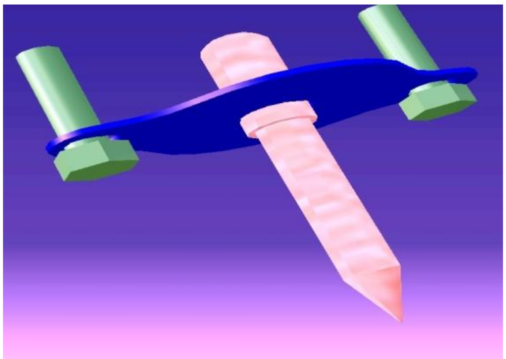
In this paper Taguchi technique is implemented to optimize the AJM process with multiple performance characteristics i.e. MRR and OC and evaluation of significant control parameters. The pressure, nozzle-tip-distance, abrasive grain size are select as a control parameter whereas the response of MRR and SR. Optimal parameter settings are carried out using this technique.

II. EXPERIMENTAL SCHEME

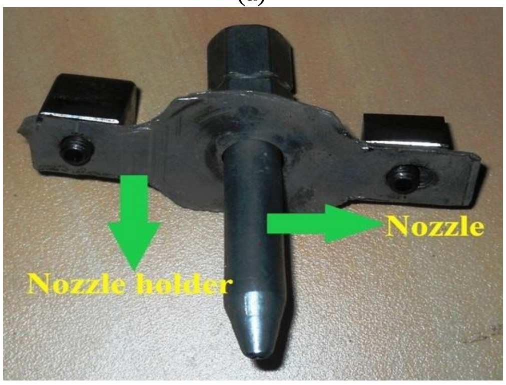
2.1 Experimental set up

2.1.1 Nozzle and its holding arrangement

For holding the nozzle a holding arrangement was modelled as shown in Fig. 1(a). In the fabrication stainless steel alloy nozzle was used. Fig. 1(b) shows the designed and fabricated nozzle holding arrangement. The nozzle holder was made up of stainless steel sheet.



(a)

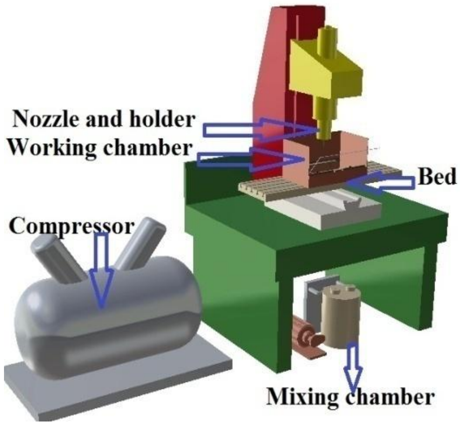


(b)

Figure 1 Nozzle holding arrangement; (a) model and (b) fabricated

2.1.2 Assembly of AJM

After completing all the component of AJM, assembly was done by taking different tool as per requirement. First modeled assembly then full assembly done as shown in Fig. 2(a) and Fig. 2(b) respectively.



(a)

(b)

Figure 2 Assemble set up of AJM (a)modeled assembly and (b) fabricated assembly

2.2 Setting of experimental parameters

The experimental parameter set up data are designed in the Taguchi method and finding the best response under optimum condition. It is used for estimating the individual factor contribution and also their interaction in the process response. It generates and analysis the main effect plot and interaction plot for signal to noise ratio, means, and standard deviations. In this experiment, a two factor and three levels setup (Table 1) is chosen with a total of nine numbers of experiments to be conducted and hence L_9 Orthogonal Array (OA) was chosen.

