

Effect of Abrasive Particle Size and Air Pressure on Machining Performance of Multi-Criteria of AJM on Natural fiber reinforced Composites

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Abstract

In the recent year, many multi-criteria decision-making methods have been proposed to evaluate and examine the effectiveness of different machining processes. The aim of this study is to propose a multi-criteria decision making (MCDM) approach to optimize the machining parameters of Abrasive jet machining (AJM) in the fiber reinforced polymer (CFRP) materials. In AJM, drilling experiment was done on CFRP composite material as the work piece and aluminum oxide (Al_2O_3) as abrasive powder. The effect of Overcut (OC) and Material removal rate (MRR) of this material was found by using L_9 orthogonal array based on Taguchi design. Selected control parameters are pressure of air and stand-off distance, and output responses such as MRR and OC were calculated. These responses are contradicting in nature, for eliminating this modification has been converted into single response optimization techniques known as PCA based grey relation analysis. In this result PCA based GRA means principal component analysis combined with grey relation analysis and simultaneously optimized single quality characteristics known as overall quality performance index (OQPI).

Keywords: -Abrasive Jet Machining, Multi-Criteria Decision Making, Fiber Reinforced Polymer, Principal component analysis, Grey Relation Analysis.

1. Introduction

AJM is also named as abrasive micro blasting, is a nonconventional machining process that carries a high-pressure air stream with small abrasive particles to impinge the work surface through a nozzle for material removal of the work piece [1].

Carbon fiber reinforced polymer (CFRP) composites are used for light-weighting of structural components of an aircraft which in turn leads to an improved fuel economy; reduced emissions and increased payload of aircrafts. Material behavior under conventional machining is different to homogeneous metals and alloys. The non-homogeneity, anisotropy, and high abrasiveness and hardness of the reinforcement fibers make the machining of CFRP a difficult task [2]. Carbon fibers are used in composites with a lightweight matrix. Carbon fiber composites are ideally suited to applications where strength, stiffness, lower weight, and outstanding fatigue characteristics are critical requirements [3]. According to Mutavdjich higher the tensile strength of the organic compound the higher is the tenacity of the carbon fiber [4].

Lin and Chen presents Drilling of carbon fiber-reinforced composite. And to describe effects of cutting speed as well as other cutting parameters on drilling characteristics, including cutting forces and tool wear when drilling carbon fiber-reinforced composite materials at high speed [5]. Yan et al. [6] investigated the effects of catalyst content, polymerization temperature and time on the viscosity average molar mass and degree of crystallinity.

The mechanical properties of the composites with different post-heat treatments were further investigated. Mahabalesh Palleda [7] investigated the influence of the different chemical such as acetone, phosphoric acid and polymer (polyacrylamide) in the ratio of 30% chemicals with 70% of water. Abrasive assisted electrochemical jet machining is a hybrid manufacturing technology coupling erosion and corrosion concurrently to remove metals [8].

This work presents various issues observed in AJM on CFRP composite materials, and the effects of AJM are analyzed in processing these composite materials. Drilling experiment was done on CFRP composite material as the work piece and aluminum oxide (Al_2O_3) as abrasive powder. The two output responses are finding MRR and SR and this response contradicting in nature, for eliminating this variation has been converted into single response optimization techniques is known as PCA based grey relation analysis have been applied.

2. Conduct of Experiment

Experimental set up is shown in the Fig.1. In this experiment nozzle diameter (2mm), abrasive particle size (50 μm) is kept constant. The machining parameter Stand of Distance (SOD) and Pressure (P) are varying. For calculating initial and final weight electronic balance weight machine (SHINKO DENSHI Co. LTD, JAPAN, Model: DJ 300S.), was used. it has 300 gm. weight capacity and 0.001gm accuracy. The diameter of hole and nozzle diameter before experiment and nozzle dia. after experiment was measurement by tool maker microscope and optical microscope. In this experiment diameter of drilled hole was calculated by taking of the mean diameters of both the data two microscope. CFRP sample piece is obtained according to the standard dimensions i.e. the sample pieces have square section of 50 mm and thickness of the sample piece is 2mm.

