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Analysis on Performance of Different Parameters during Abrasive Jet Machining by Taguchi Method

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Abstract-

This paper presents the effects of parameters of micro AJM on material removal rate (MRR, gm/sec) and overcut (mm) during micro machining of Silicon glass. A micro AJM setup has been fabricated for this purpose. A tungsten carbide nozzle having diameter 1.3mm, 1.5mm, 2.3mm is considered. For this experiment SiC abrasive with grit size 70µm is selected. Another parameter ranges are Pressure 50psi, 55psi, 60psi, Nozzle Tip Distance 8mm, 10mm, 12mm is considered. It is observed that MRR of glass, machining by AJM, is increased by increasing Pressure.MRR also increased by decreasing Nozzle Diameter. The optimum value of MRR is obtained at Pressure 60psi, Nozzle Tip Distance 8mm, and Nozzle Diameter 1.5 mm. Further in the Over cut, it is observed that over cut decreased by increasing Pressure. The optimum value is obtained at Pressure 60psi, Nozzle Tip Distance 10mm and Nozzle Diameter 1.5mm.

Keywords: Abrasive jet machining, Nozzle diameter, Nozzle Tip Distance, overcut, material removal rate, Taguchi L9 orthogonal array.

I. INTRODUCTION

In abrasive jet machining, abrasive particles are mixed with compressed air and directed on the target surface through a nozzle. The particle coming out of the nozzle with very high velocities impinges the target surface and removes the material by erosion. A large number of investigations which have been carried out on AJM explaining various erosion mechanism and experiments have been carried out to determine the effect of various input parameters on material removal rate, penetration rate, and on surface finish. Different material removal mechanism has been proposed by various investigators. It has been studied that due to plastic deformation, material removal mechanism causes crack and spalling of ductile material.

Erosion of brittle materials is now an established field, and it is well known that erosive wear results from the propagation and intersection of cracks produced by impacting projectiles. Therefore, the phenomenon carries the risk of cracks remaining in the surface, possibly leading to premature failure of the component, which produces a serious problem when applied to micro-machining of brittle materials. The use of fine abrasives as a projectile is one of the appropriate solutions because smaller particles tend to make the material removal behavior more ductile. Indeed, the size of the particles usually used in the AJM process is much finer than that dealt with in erosion tests. One of the practical applications of the AJM process is decoration or texturing of brittle materials, for instance, window glass and mirrors, where the engraved holes provide an optical effect on the surface. With regard to glass materials, therefore, an attempt to understand the material removal mechanism during AJM has been undertaken.

Silica glass generally has the property of being transparent. Because of this, it has a great many applications. One of its primary uses is as a building material, traditionally as small panes set into window openings in walls. Because glass can be formed or moulded into any shape, and also because it is a sterile product, it has been traditionally used for vessels: bowls, vases, bottles, jars and glasses. In its most solid forms it has also been used for paperweights, marbles, and beads. Glass is both reflective and refractive of light, and these qualities can be enhanced by cutting and polishing to make optical lenses, prisms and fine glassware. Glass can be coloured by adding metallic salts, and can also be painted. These qualities have led to the extensive use of glass in the manufacturing of art objects and in particular, stained glass windows. Although brittle, glass is extremely durable, and many examples of glass fragments exist from early glass-making cultures. Silica (the chemical compound SiO_2) is a common fundamental constituent of glass.

II. EXPERIMENTAL PLANNING

2.1 AJM set up

All the experiments have been conducted using the developed AJM set up. Various parts of AJM are shown in figure 1. AJM set up is fabricated. It is consist of following parts

a. Air compressor: It pressurizes the gas.
b. Air filter: It filters the gas before entering the compressor and mixing chamber.
c. Dehumidifier: It extracts extra moisture from the air coming through compressor.
d. Pressure Gauge: They are used to control the pressure.
e. Pressure regulator: It regulates the flow rate of abrasive jet.
f. Mixing chamber: It is used to mix the gas and abrasive particles
g. Vibrator or Mixer: It is provided below the mixing chamber. It controls the abrasive powder feed rate in the mixing chamber.
h. Nozzle: It forces the abrasive jet over the work piece. Nozzle is made of hard and resistant material like tungsten carbide.
i. Arrangement to hold the work piece, one fixture is fabricated.

