Analysis and Optimization of Machining Parameters of AJM on Composite Fiber Reinforced Polymer

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Abstract: **- Abrasive jet machining (AJM) is widely used in aerospace, marine and automotive industries for trimming composites. However, AJM demonstrates some challenges when cutting composite fiber reinforced polymer (CFRP) materials such as cut accuracy andquality. 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 effect of Overcut (OC) and Material removal rate (MRR) of this material was finding by using L_9 orthogonal array based on Taguchi design and considering the, pressure of air and stand-off-distance are control parameter. This two output responses (MRR and OC) are contradicting in nature, for eliminating this modification has been converted into single response optimization techniques is known as PCA based grey relation analysis. In this result PCA based GRA means principal component analysis combine with grey relation analysis and simultaneously optimized single quality characteristics know overall quality performance index (OQPI).**

Key Words: **- Abrasive Jet Machining, Fiber Reinforced Polymer, Principal component analysis, Grey Relation Analysis.**

I. INTRODUCTION

AJM is also named as abrasive micro blasting, 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 for material removal of the work piece [1]. The Schematic diagram of AJM are shown in Fig.1.

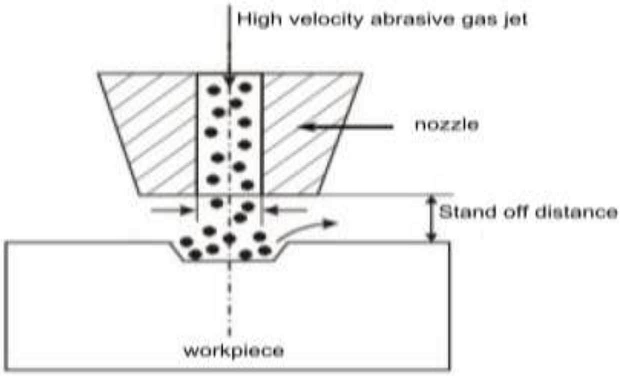

Fig. 1 Schematic diagram of AJM

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 homogenous 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 Mutavgjichigher 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 responses 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.

II. FABRICATION OF CFRP AND ITS STEPS FOR MAKING

The term carbon fiber is used to describe one of the following three products, material composed offine carbon fibers, carbon-reinforced plastic, or the trade marked carbon fiber insulation. But, while carbon fiber fabricators are involved in the creation of all three products, basic carbon fiber fabrication refers to the manufacture of the ultra-thin carbon fibers. Reinforcement is combining or joining two layers of similar or dissimilar material with the help of reinforcing agent. Epoxy resin is used as matrix for fabrication of CFRP. There aredifferent materials required for the fabrication of CFRP. 1. Carbon Fiber Cloth 2. EpoxyResin, 3. Hardener and 4. Accelerator.

There are the steps for making of CFRP

- A smooth plywood is considered as a work bench for the fabrication of CFRP.
- Carbon fiber cloth is cut into standard dimensions in which carbon fiber is oriented at an angle of10˚, 30˚, 50˚and 70˚to its longitudinal axis.
- A mixture of epoxy resin, hardener and accelerator is prepared. In 1liter of resin, 40 ml of hardener and 30ml of accelerator is mixed.
- Then carbon fiber cloth is placed over plywood and mixture of epoxy resin, hardener and accelerator is applied over carbon fiber cloth and then carbon fiber cloth in which carbon fiber is oriented at an angle of 10˚ to its longitudinal axis is placed over it and the same mixture is applied again.
- The fourth step is repeated, until thickness of 5 mm is obtained.
- Step four and five are repeated in order to fabricate CFRP in which carbon fibers are oriented at an angle of 30˚, 50˚ and 70˚to their longitudinal axis respectively.
- Finally, the curing time provided is 24 hours in open atmosphere.

III. SAMPLE PIECE FOR MACHINING

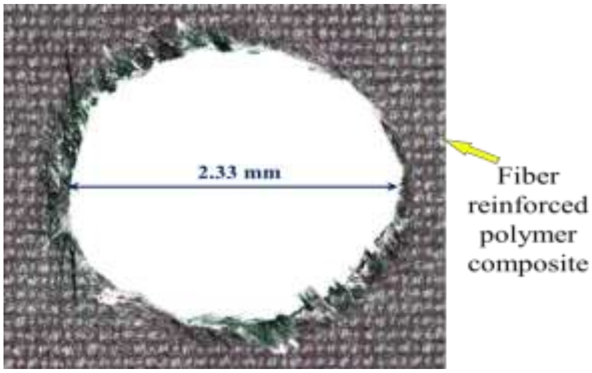

Fig. 2 Drilled cavity on work piece

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. After machining the drilled cavity on CFRP composite material are shown in Fig.2.