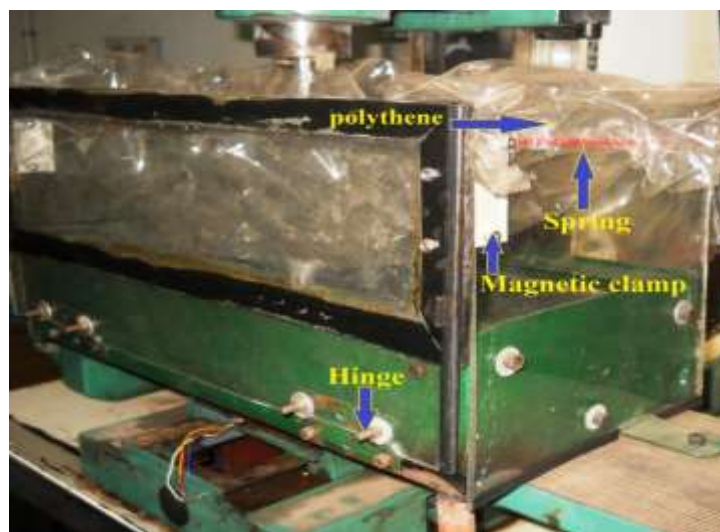


Fig 1 Tool and work-piece of abrasive jet machining

3. Machining parameters and their selection

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 L₉ Orthogonal Array (OA) was chosen. Machining parameters and their level are presented below, and other parameters are kept constant during this experiment. The observed value of MRR and Overcut are presented in Table 2.

Table 1 Control Parameters and their levels

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

Table 2 Experimental observed value

Run no	SOD (mm)	P (bar)	Weight of Composite material (gm)		Over Cut (mm)	MRR (mm ³ /min)
			Initial weight	Final weight		
1	0.6	2	65.679	65.675	0.1325	1.667
2	0.6	4	65.674	65.665	0.1825	3.750
3	0.6	6	65.665	65.648	0.4375	7.083
4	0.8	2	65.729	65.723	0.1450	2.500
5	0.8	4	65.723	65.709	0.3065	5.833
6	0.8	6	65.709	65.684	0.5075	10.417
7	1.0	2	65.764	65.759	0.1600	2.083
8	1.0	4	65.759	65.748	0.2065	4.583
9	1.0	6	65.748	65.729	0.4575	7.917

4. Influence of machining parameters on MRR and OC

During the process of AJM, the influence of machining parameter like SOD and pressure has significant effect on MRR on composite material as shown in main effect plot for MRR in Fig.2. 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[9]. The other factor SOD does not influence much as compared to pressure. It is clearly indicated from the above figure 2 at SOD 0.8mm the MRR was maximum. It decreases with increase in SOD and decreases with decrease in SOD. It suggests that the effect of one factor is dependent upon another factor.

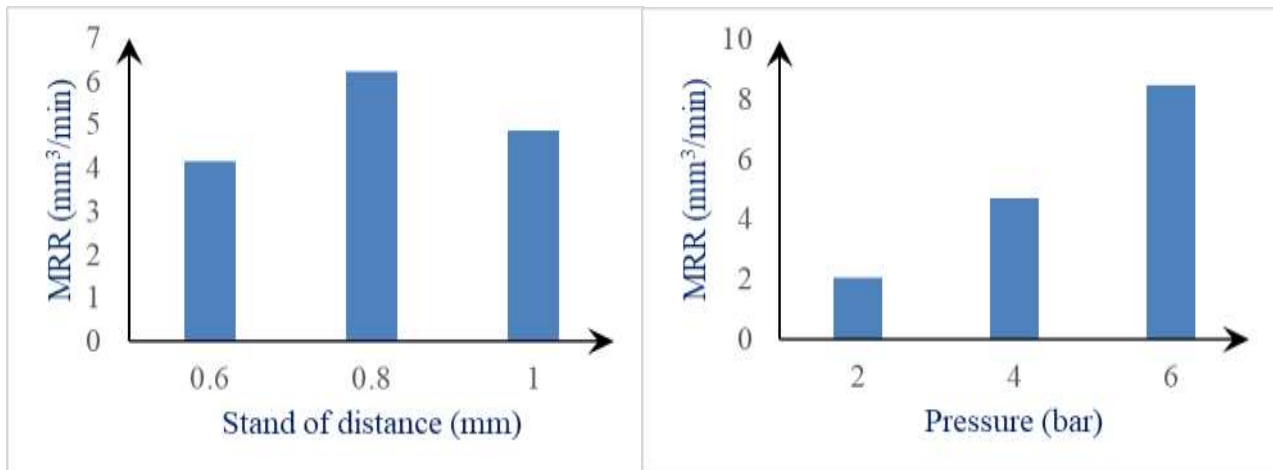


Fig 2 Main effect plot for mean of MRR

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. 3. The pressure (p) is directly proportional to OC in the range of 2 to 6 bar.