Figure 1: Set up of AJM

2.2 Response Variables

In the present work two important response variables viz. material removal rate (MRR) and Over cut was measured and studied. MRR of each sample was calculated from weight difference of work piece before and after the performance trial:

$$MRR = \frac{\text{Difference of weight of work piece before and after machining } (W_1\text{-}W_2)}{\text{Time of machining (T)}}$$

Where: W_1= Initial weight of work piece material (gm), W_2= Final weight of work piece material (gm)
T = Time period of trails in seconds

Over cut = $D_1 - D_2$

Where: D_1 = Min diameter of work piece, D_2 = Nozzle diameter

2.3 Process parameters

Variables like pressure, nozzle tip distance, and nozzle diameter have been selected as parameters. On the basis of literature review and preliminary experiments conducted by using one variable at a time approach, the feasible range for the machining parameters was defined. Table 1 shows set of parameters along with their range which were expected to affect the resultant machining objective functions

Table 1: Parameters Available and Used for Experimentation

S.No	Parameters	Level		
		1	2	3
1	Pressure (Psi)	50	55	60
2	Nozzle Tip Distance (mm)	8	10	12
3	Nozzle Diameter (mm)	1.2	1.5	2.3

Using Taguchi's method the L9 orthogonal array of these parameters was generated. This array consists of three control parameters and three levels. Experiment was performed as per set of parameters in L9 orthogonal array.

2.4 Machining of silica glass work pieces:

For performing the experimental work on silica glass, the work piece were cut in the dimensions of 150mm x150mm and thickness 2.8mm. Black colour Silicon Carbide abrasive having mesh size 150mm and grit size 70µm is used during the experiment. First of all the setting of the glass piece on the fixture and clamped shown in the figure 2, so that there should not be any displacement or error due to the vibration while the AJM is in the working condition. The setting of nozzle was done with the help of wrench. Using the scale, Nozzle Tip Distance is calculated from the top surface of work piece i.e. Glass to the Nozzle Tip by ensuring the Nozzle in the vertically straight position. This setting is maintained for all the three Nozzles. After the setting of the Nozzle to the AJM machine the switch on the compressor for builds up the pressure as required. Then slowly open the valve and checked the gauge pressure. When gauge pressure reached at the set value, and then put the lever ON for mixing the abrasive with the compressed air. There after kept the flow valve ON for impinging the abrasive on the work piece. When the machining finishes then close all the valves one by one and checked the piece and weight taken. 9 readings each by using three different nozzles at different condition have been taken on the work piece for the more accuracy in the experiment.

Figure 2: Setting of the WC Nozzle

Figure 3 shows the machined work piece after 6^{th}, 7th and 8^{th} experiment (from left to right respectively)