Table 1 Factors or parameters and their levels

Factor	Symbol	Unit	Level		
			1	2	3
Stand of distance	(SOD)	mm	0.6	0.8	1.0
Pressure	(P)	Bar	2	4	6

2.3 Experimentation

Experimental set up is shown in the Fig. 3. In this experiment nozzle diameter (2 mm), abrasive particle size (50µm) is kept constant. The machining parameter Stand of Distance(SOD) and Pressure (P) are varying (Table 1). For calculating initial and final weight electronic balance weight machine (SHINKO DENSHI Co. LTD, JAPAN, Model: DJ 300S.), with 0.001gm accuracy was used. The hole diameter of drilled glass piece, nozzle diameter before experiment and nozzle diameter after experiment was measured by tool maker microscope and optical microscope. In this experiment diameter of drilled hole was calculated by taking of the mean diameter of both the data two microscope.

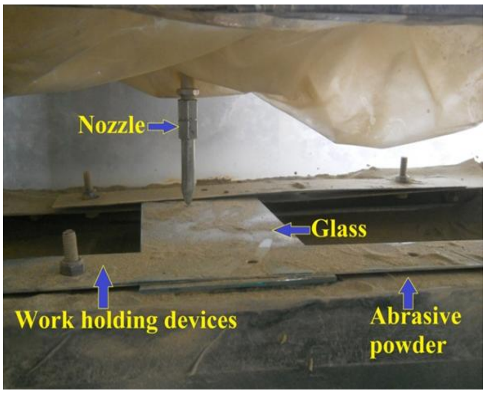


Figure 3 Experimental set up

Atmospheric air used as a medium of carrier gas, aluminum oxide was used as an abrasive powder, stainless steel alloy nozzle. Glass was taken as a work piece. Properties of glass and abrasive particle are shown in Table 2 and Table 3 respectively.

Table 2 Properties of work piece (glass)

Chemical composition	SiO_2 (74%),Na_2O (13%), CaO (10.5%), Al2O3(1.3%),K_2O (0.3%), SO_3 (0.2 %), MgO (0.2%)TiO_2 (0.01%) Fe_2O_3(0.04%)
Glass transition temperature	573 ^{0}c
Density	2400 kg/m^3
Refractive index	1.518

Table 3 Properties of abrasive particle, aluminum oxide

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

2.3.1 Material removal rate

During the process of machining the high velocity jet of abrasive air mixture is bombarded into the glass work piece .The each particle of abrasive powder removes material from work piece. The MRR is defined as the ratio of the difference of weight of the work piece before and after machining to the product of machining time and density of the material (1). Machining time is taken as 1min.

$$MRR= \frac{Wb - Wa}{t \times \rho} \quad (1)$$

Whereas Wb = Weight of work piece before machining.

Wa = Weight of work piece after machining

ρ =Density of glasswork piece

2.3.2 Overcut

It is the distance by which the machined hole in the work piece exceeds the nozzle bore diameter size. During the process of machining AJM, cavity produced are always larger than the nozzle hole diameter this difference is called Overcut (OC). It becomes important for space application, when close tolerance components are required to be produced. OC is measured as half the difference of diameter of the hole produced in the work piece to the tool (2).

$$OC = \frac{Dw - Dt}{2} \quad (2)$$

Whereas Dw = diameter of hole produced in the work piece and Dt = Diameter of tool After the machining of work piece using Taguchi design parameter setting in AJM, the observation data (L_9 OA) are represented in Table 4. Drilled hole of nine experiments by AJM are shown in Fig. 4.

Run no	SOD (mm)	P(bar)	MRR (mm^3/min)	OC(mm)
1	0.6	2	1.667	0.1325
2	0.6	4	3.750	0.1825
3	0.6	6	7.083	0.4375
4	0.8	2	2.500	0.1450
5	0.8	4	5.833	0.3065
6	0.8	6	10.417	0.5075
7	1.0	2	2.083	0.1600
8	1.0	4	4.583	0.2065
9	1.0	6	7.917	0.4575

Table 4 Observation table (L_9 OA)

