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Research Article

Optimization of Multi-Objective Optimization of Machining Parameters of AJM using Quality Loss Function

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Abstract

Abrasive Jet Machining (AJM) is a non-conventional machining process that carried a high-pressure air stream with small abrasive particles to impinge the work surface through a nozzle. In this paper drilling experiment was done on glass as the work piece and aluminum oxide (Al2O3) as abrasive powder on AJM. 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. The multi-objective optimization of AJM process using the Taguchi's quality loss function has been carried out for responses of AJM. The air pressure and stand-off-distance are considering control parameter.

Keywords: *Abrasive jet machining; Abrasive powder; Glass material; Loss function; Taguchi method.*

1. Introduction

The material removal occurs by the erosive action of the abrasive particles striking the work piece surface. The material removal capability of AJM is very low so it is used in a finishing process. It is as an effective machining method for hard and brittle materials . and it's similar to sand blasting process but difference is finer abrasive powders and smaller nozzles are used in AJM.

The AJM process was started a few decades ago, till today experimental and theoretical study on the Abrasive Jet Machining process occurs. Ke et. al 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. The theoretical analysis and associated with mathematical models for the velocity of abrasive particles in an abrasive air jet machining by using the Bernoulli's equation of compressible of flow jet air velocity was calculated. Considering particle mean diameter, nozzle length, air density and air flow velocity particle velocity at the nozzle exit is determined. Gradeena et. al used a cryogenic abrasive jet machining apparatus for solid particle erosion of poly-dimethylsiloxane (PDMS) using aluminum oxide as an abrasive at a temperature range between -1780C to 170C. He observed that optimum machining of PDMS occurred at temperature approximately at -1780C and the attacking angle in between 300 to 600. The optimum erosion rate occurred at impact angles between of 200–300 when machining the aluminum 6061-T6, 316L stainless steel and Ti–6Al–4V alloy and taking the 50 µm Al2O3 abrasive powder. Routara et.al described the multi response optimization of AJM process using grey relation analysis. The Pressure, nozzle-tip-distance, abrasive grain size are select as a control parameter whereas the response of MRR and SR. The multiple quality characteristics of grade and recovery using the Taguchi quality loss function has been applied for chromite concentration with MGS [6]. The selected control parameters are drum speed, tilt angle, wash water flow rate, and shake amplitude. They proved that the multi quality characteristic such as grade and recovery has greatly improvement through this study.

In this experiment using Taguchi quality loss function to optimize the AJM process with multiple performance characteristics i.e. MRR and OC.

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2. Experimentation

In this experiment the whole work can be done by Abrasive Jet Machine and experimental set up is shown in the Fig. 1. Atmospheric air used as a medium of carrier gas, aluminum oxide was used as an abrasive powder the properties of abrasive powder as shown in the Table 1. In this experiment nozzle (Stainless steel alloy) with 2 mm diameter are used for machining. Glass was taken as a work piece.

Table 1 Properties of abrasive power

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

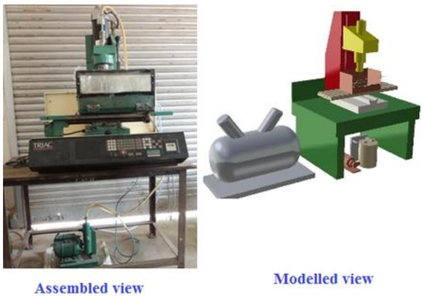

Fig. 1. Abrasive jet machining

2.1 Design of experiment

In this experiment two machining parameters such as Stand of Distance (SOD) and Pressure (P) each are three variables total nine experiments are conducted using L9 OA based on Taguchi design. The machining parameter and their levels are shown in Table 2. MRR is calculated by electronic balance weight machine and Overcut of glass piece was measurement by tool maker microscope.

Table 2 Machining parameters and their levels

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

2. Results and discussion

2.1. Influence of MRR

The experimental observed value of MRR and OC are tabulated in Table 3. During the process of AJM, the influence of machining parameter like SOD and pressure has significant effect on MRR. The main effect plot for MRR is shown in Fig. 2. According to the plot 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 figure 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.

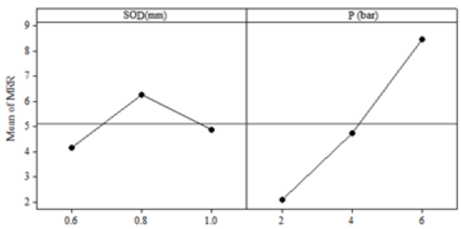

Fig. 2 Main effect plots for MRR

2.2. Influence of OC

In the machining 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. 3. The pressure (p) is directly proportional to OC. 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.