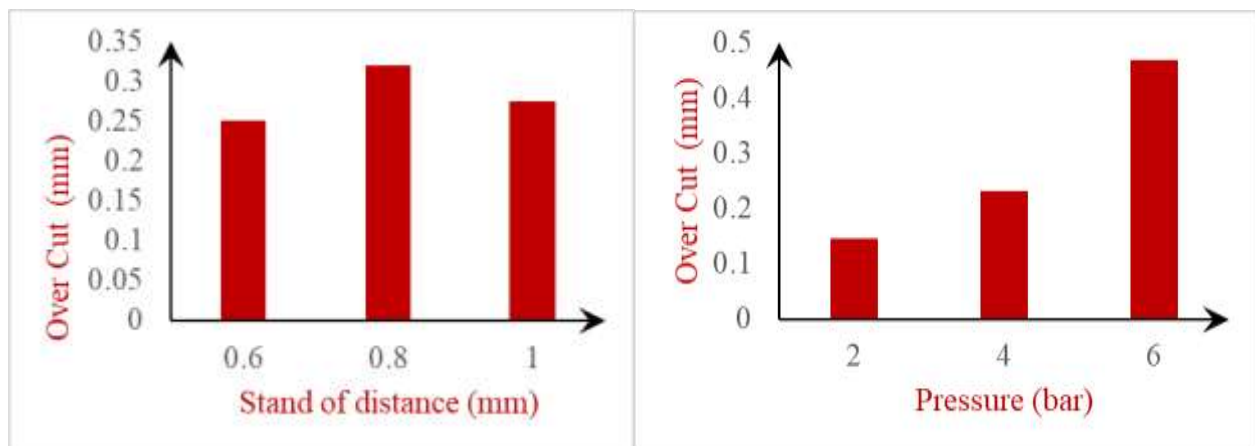


Fig. 3 Main effect plot of mean for OC

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 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 decreases with decrease in SOD.

5. PCA- based GRA method:

PCA based GRA method is used to convert multiple responses into a single characteristic index known as overall quality performance index (OQPI)[10]. For calculation of optimal OQPI value involves following steps:

- Converting the experimental data into S/N ratio.
- Calculating the principal component scores (PCS).
- Obtaining normalized PCSs.
- Calculating the grey relation coefficient using principal component score.

5.1 Calculating OQPI

At first, the experimental values of MRR and OC are converted into S/N ratio. According to this method, the three types of S/N ratios are categorized into lower-the-better (LTB), higher-the-better (HTB), and the nominal-the-better (NTB). The S/N ratio with LTB and HTB represented following equation 1 and 2 for MRR and OC respectively[11-12].

LTB response variable

$$\eta_{ij} = -10 \log \left[\frac{1}{n} \sum_{i=1}^n y_i^{-2} \right] \quad (1)$$

HTB response variable

$$\eta_{ij} = -10 \log \left[\frac{1}{n} \sum_{i=1}^n y_i^2 \right] \quad (2)$$

Where η_{ij} denotes the S/N ratios i^{th} experiment and j^{th} response) calculated from observed values, y_i represents the experimentally observed value of the i^{th} experiment and $n=1$ is the repeated number of each experiment in L_9 OA is conducted. The second steps conduct PCA on the S/N ratios to obtain uncorrelated PCSs corresponding to each experimental run, in the form of PCS_{il} it can be obtained by follows:

$$(3) \quad PCS_{il} = a_{1l}\eta_{i1} + a_{2l}\eta_{i2} + \dots + a_{jl}\eta_{ij}$$

Where $a_{1l}^2 + a_{2l}^2 + \dots + a_{jl}^2 = 1$. The $a_{1l}, a_{2l}, \dots, a_{jl}$ are the elements of Eigen vector corresponding to the l^{th} Eigen value of response variables. It can be calculated by MINITAB software. The eigenvalue and eigenvector are shown in Table 3. The third steps normalized the PCSs value by using equation 4.

$$(4) \quad X_{il} = \frac{PCS_{il} - PCS_{il}^{\min}}{PCS_{il}^{\max} - PCS_{il}^{\min}}$$

Where X_{il} and PCS_{il} are normalized and observed data, respectively for i^{th} experiment using l^{th} principal component score. The smallest and largest values of PCS_{il} for the l^{th} PCS are $\min PCS_{il}^{\min}$ and $\max PCS_{il}^{\max}$ respectively.