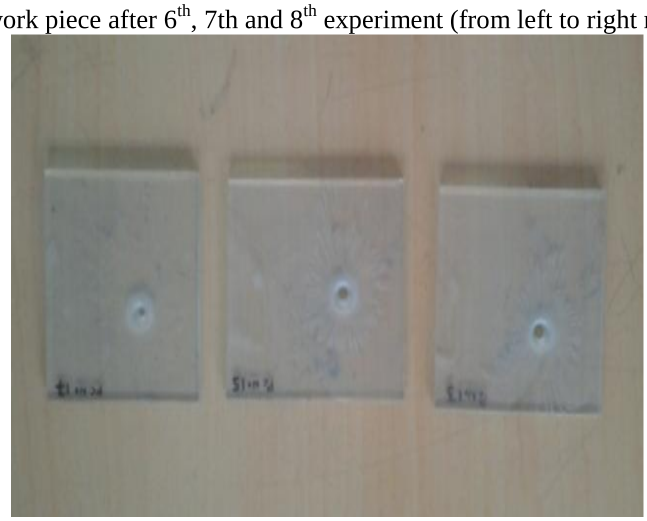


Figure 3: Machined Work Piece with variable Nozzle

III. RESULTS AND DISCUSSIONS

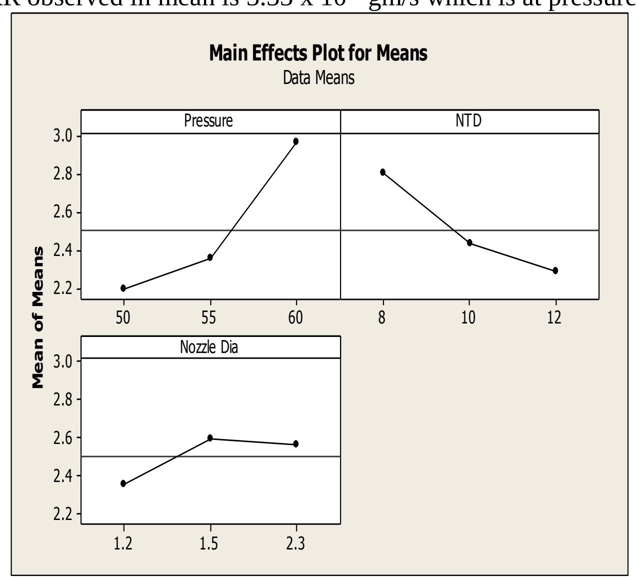
The effect of machining parameters pressure, nozzle tip distance, and nozzle diameter is evaluated using ANOVA. Three repetitions for each of 3 trials were completed in the case of variable nozzle diameter so as to measure MRR and also later Signal to Noise ratio (S/N ratio) is evaluated using the Minitab software. The results of MRR of the 9 experiments with repetition are given in Table 2 below.

Table 2: Results after AJM at various Input Parameters

S. No	Pressure (psi) = C1	NTD (mm) = C2	Nozzle dia (mm) = C3	Weight before machining (gm)	Weight after machining (gm)	Weight loss (gm)	Time (sec)	MRR = C4x10^{-2} (gm/s)	SNRA1 = C5
1	50	8	1.2	25.3	25.1	0.2	9	2.22	6.9271
2	50	10	1.5	25.4	25.2	0.2	9	2.22	6.9271
3	50	12	2.3	25.7	25.4	0.3	14	2.14	6.6083
4	55	8	1.5	29.2	29.0	0.2	7	2.85	9.0969
5	55	10	2.3	25.5	25.3	0.2	9	2.22	6.9271
6	55	12	1.2	25.5	25.3	0.2	10	2.00	6.0206
7	60	8	2.3	25.2	24.9	0.3	9	3.33	10.4489
8	60	10	1.2	25.4	25.2	0.2	7	2.85	9.0969
9	60	12	1.5	26.8	26.5	0.3	11	2.72	8.6914

3.1 Result and analysis of MRR

From the Table 2, it is observed that C1, C2, and C3 are the parameters taken and C4, and C5 are the responses of the data. After compiling, the Signal to Noise ratio is calculated in C5. It is concluded that the maximum material removal rate i.e.; MRR observed in mean is 3.33 x 10^{-2} gm/s which is at pressure 60psi, NTD 8mm and 2.3mm nozzle diameter.



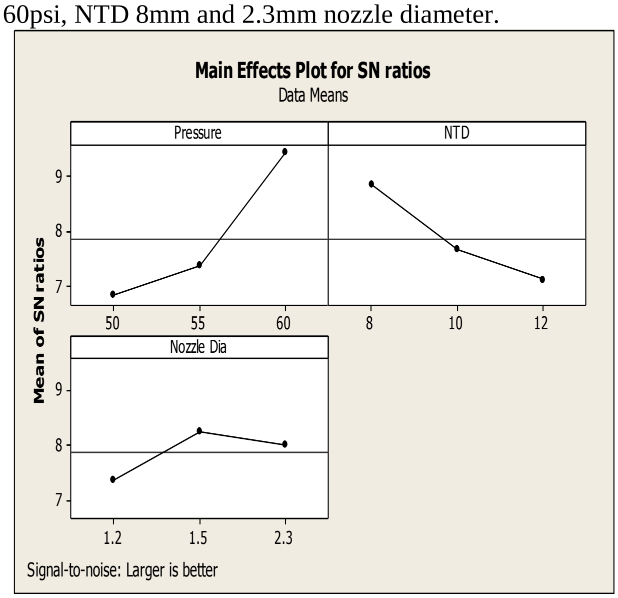


Figure 4: Effect of Parameters on Mean of MRR (left side) & Mean of S/N ratio of MRR (right side)

