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Design, Fabrication and Optimization of Process Parameters of Abrasive Jet Machining

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Abstract

The abrasive jet machining (AJM) is a non-traditional machining process in which abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air. Hard or brittle materials are preferred to be cut by Abrasive jet machine. Finishing operation such as cutting, deburring, etching etc are usually carried out.

In this present investigation Abrasive Jet Machining set up has been successfully fabricated. It focuses on the optimization of the process parameters of Abrasive Jet Machining using the Taguchi method. Pressure, nozzle stand of distance and angle between work piece and nozzle tip have been selected as input parameters and MRR has been chosen as output parameter. Silica sand with grit size 600µm has been chosen as abrasive. Making holes on glass composite have been carried out. Experiments have been done by selecting L9 orthogonal array and results have been optimized with Response Surface Methodology. ANOVA is used to identify the significant process parameters. In the abrasive jet machining of glass composite, statistical results (at a 95% confidence level) states that the pressure, angle between the work piece and nozzle jet, and Stand-off distance affect the metal removal rate by 29.4%, 19.3% and 50.95% respectively. The result shows that the maximum metal removal rate is 0.023 g/sec when stand-off distance is 15 mm by Taguchi's optimization method. The result obtained by ANOVA states that the Stand-off distance is the most Significant process parameter.

Keywords: AJM, Design and Fabrication, Machining of Glass (Drilling), Taguchi Orthogonal Array, MRR, Optimization, ANOVA.

1. INTRODUCTION

In conventional process one of the most important machining operations is to make hole in the work piece for tightening the products or the assembly. But producing hole in brittle material like glass is very difficult in conventional machining process; therefore Abrasive Jet Machining (AJM) has been used to overcome this problem [1]. AJM is also used for etching, deburring and cleaning of very hard and brittle metals, alloys and non-metallic materials (e.g. ceramics, silicon, mica, composite, and germanium). AJM is a non-traditional machining process in which there is no physical contact between the work piece and the tool and material removal takes place by micro-cutting action as well as brittle fracture of the work material and shocks and thermal stresses are not developed. In AJM material removal takes place due to impingement of fine abrasive particles (e.g. Al_2O_3, Sic, glass beeds, dolomite, and sodium bi-carbonate typically of 50 microns) that are mixed in a suitable proportion with high pressure carrier gas or air or N_2, CO_2 on the work piece at high velocity. Pressure energy of carrier gas or air is converted to its kinetic energy to obtain this high velocity steam of abrasives. The abrasive particles with air are directed through a specially designed precision jet nozzle of diameter 0.2 to 1.0 mm on to the work piece to be machined with a stand-off distance of around 2 mm and erosion takes place and both the fractured particles and abrasive particles are carried away by the gas steam. The range of jet velocity is between 150-300 m/s and pressure is from three to ten times atmospheric pressure. Reuse of abrasives is not suitable because of the decrease of cutting ability after the usage. In AJM, finer abrasive grits are used and parameters can be controlled more effectively providing better control over product quality that is different from shot or sand blasting [2, 3, 10].

2. METHODS

2.1. Design of Experiments (DOE): Multi variety data analysis is complemented with the help of experimental design. It basically generates a structured data tables. For modeling purpose the structured variation table has been implemented. The best combined factors for the best output can be determined by studying the various effects of the individual process parameters [8,9,11].

Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality by reducing the variance. In Taguchi method experimental runs are organized as per design of experiments (DOE) based on orthogonal arrays (OA) [4].Orthogonal arrays offer many benefits. First of all, the conclusions achieved from such experiments are valid over the entire experimental region spanned by the control factors and their settings. Secondly, there is a large saving in the experimental effort. Thirdly, the data analysis is very easy. Finally optimization of the parameters has been performed efficiently [4].

2.2. ANOVA: Analysis of variance is a method of portioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. The frequency test (F-Test) is utilized in statistics to analyze the significant effects of the process parameters, which form the quality characteristics [5].