Table 3 Eigen analysis of the correlation matrix

Variable	Eigen vectors		Eigen value	Proportion
	PC1	PC2		
SN-MRR	-0.707	-0.707	1.9578	0.979
SN-OC	0.707	-0.707	0.0422	0.021

Then next step is to calculate the grey relation coefficient (GRC) of normalized PCSs data with the help of equation 5.

$$\zeta_{ij} = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{il} + \zeta \Delta_{\max}}$$

(5)

Where $\Delta_{il} = |1 - X_{il}|$. ζ is the GRC of i^{th} experiment using j^{th} response, $\Delta_{\max}$ and $\Delta_{\min}$ are the global maximum and global minimum values in the different data series, respectively. The distinguishing

coefficient varies between 0 and 1, which is to expand or compress the range of GRC. After calculating the GRCs, for l no. of PCS, the final steps OQPI (γ) can be calculated using equation 6.

(6)

Where w_i is the proportion of variance explained by i^{th} principal component and $\sum_{i=1}^n w_i = 1$ The

magnitude of γ imitates the overall degree of standardised deviation of the i^{th} experimental run. In general, a scale item with a high value of γ indicates that the respondents have a high degree of favourable consensus on the particular item. The OQPI values of i^{th} experimental run is tabulated in Table 4.

Table 4 Steps for Calculation of PCA based GRA

Run no.	SN-MRR	SN-OC	PCS-1	PCS-2	GRC 1	GRC 2	OQPI
1	4.4387	17.5557	9.2737	-15.5500	0.9352	1.0000	0.9365
2	11.4806	14.7747	2.3289	-18.5625	0.5692	0.3665	0.5649
3	17.0043	7.1804	-6.9455	-17.0986	0.3738	0.5295	0.3771
4	7.9588	16.7726	6.2314	-17.4851	0.7296	0.4739	0.7243
5	15.3178	10.2714	-3.5678	-18.0916	0.4272	0.4068	0.4268
6	20.3549	5.8913	-10.2257	-18.5560	0.3333	0.3670	0.3340
7	6.3738	15.9176	6.7475	-15.7600	0.7579	0.8925	0.7607
8	13.2230	13.7016	0.3384	-19.0357	0.5118	0.3333	0.5080
9	17.9712	6.7922	-7.9036	-17.5077	0.3610	0.4710	0.3633

5.2. Analysis of OQPI

The higher value of OQPI means comparability sequence has a stronger correlation to the reference sequence. Fig.4 represents main effect plots for OQPI and this graph depicts that the optimal machining parameters setting is Stand of distance 0.6 mm and Pressure 2 bar which would simultaneously ensure better Productivity in terms of maximum value of MRR and better quality in terms of minimum value for OC.

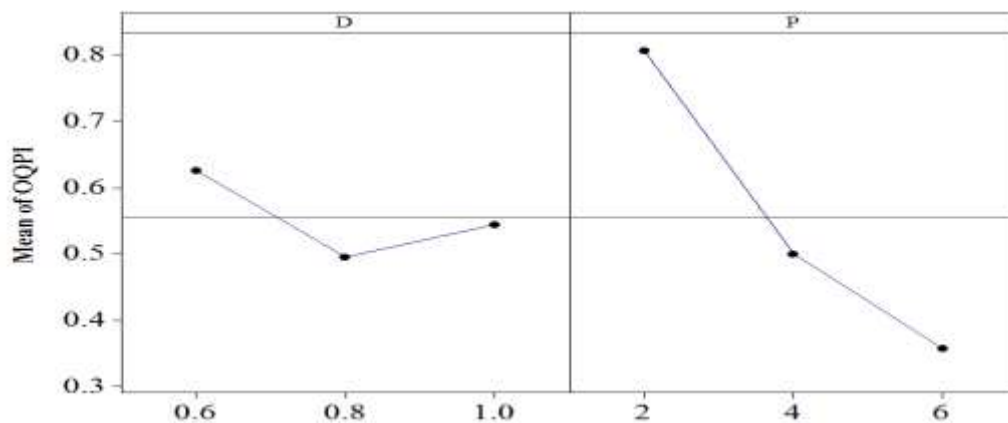


Fig.4 Overall quality performance index values

6. CONCLUSIONS

The AJM is can be used for drilling operation of composite fiber reinforced polymer material. Experimental work was done by considering SOD and Pressure are machining parameter to study MRR and OC. For MRR both SOD and pressure are significant factor and for OC only pressure is significant. MRR is increases with increase in pressure. For increase in SOD firstly MRR increases then it is remaining constant after that it is decreases.

For multi-objective optimization using PCA based grey relation analysis, optimal machining parameters setting was finding to Stand of distance 0.6 mm and Pressure 2 bar which would simultaneously ensure better Productivity in terms of maximum value of material removal rate and better quality in terms of minimum value for overcut of fiber reinforced polymer material.

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