In Figure 4, the graph is plotted between mean of MRR and various parameters. Here the mean value for pressure is lower which is 2.19 x 10^{-2} gm/s at 50 psi then climbs up to 2.35 to 55psi and after that to 2.96 x 10^{-2} gm/s at 60 psi. The mean value is first rises when NTD kept lower side. It is 2.80 x 10^{-2} gm/s when the NTD is 8mm and it falls to 2.43 x 10^{-2} gm/s at NTD 10mm thereafter again falls down to 2.28 x 10^{-2} gm/s at NTD 12mm. From the graph it is observed that the mean value is lower when nozzle diameter kept lower side. It is 2.35 x 10^{-2} gm/s when nozzle diameter 1.2mm.After that, the value of mean rises rapidly to 2.59 x 10^{-2} gm/s when nozzle diameter kept 1.5mm.Again mean starts falling to 2.56 x 10^{-2} gm/s when nozzle diameter kept 2.3mm.

Figure 4 also shows effect of various parameters on the mean of S/N ratio of material removal rate plotted utilizing the machining results obtained. It is observed from the plot shows same trend as shown by plot of mean of MRR. This further verifies the effects and results of parameters.

Table 3: Ranking of Parameters by Response of S/N ratio of MRR

Response Table for Signal to noise ratio			
Level	Pressure	NTD	Nozzle Dia
1	6.821	8.824	7.348
2	7.348	7.650	8.238
3	9.412	7.107	7.995
Delta	2.592	1.718	0.890
Rank	1	2	3

Table 3 shows the response table for the signal to noise ratio for Nozzle diameter, NTD, and pressure. Here the pressure is most dominating factor i.e. has large effect on MRR. Nozzle diameter has the smallest effect on the material removal rate

3.2 Result and analysis of Over Cut

After the experiment, data of Over cut generated with S/N Ratio and Mean through Taguchi method. Table 4 shows the response table for the signal to noise ratio for Nozzle diameter, NTD, and pressure. Here the pressure is most dominating factor.

Table 4: Observation of Over Cut

Sl no	Pressure (psi)	NTD (mm)	Nozzle dia (mm)	Over cut (mm)	SNRA1
1	50	8	1.2	0.65	3.71473
2	50	10	1.5	0.88	1.11035
3	50	12	2.3	0.60	4.43697
4	55	8	1.5	0.68	3.34982
5	55	10	2.3	1.25	2.00141
6	55	12	1.2	0.45	6.93575
7	60	8	2.3	0.86	1.31003
8	60	10	1.2	0.45	6.93575
9	60	12	1.5	1.60	4.08240

Figure 5 shows the graphical representation of Mean of SN ratio of overcut.