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3. EXPERIMENTAL DETAILS

3.1 List of Components:

3.1 List of Components: The various components that has been used during fabrication of AJM are listed below-

Table 1

List of components with specification

S. No.	Components Name	Specification
1.	Reciprocating Air compressor	2 HP
2.	Sand blasting gun	Stainless steel
3.	Pressure gauge	0-180 psi
4.	Cock valve	Brass material
5.	Hose pipe	-----
6.	Angle rod for table	M.S (25ft)
7.	M.S. Plate	1.5ft/2ft
8.	Base of table	2ft/3ft
9.	Glass (for safety)	18inch/18inch
10.	Aluminum Sheet	18inch/18inch

To carry out the given experiment glass has been selected as work piece material and the silicon oxide (SiO_2) as abrasive.

3.2 Design Calculation of Components

3.2.1 Design of Cylinder (Steel)

Considering it as a closed cylinder of length=22cm
Let P = Intensity of pressure =4kg/cm^2
D = Internal diameter of cylinder =12cm
L = Length of the cylinder =22cm
T = Thickness of the cylinder=0.7cm
F_t= Ultimate hoop stress in the cylinder material =1000kgf/cm^2
Factor of safety =2
Therefore,
Allowable hoop stress =500kg/cm^2
Using the relation,
$T=PD/2F_t$
T = (10*12)/2*500
T =0.12cm=1.2mm
But we have selected a thickness =2.5mm
At 2.5mm thickness the hoop stress developed:
$T=PD/2F_t$
Ft=PD/2T
= (10*12)/2*0.7
=85kg/cm^2
Therefore, actual hoop stress developed= 85kg/cm^2 , the thickness is 0.07cm of where the allowable hoop stress is 500kg/cm^2.Therefore it is on safer side condition.
For assembling, all the parts have been mounted on a stand, made up of angles (frames). The dimensions of the frame are Height=30inch, Length=36inch, and Breadth=24inch.

3.3 Modeling of the components

3.3.1 Modeling of Sand-Blasting Gun Holder

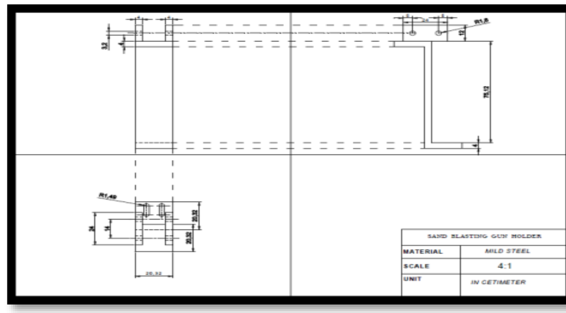

Fig. 1. Modeling of Sand Blasting Gun Holder

3.3.2 Final Assembly: The various parts are assembled together to get the entire setup for performing the experiments.

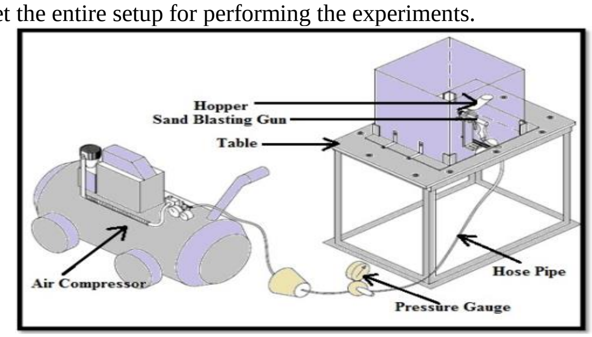

Fig. 2. Experimental Set-up of AJM

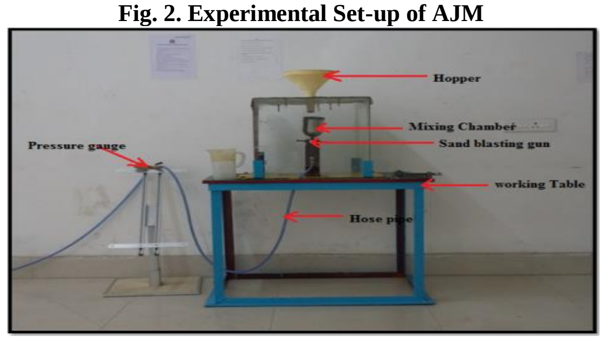

Fig. 3. AJM Set-up

3.3.3 Design of Experiments and Data Analysis

The AJM performances are affected by the process parameters and thus the aim of the experiment is to optimize the process parameters.

