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ANALYSIS OF ABRASIVE JET MACHINING PARAMETERS ON MRR AND KERF WIDTH OF HARD AND BRITTLE MATERIALS LIKE CERAMIC

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ABSTRACT

Design of experiments is performed to analyse the effect of air pressure, nozzle diameter and Stand off distance on the Material Removal Rate (MRR) and Kerf width of hard and brittle materials like Ceramics. The results of the machining experiments were used to characterise the main factors affecting MRR and Kerf width by the Analysis of Variance (ANOVA) method. The maximum MRR obtained during experimentation is 0.09476 gm/sec & minimum Kerf width is 5.7325 mm. The nozzle diameter was found to be the most significant parameter influencing the MRR in cutting process.

Keywords: AJM, MRR, Kerf width, DOE, ANOVA, Ceramic

INTRODUCTION

Abrasive jet machining is a machining process used for cutting parts in manufacturing industries. In this process material is removed from a work piece by bombarding small abrasive particles along with pressurised air with high velocity to erode material from work piece. The traditional methods used for machining processes like cutting and deburring can be efficiently replaced by Abrasive Jet Machine. Hard and Brittle materials can be efficiently cut by using

this technique. In the present work an experimental investigation of cutting the ceramic tiles with abrasive jet machining is carried out and the effect of different cutting parameters on the Material Removal rate is studied.

The material used for cutting in the analysis is ceramic tiles. The abrasive material used for cutting is emery particles which promote the cutting.

DOE techniques enable designers to determine simultaneously the individuals and interactive effects of many factors that could affect the output results in any design. There are three input parameters and three levels. Full factorial experimental design will give rise to total $3^3=27$ experiments which is time consuming and lengthy procedure.

Taguchi found out new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal array. This standard array gives a way of conducting the minimum number of experiments which could give the full information of all the factors that affect the response parameter instead of doing all experiments.

ANOVA was developed by Sir Ronald Fisher in 1930 and can be useful for determining influence of any given input parameter for a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. ANOVA is statistical based objective decision making tool for detecting any differences in average performance of groups of items tested. While performing ANOVA degrees of freedom should also be considered together with each sum of squares. In ANOVA studies a certain test error, error variance determination is very important. Obtained data are used to estimate F value of Fisher Test (F-test). Variation observed (total) in an experimental attributed to each significant factor or interaction is reflected in percent contribution (P), which shows relative power of factor or interaction to reduce variation.

In this paper, L_9 orthogonal array is employed to analyze experimental results of machining obtained from 9 experiments by varying three process parameters viz. Nozzle Diameter (A), Pressure of air (B) and Stand Off Distance (C). ANOVA has been employed and compared with Taguchi method.

MATERIALS AND METHOD

The Rectangular hard and brittle materials (Ceramics) specimens were used for experimentation. These tiles possess good abrasion resistance, a decent water absorption capacity, good frost resistance, fire resistance. It has great flexural strength. The abrasive material used was the black emery particles. Emery particles are powdered from Emery rock which is very hard rock. It largely contains aluminium oxide mixed with other species as the iron-bearing spinel hercynite and magnetite and also rutile (titania).

Chemical Formula: Al_2O_3 +an iron bearing mineral+ trace impurities such as Mullite, Titania, Silica and Magnesia

These emery particles along with the pressurised air were bombarded on the ceramic tiles to obtain the cutting procedure.

Abrasive Jet Machining was done on the ceramic tiles with the use of abrasive particles (emery particles) which were imparted with air pressure from a compressor. Following the Taguchi analysis nine set of experiments were performed in nine different pieces of ceramics. A new apparatus was developed by inserting a PVC pipe with holes drilled at the bottom into the cylinder consisting emery (abrasive) particles. Because of the insertion an optimized quantity of air and particle mixture was obtained. Optimized mixture refers to more amount of

air and less amount of the abrasive particles. The upper kerf and lower kerf width to be obtained ideally should be equal but practically both the widths differed. Thus the average of both the widths was taken for the calculation purpose. The compressor pressure was controlled as per the requirements of the reading to be taken. For calculating MRR, the time required for obtaining an almost throughout hole was measured.

Table 1: Machining parameters and levels:

Machining Parameters	Level 1	Level 2	Level 3
Nozzle Diameter (mm)	3	4	5
Pressure (kgf/cm ²)	4	5	6
Stand of Distance(mm)	20	30	40

The material removal rate was calculated by weighing the ceramic specimen prior to performing the cutting operations and after performing the operations. Thus difference in the weight was calculated. Consequently the time required for the hole to be drilled was measured.