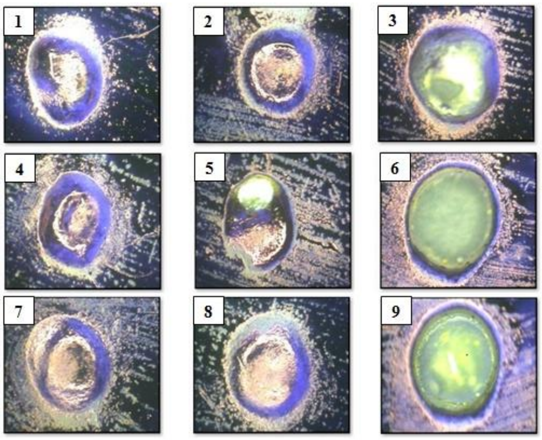


Figure 4 Machined work piece (drilled hole)

III. RESULTS AND DISCUSSION

3.1 Optimal parameter setting and ANOVA
3.1.1 MRR

The observed values of MRR are shown in Table 4. During the process of AJM, the influence of machining parameter like SOD and pressure has significant effect on MRR as shown in main effect plot for MRR in Fig 5. The pressure (p) is directly proportional to MRR in the range of 2 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. It is clearly indicated from the above Fig. 5. at SOD 0.8mm the MRR was maximum. It decreases with increase in SOD and also decreases with decrease in SOD. It suggests that the effect of one factor is dependent upon another factor. For high MRR, the optimal setting of parameters are; SOD at level 2 and pressure at level 3.

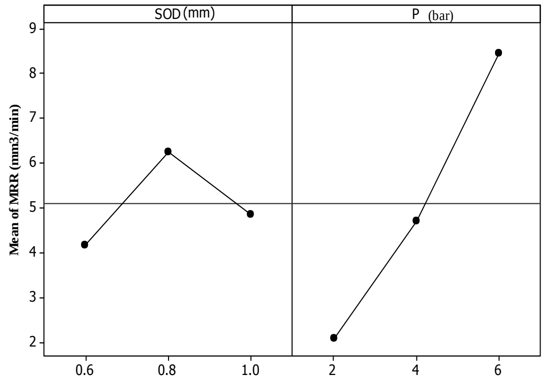


Figure 5 Main effect plot of MRR

The analysis of variances for means is shown in Table 5, which is clearly indicates that SOD of the nozzle is not important for influencing MRR and pressure (p) is the most influencing factors for MRR. The case of MRR, it is “Larger is better”, so from this table it is clearly definite that pressure is the most important factor then SOD, From the % of contribution it is shown in the table 5.2 that the p has 87.87 % contribution, SOD have 9.59 % contribution and error comes 2.57% .

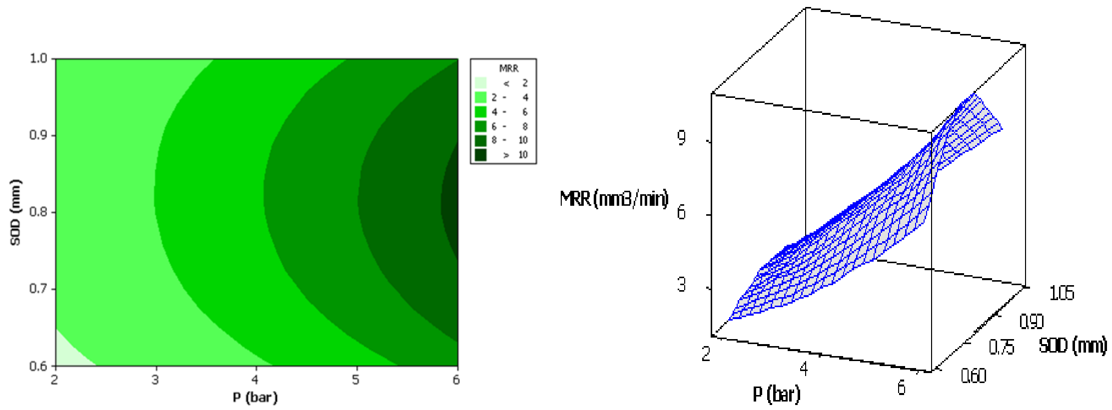
From the estimated model coefficient for means table 6, The R^2 parameter indicates that the amount of variation observed on MRR is explained by the input factors. R^2 = 97.4 % indicate that the model is able to predict the high accuracy response. R^2 Adjusted is also called a R^2 modified that has been adjusted for the number of terms in the model. If unwanted terms are included in the model, R^2 (=97.4 %) can be artificially high, but R^2 adjusted (=94.8 %.) may be smaller. In the modeling, the standard deviation of errors S= 0.6734.