- **Process parameters and their levels**

The three parameters in this experiment have been taken at 3 levels as shown in Table No. 2.

Table 2 Input Parameters

S. No	PARAMETERS	LEVEL 1	LEVEL 2	LEVEL 3
01	Pressure (Psi) (A)	50	65	80
02	Angle between the Work piece and Nozzle Jet (Degree) (B)	50	70	90
03	Stand-off distance (mm) (C)	5	10	15

- **DOE and Results**

The feasible combinations of the input parameters along with the output parameters (MRR) have been shown the given Table 3. MRR of each sample was calculated from weight difference of work piece before and after the performance trial:

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

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.

Table 3 DOE and Results

S. No.	Stand-Off Distance (mm)	Angle Between Workpiece And Nozzle Tip (degree)	Pressure (psi)	Time (sec)	Weight Before Machining (gm)	Weight After Machining (gm)	MRR (g/sec)
1	5	50	50	12	118.96	118.76	0.017
2	10	70	50	13	109.31	109.09	0.017
3	15	90	50	17	108.89	108.51	0.022
4	10	50	65	13	119.38	119.11	0.021
5	15	70	65	10	109.09	108.87	0.023
6	5	90	65	13	104.33	104.05	0.021
7	15	50	80	7	119.11	118.96	0.022
8	5	70	80	10	108.87	108.70	0.017
9	10	90	80	14	104.05	103.75	0.021

All the observed values are calculated based on "Higher is better".

4. RESULTS AND DISCUSSION

5.

4.1 Optimization of Process Parameters

The experimental results have been transformed into means and signal-to-noise (S/N) ratio and it is shown in Table 4. Higher value of S/N ratio is calculated for optimized combination of parameters as maximum MRR. The mean and S/N ratios for MRR have been calculated by statistical software **"MINITAB 16"** [8,9,11]**.**

Table 4 Mean value and S/N Ratio

Pressure (Psi)	Angle between the Work piece and Nozzle Jet (Degree)	Stand-off distance (mm)	MRR (gm/sec)	S/N Ratio	MEANS
50	50	5	0.017	-35.3910	0.017
50	70	10	0.017	-35.3910	0.017
50	90	15	0.022	-33.1515	0.022
65	50	10	0.021	-33.5556	0.021
65	70	15	0.023	-32.7654	0.023
65	90	5	0.021	-33.5556	0.021
80	50	15	0.022	-33.1515	0.022
80	70	5	0.017	-35.3910	0.017
80	90	10	0.021	-33.5556	0.021

Table 5 Response Table for Signal to Noise Ratios- Larger is Better

Level	Pressure (Psi)	Angle between the Work piece and Nozzle Jet (Degree)	Stand-off distance (mm)
1	-34.64	-34.03	-34.78
2	-33.29	-34.52	-34.17
3	-34.03	-33.42	-33.02
Delta	1.35	1.09	1.76
Rank	2	3	1

Table 6 Response Table for Means

Level	Pressure (Psi)	Angle between the Work piece and Nozzle Jet (Degree)	Stand-off distance (mm)
1	0.01867	0.02000	0.01833
2	0.02167	0.01900	0.01967
3	0.02000	0.02133	0.02233
Delta	0.00300	0.00233	0.00400
Rank	2	3	1

From the response tables of means and S/N ratio (Table 5 and Table 6), the rank of process parameters has been achieved as Stand-off distance 1, pressure 2 and angle between the Work piece and Nozzle Jet 3.