IV. 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 L_9 Orthogonal Array (OA) was chosen. Machining parameters and their level are presented below, and other parameters are kept constant during this experiment.

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

V. INFLUENCE OF MACHINING PARAMETERS ON MRR

The observed values of MRR are shown in Table 2. 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. 3. 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. The other factor SOD does not influence much as compared to pressure. It is clearly indicated from the above Fig. 3 at SOD

0.8mm the MRR was maximum. It decreases with increase in SOD and also decreases with decrease in SOD, this type of curved also represented Padhy et al [9-10]. It suggests that the effect of one factor is dependent upon another factor.

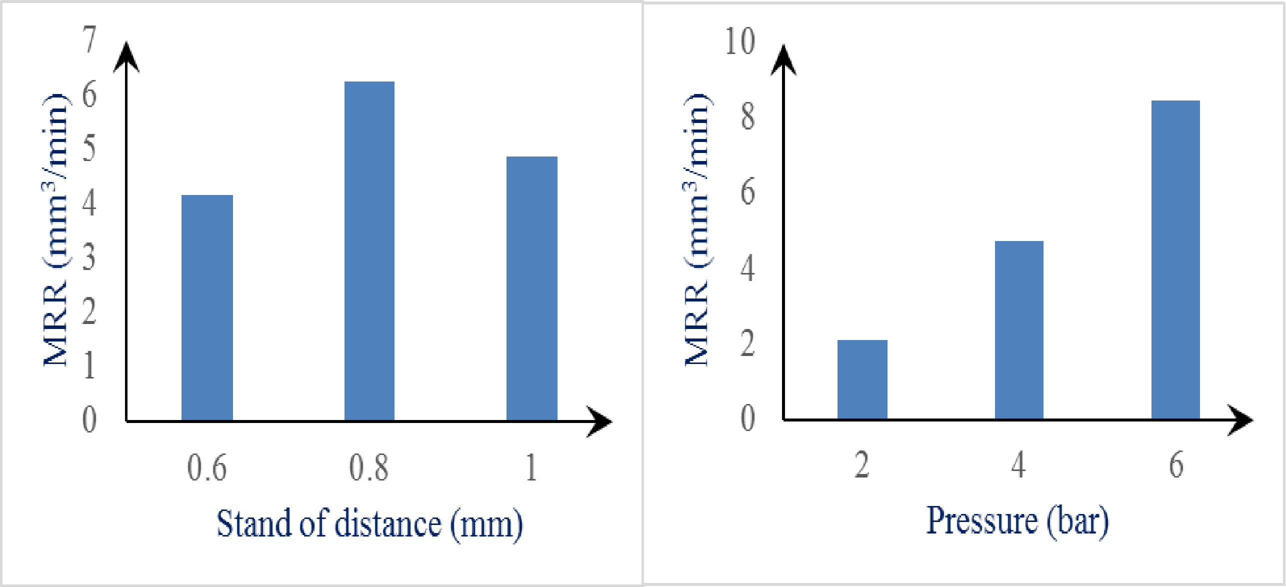

Fig 3 Main effect plot for mean of MRR

The analysis of variances for means is shown in Table 3, which is clearly indicates that SOD of the nozzle is not important for influencing MRR and pressure (p) is the most influencing factors for MRR.The case of MRR, it is "Larger is better", so from this table it is clearly definite that pressure is the most important factor then SOD, From the % of contribution it is shown in the table 5.3 that the p has 87.87 % contribution, SOD have 9.59 % contribution and error comes 2.57 % .

Sum of square (seq. SS) is necessary to find out the total amount of variation that can be observed by each factor.

Degree of freedom (DF) defines the number of independent factor of information involving the response data needed to calculate the sum of squares. Degree of freedom of each component is (n-1) where n is the number of observation observed in this experiment.

The delta values are pressure (p) and SOD 6.389 and 2.083 respectively, depicted in Table 4 of response table of MRR.

Table 3 Analysis of variance for MRR

Source	DF	Seq SS	Adj MS	F	P	% Contribution
SOD	2	6.752	3.3758	7.44	0.045	9.59
P	2	61.847	30.9234	68.19	0.001	87.84
Residual Error	4	1.814	0.4535			2.57
Total	8	70.413				

Table 4 Response table for MRR

Level	SOD	P
1	4.167	2.083
2	6.250	4.722
3	4.861	8.472
Delta	2.083	6.389
Rank	2	1

VI. INFLUENCES OF MACHINING PARAMETERS ON OVER CUT

The observed values of Over Cut (OC) are shown in Table2. 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. 4. The pressure (p) is directly proportional to OC in the range of 2 to 6 bar.