Comparing the p-value with the α-value (= 0.05), it is observed that if the p-value is less than or equal to α, then the effect is significant otherwise it is not significant. From the above figure it is indicates that SOD and P both are significant.

In Fig. 6(a), contour plot of MRR (SOD verses P) shows that the MRR is maximum when pressure is maximum and MRR is maximum when SOD is in the range 0.7 to 0.9mm. From the surface plot of Fig 6(b), shows that MRR is increases rapidly with pressure and MRR are maximum in the region of SOD (0.75-0.9 mm).

3.1.2 OC

The observed values of OC are shown in Table 4. During the process of AJM, the influence of machining parameter like SOD and pressure has significant effect on OC, as shown in main effect plot for OC that is Fig. 7.



(a) (b)

Figure 6 (a) Contour plot and (b) surface plot for MRR

Table 5 Analysis of variance for MRR

Source	DF	Seq SS	Adj MS	F	P	% Contribution
SOD	2	6.752	3.3758	7.44	0.045	9.59
P	2	61.847	30.9234	68.19	0.001	87.84
Residual Error	4	1.814	0.4535			2.57
Total	8	70.413				

Table 6 Estimated Model Coefficients for MRR

Term	Coef	SE Coef	T	P
Constant	5.0926	0.2245	22.686	0.000
SOD 0.6	-0.9259	0.3175	-2.917	0.043
SOD 0.8	1.1574	0.3175	3.646	0.022
P 2	-3.0092	0.3175	-9.479	0.001
P 4	-0.3706	0.3175	-1.167	0.308
S = 0.6734		R-Sq = 97.4%	R-Sq(adj) = 94.8%	

The pressure (p) is directly proportional to OC in the range of 2 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 and also make OC higher. The other factor SOD also influences on the OC. It is clearly indicated from the above figure at SOD 0.8mm the OC was maximum. It decreases with increase in SOD and also decreases with decrease in SOD. To minimize the OC, The optimal settings of parameters are; both SOD and pressure is at level 1.

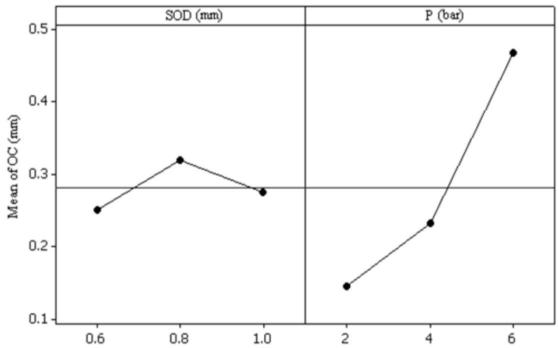
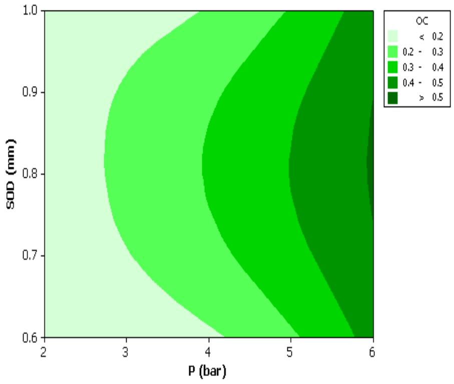
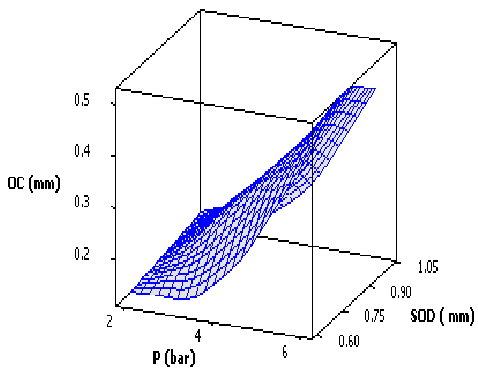