RESULTS AND DISCUSSION

Table 2 shows experimental design matrix and material removal rate and hole diameter value for ceramic tiles, S/N ratio is calculated using Higher the better characteristics for Material Removal Rate.

$$S/N = -10 \log \left(\frac{1}{n} \sum_{i=1}^n 1/Y_i^2 \right) \quad \text{..... (Eq.1)}$$

S/N ratio is calculated using Lower the better characteristics for Average kerf Width.

$$S/N = -10 \log \left(\frac{1}{n} \sum_{i=1}^n Y_i^2 \right) \quad \text{..... (Eq. 2)}$$

Where , n = No of measurements in a trial/row

Y_i = i^{th} measured value in a run/row

Table 2 Experimental Design Matrix and Results

Exp t. No.	Abrasive Jet Machining Parameter			Wt differenc e (gm)	MRR (gm/sec)	S/N ratio for MRR	Avg Kerf width (mm)	S/N ratio for avg. kerf
	Nozzle Diamete r (mm)	Pressure (kgf/cm^2)	Stand Of Distan ce (mm)					
1	3	4	20	0.53	0.05461 9	-25.2531	5.732 5	-15.1669
2	3	5	30	0.65	0.04850 7	-26.2838	8.58	-18.6697
3	3	6	40	1.085	0.09476	-20.4675	10.45	-20.3823
4	4	4	30	0.752	0.06064 5	-24.3441	8.82	-18.9094
5	4	5	40	0.754	0.04597 6	-26.7495	7.98	-18.0401
6	4	6	20	0.5	0.04646 8	-26.6568	7.13	-17.0618
7	5	4	40	1.863	0.08965 4	-20.9487	13.15 5	-22.3818
8	5	5	20	0.807	0.06555 6	-23.6677	8.395	-18.4804
9	5	6	30	1.163	0.08248 2	-21.6728	10.25	-20.2145

Responses for Signal to Noise Ratios of Larger is better characteristics is shown in Table 3(a). Significance of machining parameters (difference between max. and min. values) indicates that nozzle diameter is significantly contributing towards the machining performance as difference gives higher values for MRR.

Similarly, responses for Signal to Noise Ratios of Smaller is better characteristics is shown in Table 3(b). Significance of machining parameters (difference between max. and min. values) indicates that SOD is significantly contributing towards the machining performance as difference gives higher values for average Kerf width.

Table 3-Response Table for Signal to Noise Ratio for
(a) MRR and (b) Avg. Kerf width

(a)				(b)			
Level	A	B	C	Level	A	B	C
1	-24.00	-23.52	-25.19	1	-18.07	-18.82	-16.90
2	-25.92	-25.57	-24.10	2	-18.00	-18.40	-19.26
3	-22.10	-22.93	-22.72	3	-20.36	-19.22	-20.27
Delta	3.82	2.63	2.47	Delta	2.36	0.82	3.37
Rank	1	2	3	Rank	2	3	1

Fig.3 Effect of nozzle dia., Pressure, SOD on MRR

Fig.4 Effect of nozzle dia., Pressure, SOD on Avg. Kerf width

Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. MINITAB software of ANOVA module was employed to investigate effect of process parameters nozzle diameter, pressure, SOD.

Table 4-Analysis of Variance for S/N ratios for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	21.893	21.893	10.947	3.50	0.222
B	2	11.490	11.490	5.745	1.84	0.353
C	2	9.197	9.197	4.599	1.47	0.405
Residual error	2	6.257	6.257	3.129		
Total	8	48.838				

Table 5-Analysis of Variance for S/N ratios for avg. Kerf Width

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Nozzle dia.	2	10.777	10.777	5.3885	2.36	0.297
Pressure	2	1.016	1.016	0.5079	0.22	0.818
SOD	2	17.907	17.907	8.9536	3.93	0.203
Residual Error	2	4.562	4.562	2.2811		
Total	8	34.262				

Table 4 and 5 shows Analysis of variance for S/N ratio. F value (3.50) of parameter indicates that Nozzle diameter is significantly contributing towards cutting performance. F value (1.47) of parameter indicates that Stand off Distance is contributing less towards cutting operation for MRR. F value (3.93) of parameter indicates that Stand of distance is significantly contributing towards cutting performance. F value (0.22) of parameter indicates that Air Pressure is contributing less towards cutting operation for Kerf width.

Literature review shows that the effect of nozzle diameter (D) on the material removal rate (MRR), when different sizes of abrasive particles are used. It shows that the nozzle diameter is an important factor affecting the MRR due to the resulted speed and flow rate of the abrasives (Ref. 3). As the distance between the face of the nozzle and the working surface of the work increases, the diameter of hole also increases because higher the Stand Off Distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment. It is desirable to have a lower Stand Off Distance which may produces smoother surface due to increased kinetic energy (Ref. 5).

The results obtained from the experimental work closely matches with the literature review. Nozzle diameter is the most influential factor when it comes to the MRR and Stand Off distance is the most influential factor when it comes to the average kerf width.

The holes obtained by using the abrasive jet machine are as depicted in the following photographs. The upper kerf width and the bottom kerf width varies according to the input parameters. The photographs of some combinations are

Fig 5. Results obtained with nozzle diameter 3mm, Air pressure 4 kgf/cm² and distance 20mm.

Fig 6. Results obtained with diameter 5mm, Air pressure 4 kgf/cm² and distance 40 mm.

CONCLUSION

Taguchi method of experimental design has been applied for investigating the effect of machining parameters on upper and bottom kerf width and the material removal rate in gram per seconds. Results obtained from Taguchi method closely matches with ANOVA. Best parameters found for *Larger MRR* are: Nozzle Dia.3 mm, Air Pressure 6 kgf/cm², SOD 40 mm. Best parameters found for *Smaller Kerf width* are: Nozzle Dia.3 mm, Air Pressure kgf/cm², SOD 20 mm. Nozzle diameter is the most influential factor when it comes to the MRR and Stand Off distance is the most influential factor when it comes to the average kerf width.

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