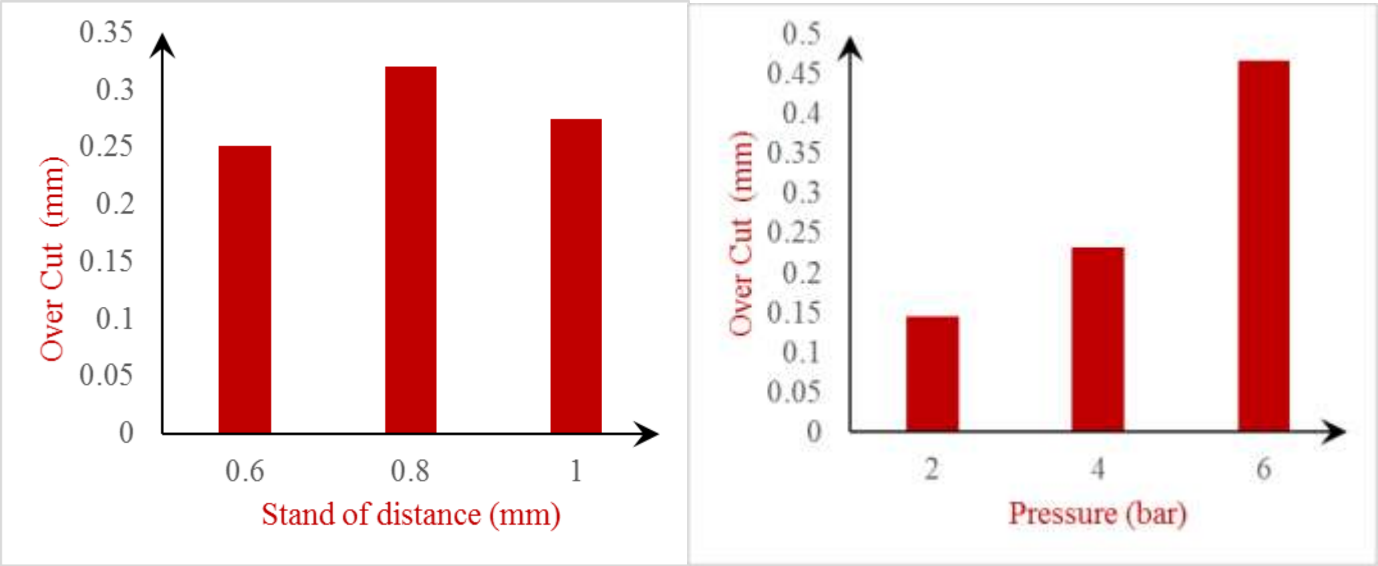

Fig. 4 Main effect plot of mean for OC

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 also 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 also decreases with decrease in SOD.

The analysis of variances for the factors is shown in Table 5 .which is clearly indicates that both SOD of the nozzle and pressure also important for influencing OC The delta values are pressure (p) and SOD 0.3217 and 0.0688 respectively, depicted in Table6. The case of OC, it is “Smaller is better”, so from this table it is clearly define that pressure is the most important factor then SOD, this is also conform that response table of means that’s shown in same table. From the % contribution of p has 93.47 %.SOD have 4.12 % contribution and error comes 2.41 %.

Table. 5 Analysis of Variance for OC

Source	DF	Seq SS	Adj MS	F	P	% Contribution
SOD	2	0.007331	0.003666	3.41	0.137*	4.12 %
P	2	0.166404	0.083202	77.42	0.001	93.47 %
Residual Error	4	0.004299	0.001075			2.41 %
Total	8	0.178034				
* Indicates the insignificant factor						

Table 6 Response Table for OC

Level	SOD	P
1	0.2508	0.1458
2	0.3197	0.2318
3	0.2747	0.4675
Delta	0.0688	0.3217
Rank	2	1

VII. CONCLUSIONS

By addition of long chain polymers to the water, the divergence of the jet can be reduced significantly by that, uniform bottom skin surface can be expected.By effective design of the CFRP, the efficiency can be improved, and divergence of the jet can be reduced, which helps in achieving uniform bottom skin surface that is near to the quality of the Abrasive jet cut top skin. Abrasive jet machining can be made to eliminate the no uniform surface issue on the skin of the CFRP structure.

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 remain constant after that it is decreases.

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