Figure 7 Main effect plot for OC

The analysis of variances for the factors is shown in Table 7 .which is clearly indicates that both SOD of the nozzle and pressure also important for influencing OC. From the % contribution of p has 93.47 %.SOD have 4.12 % contribution and error comes 2.41 % .





(a) (b)

Figure 8(a) Counter and (b) surface plot of OC

From the estimated model coefficient for Table 8. The R^2 parameter indicates that the amount of variation observed on MRR is explained by the input factors. R^2 = 97.6 % indicate that the model is able to predict the high accuracy response. R^2 Adjusted is also known as a R^2 modified that has been adjusted for the number of terms in the model. If unwanted terms are included in the model, R^2 (97.6 %) can be artificially high, but R^2 adjusted (=95.2 %.) may be smaller. In the modeling, the standard deviation of errors S= 0.03278.

Table 7 Analysis of variance for OC

Source	DF	Seq SS	Adj MS	F	P	% Contribution
SOD	2	0.007331	0.003666	3.41	0.137*	4.12%
P	2	0.166404	0.083202	77.42	0.001	93.47 %
Residual Error	4	0.004299	0.001075			2.41 %
Total	8	0.178034				
* Indicates the insignificant factor						

Table 8 Estimated Model Coefficients for OC

Term	Coef	SE Coef	T	P
Constant	0.28172	0.01093	25.781	0.000
SOD 0.6	-0.03089	0.01545	-1.999	0.116
SOD 0.8	0.03794	0.01545	2.455	0.070
P 2	-0.13589	0.01545	-8.793	0.001
P 4	-0.04989	0.01545	-3.228	0.032
S = 0.03278 R-Sq = 97.6% R-Sq(adj) = 95.2%				

Comparing the p-value with the α-value (= 0.05), it is observed that if the p-value is less than or equal to α, then the effect is significant otherwise it is not significant. From the above figure it is indicates that SOD is insignificant and P are significant.
From the above contour plot of OC Fig 8(a), (SOD verses P) shows that the OC is minimum when pressure is in between 2-3 bar and OC is maximum when SOD is in the range 0.7 to 0.9 mm. From the above surface plot Fig 8(b), shows that see that OC is increases rapidly with pressure and OC maximum in the region of SOD (0.75-0.9 mm).

IV. CONCLUSIONS

In this paper, AJM fabrication was done and later drilling experiment was carried on the glass work piece. The AJM is can be used for drilling and milling of glass plates or other brittle materials. Experimental work was done by considering SOD and pressure are machining parameter to study MRR and OC. The effect of observed value of MRR and OC was analyzed by Taguchi design. From analysis it was concluded that the pressure and SOD both are significant for MRR and only pressure is significant for OC. Individual optimal settings of parameters are carried out to minimize the OC and Maximize the MRR. More number of experiment may be done by using different type of ceramic nozzle such as tungsten carbide, boron carbide etc. AJM used for removing of oxide on metal and resistive coating of metal. It is mainly used to machining of brittle, fragile and heat sensitive material such as glass, ceramic, sapphire and quartz. Also used for manufacturing of nylon and Teflon component, making of electronics device

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