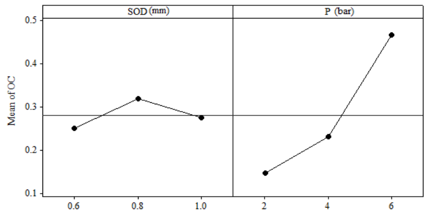

Fig. 3 Main effect plots for OC

3.3. *Multi-objective optimization using Taguchi quality loss function*

The Taguchi quality loss function is to calculate the deviance between the experimental value and desired value. The calculation of Taguchi quality loss function is following steps,

1. All experimental value converted to loss function (L_{ij}).
2. Normalized loss function (N_{ij}).
3. Calculated the total loss function (TL_{ij}).
4. Finally calculated the Taguchi quality loss function (ηj).

In the first steps for all experimental observed value of MRR and OC are converted into loss function (L_{ij}) that is shown in Table 3. MRR is Higher-The-Better (HTB) quality characteristics and OC is the Lower-The-Better (LTB) quality characteristics. The loss function of HTB and LTB quality characteristics are show in equation 1 and 2 respectively.

LTB response variable $L_{ij} = y_{ij}^2$ (1)

HTB response variable $L_{ij} = \frac{1}{y_{ij}^2}$ (2)

Where, L_{ij} and y_{ij} is the loss function and experimental value, respectively, for i^{th} experiment using j^{th} response.

The second step for normalized the loss function of MRR and OC, with the help of equation 3.

$$N_{ij} = \frac{L_{ij}}{\bar{L}_i} \quad (3)$$

Where, $\bar{L}_i = \frac{1}{n}\sum_{j=1}^{n} L_{ij}$ is the average loss function of i^{th} experimental value and n is the trial number. Then calculate the total loss function by using equation 4.

$$TL_j = \sum_{i=1}^{p} W_i N_{ij} \quad (4)$$

Where, the W_i is the weighted function and the $\sum W_i = 1$.

Table 3 Analysis of Variance for Taguchi loss function

Source	DF	Seq SS	Adj MS	F	P
D	2	0.6799	0.3399	0.23	0.805
P	2	27.3438	13.6719	9.19	0.032
Residual Error	4	5.9476	1.4869		
Total	8	33.9712			

Table 4 Observation table

S.N.	MRR	OC	L_{ij}		N_{ij}		TLj	η_j
	(mm^3/min)	(mm)	MRR	OC	MRR	OC		
1	1.667	0.133	0.3599	0.0176	0.3814	0.0197	0.2005	6.9782
2	3.750	0.183	0.0711	0.0333	0.0754	0.0373	0.0563	12.4914
3	7.083	0.438	0.0199	0.1914	0.0211	0.2145	0.1178	9.2881
4	2.500	0.145	0.1600	0.0210	0.1696	0.0236	0.0966	10.1517
5	5.833	0.307	0.0294	0.0939	0.0311	0.1053	0.0682	11.6613
6	10.417	0.508	0.0092	0.2576	0.0098	0.2886	0.1492	8.2624
7	2.083	0.160	0.2305	0.0256	0.2443	0.0287	0.1365	8.6494
8	4.583	0.207	0.0476	0.0426	0.0505	0.0478	0.0491	13.0872
9	7.917	0.458	0.0160	0.2093	0.0169	0.2346	0.1257	9.0055

p is the performance characteristics. Then the final steps to calculate the Taguchi loss function with the help of Equation 5.

$$\eta_j = -10\log(TL_j) \quad (5)$$

Where, the η_j is the Taguchi loss function and the Taguchi loss function is shown in Table 3.

The Fig. 4 shown the main effect plot for Taguchi loss function, according to this graph the SOD = 1mm, P = 4bar for optimal setting of maximum MRR and minimum OC. The analysis of variances for Taguchi loss function are shown in Table 4, in this table indicate the SOD is not significantly effect, but P is effected significantly of multi-performance characteristics index.

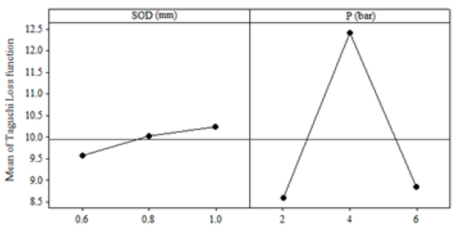

Fig. 3 Main effect plot of Taguchi loss function

Conclusions

The current study aimed at optimization of machining parameters in AJM on glass workpiece by using Taguchi based quality loss function. The following conclusions may be drawn from the present work.

1. L_9 OA based Taguchi design was used to study MRR and OC of AJM on glass material as workpiece. MRR and OC are mostly affected by pressure.
2. MRR is increases with the increasing of SOD up to optimum level then they are decreasing it.
3. Taguchi quality loss function was adopted to optimize the AJM process with multiple performance characteristics *i.e.* MRR and OC. The optimal AJM parameter setting were found to be SOD = 1mm, P = 4bar for maximum MRR and minimum OC.

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