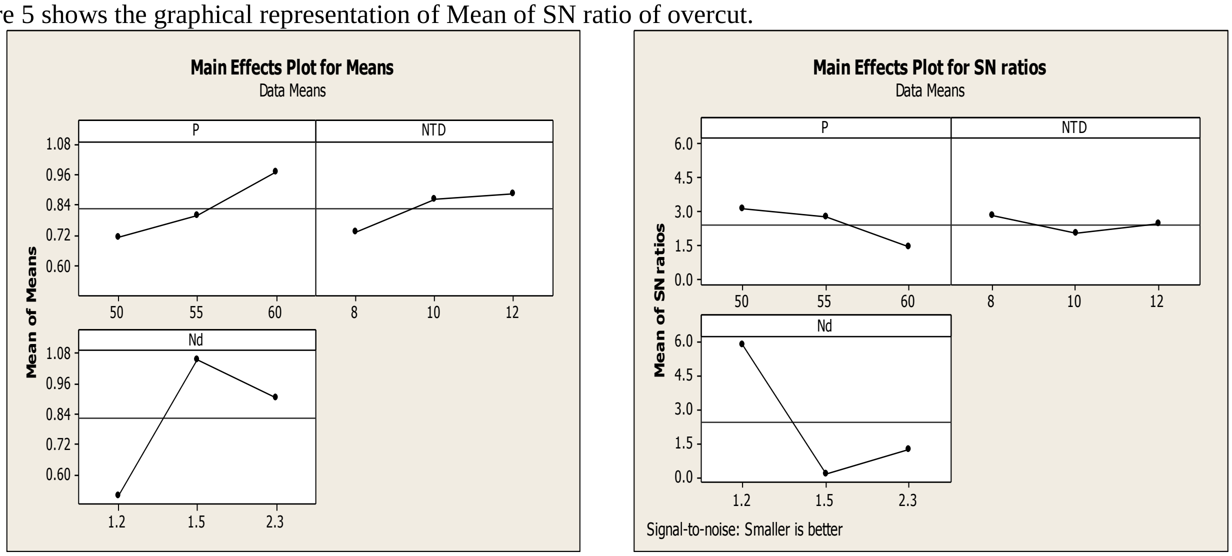


Figure 5: Effect of Parameters on Over Cut (left side) & Mean of S/N ratio of Over Cut (right side)

In Figure 5 the graph is plotted between mean of Over Cut and various parameters. Here the mean value for pressure is lower which is 0.71mm at 50 psi then climbs up to 0.79mm to 55 psi and after that to 0.97mm at 60 psi. The difference between the initial and final mean is 0.26mm. The optimum value is 0.97mm.The mean value is first rises when NTD kept lower side. It is 0.73mm when the NTD is 8mm and after that raise to 0.86mm at NTD 10mm thereafter again raises to 0.88mm at NTD 12mm.The optimum value is 0.88mm. From the graph it is observed that the mean value is lower when nozzle diameter kept lower side. It is 0.51mm when nozzle diameter 1.2mm. After that, the value of mean raises rapidly form 0.51mm to 1.05mm when nozzle diameter kept 1.5mm. Again mean starts falling to 0.90mm when nozzle diameter kept 2.3mm. The optimum value is 1.05mm.
Figure 5 also shows effect of various parameters on the mean of S/N ratio of material removal rate plotted utilizing the machining results obtained. It is observed from the plot shows opposite trend as shown by plot of mean of Over Cut. Opposite trend is due to fact that response for signal to noise ratios is taken as 'Smaller is Better'. This further verifies the effects and results of parameters.

Table 5: Ranking of Parameter based on signal to noise ratio

level	Pressure	NTD	Nozzle Dia
1	3.0964	2.8005	5.8711
2	2.7594	2.0129	0.1259
3	1.3878	2.4301	1.2465
Delta	1.7086	0.7876	5.7452
Rank	2	3	1

Table 5 shows the ranking of AJM process parameter. From this table it is clearly observed that the difference between maximum and minimum S/N ratio of parameter is high in case of Nozzle diameter is 5.74. Since 1st rank goes to Nozzle Diameter and 3rd rank for Nozzle Tip Distance, it means Nozzle Diameter is more effective on performance.

IV. CONCLUSIONS

- Higher MRR is measured 3.33 x 10^{-2} gm/s at 60 psi pressure, 8mm nozzle tip distance and 2.3mm nozzle diameter. It is observed that the optimum parameters for higher MRR are 60 psi pressure, 8mm nozzle tip distance and 1.5mm nozzle diameter.

- Minimum over cut is measured 0.45mm at two different ranks, at 60 psi pressure, 10mm nozzle tip distance and 1.2 mm nozzle diameter and again when 55 psi pressure, 12mm nozzle tip distance, and 1.2 mm nozzle diameter. It is observed that the optimum parameters for lower over cut are 50 psi pressure, 8mm nozzle tip distance and 1.2mm nozzle diameter.

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