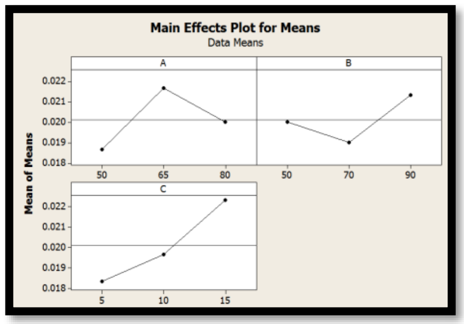

Fig.4 Main effects plot for Means

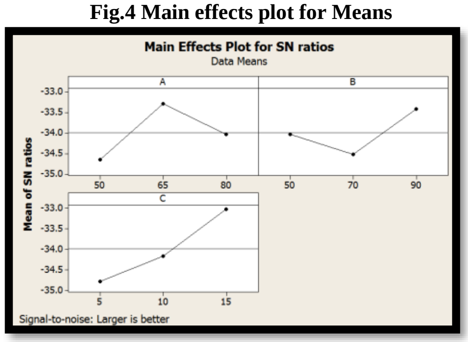

Fig.5 Main effects plot for S/N ratio

Fig.4 and Fig.5 have depicted the variation of means and S/N ratios of MRR with respect to input process parameters. From the plot it has been observed that MRR is increasing as the stand-off distance increases whereas MRR is increasing and after reaching at air pressure 65Psi its starts decreasing. Maximum MRR is obtained at the angle of 70º angle made between work piece and nozzle jet.

4.2 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) test has been performed to identify the process parameters that are statistically significant.

The purpose of the ANOVA test is to investigate the significance of the process parameters which affect the MRR in AJM. The results of ANOVA has indicated that the considered process parameters are highly significant factors affecting the MRR in AJM in the order of Stand-off distance, pressure and angle between the Work piece and Nozzle Jet. The ANOVA test has been performed at a significance level of **5% i.e. 95% confidence level [**6-7].

Table 7 Analysis of Variance for MRR (Means) (*Significant Factor)

Factors	DOF	SS^2	MS	F	P
Pressure	2	0.000014	0.000007	61.00	0.016*
Angle between W/p & nozzle	2	0.000008	0.000004	37.00	0.026*
SOD(mm)	2	0.000025	0.000012	112.0	0.009*
Error	2	0.000000	0.000000		
Total	8	0.000047			

Table 8 Analysis of Variance for MRR (S/N ratios)

(*Significant Factor)

Factors	DOF	SS^2	MS	F	P
Pressure	2	2.75138	1.37569	83.05	0.012*
Angle between W/p & nozzle	2	1.80650	0.90325	54.53	0.018*
SOD(mm)	2	4.76919	2.38460	143.96	0.007*
Error	2	0.03313	0.01656		
Total	8	9.36021			

Where, DF=Degrees of freedom, Seq SS=Sequential sum of squares, Adj SS=Adjusted sum of square, Adj MS=Adjusted mean square and F=Fisher ratio.
The conclusion made from above Table 7 and Table 8 is that, Stand-off distance, pressure and angle between the Work piece and Nozzle Jet are significant factors as corresponding P values are less than 0.05 and the developed model is significant .From the results obtained by ANOVA it has been found that the Stand-off distance is the most Significant parameter having an F value of 143.96 (Table 8).

6. CONCLUSION

AJM set up has been properly designed and fabricated. This study has discussed an application of the Taguchi method for investigating the effect of input process parameters i.e. pressure, Angle between work piece and nozzle jet and stand-off distance on response MRR. Following can be concluded from the present study:

- The maximum metal removal rate 0.023 g/sec and it is obtained at 65 psi pressure, 70°angle between work piece and nozzle jet and 15 mm stand-off distance. 600 microns size of SiO_2 abrasive and nozzle diameter of 2 mm has been used.
- Statistically designed experiments based on Taguchi methods have been performed by using L9 orthogonal array to analyze the metal removal rate as response variable. Conceptual S/N ratio and ANOVA approaches for data analysis drew similar conclusions.
- Statistical results (at a 95% confidence level) show that the pressure(A), angle between the work piece and nozzle jet (B), and Stand-off distance (C) affect the metal removal rate by 29.4%, 19.3% and 50.95% in the abrasive jet machining of glass , respectively.

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