Modeling of Machining Parameters on GFRP using SiC as Abrasive on Abrasive Jet Machine

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Abstract— **This paper represents the experimental investigation using Abrasive Jet Machining on Glass Fiber Reinforced Polymer (GFRP) with SiC as abrasive. The relevance of this study is that it establishes empirical relations, as a function of machining variables, relevant to study and analyze the effect of process parameters of abrasive jet machining on GFRP. The response parameters considered are material removal rate (MRR) and taper while machining variables are material thickness, pressure and standoff distance (SOD). Experiments are performed using full factorial method. The mathematical modeling is designed using regression analysis and linear regression equations for all the responses are obtained and process performance data for various parameters is analyzed using ANOVA.**

Keywords— **Abrasive Jet Machining (AJM), Glass Fiber Reinforced Polymer (GFRP), Process Parameters, MRR, DOE, Mathematical Modeling, Regression Analysis, ANOVA**

I. INTRODUCTION

GFRP has a very high strength to weight ratio and it is suitable for applications like domes, panels, cupolas and roofs. Abrasive jet machining (AJM), also called abrasive micro blasting, is a manufacturing process that utilizes high-pressure air stream carrying small particles to impinge the work piece surface for material removal and shape generation. The removal occurs due to the erosive action of the particles striking the work piece surface.

Many researchers have done work on abrasive jet machining on different materials with different abrasives [1-11]. But detailed mathematical models representing the influence of predominant machining variables on GFRP material using SiC abrasive is yet to be established. This paper attempts to develop empirical models, using full factorial method as functions of thickness, standoff distance (SOD) and pressure for the response parameters material removal rate (MRR) and taper.

II. EXPERIMENTATION

The experiments are performed on the abrasive jet machine available at Faculty of Technology and Engineering, Maharaja Sayajirao University, Vadodara. The machine and experiment set up is shown in figure 1.

Figure 1: Experimental Setup of AJM

A full factorial design includes effect of all main factors and interaction of factors, 3^3 full factorial design is selected for experimental work. The levels of input parameters chosen for experiment are shown in Table 1.

Table 1: Levels of Thickness, Pressure and SOD

Level	Thickness	Pressure	SOD
	mm	Bar	mm
-1	1	3	3
0	1.5	4	4
1	2	5	5

The MRR is calculated by measuring initial and final weight of the work piece before and after cutting in milligram per second. As the MRR is small in abrasive jet machining, 1 milligram Electronic weighing balance, Contact make, Model CA223, is used. as shown in figure 2

Figure 2: Weighing machine

For measuring the taper, both small and large diameters of the drilled hole are to be determined. For this, measuring microscope shown in figure 3 is used. Its accuracy is 1 micron. For measurement, the cross hair of microscope is adjusted at one extremity of hole and the reading is taken. By travelling the cross hair, the same process is done on other extremity. Thus the diameter can be measured at one combination of extremities and same process is repeated four times for different combination of extremities by changing the orientation of the work. After that, the taper is calculated as the ratio of difference in the diameters to the depth of the drilled hole (thickness of the work piece).

Figure 3: Measuring microscope

The final results of experimental runs by full factorial design are shown in table 2.

Table 2: Experimental runs

Runs	Input Parameters			Response Parameters	
	Thickness	Pressure	SOD	MRR	Taper
	mm	bar	mm	mg/sec	mm
1	1.0	3	3	0.000586	1.5389
2	1.0	3	4	0.000850	1.1712
3	1.0	3	5	0.000537	1.0884
4	1.0	4	3	0.001057	2.1468
5	1.0	4	4	0.000903	1.7771
6	1.0	4	5	0.000590	1.5456
7	1.0	5	3	0.001641	2.3085
8	1.0	5	4	0.001429	1.2586
9	1.0	5	5	0.000645	1.5358
10	1.5	3	3	0.001096	1.8320
11	1.5	3	4	0.001006	1.5379
12	1.5	3	5	0.000782	1.2991
13	1.5	4	3	0.001432	2.4721
14	1.5	4	4	0.001670	1.6675
15	1.5	4	5	0.001143	1.0879
16	1.5	5	3	0.002043	1.9997
17	1.5	5	4	0.001872	1.6026
18	1.5	5	5	0.001187	1.2991
19	2.0	3	3	0.000998	2.1875
20	2.0	3	4	0.001387	1.0826
21	2.0	3	5	0.000936	0.9215
22	2.0	4	3	0.001776	2.3997
23	2.0	4	4	0.001921	1.8448
24	2.0	4	5	0.001031	1.2488
25	2.0	5	3	0.002383	2.1445
26	2.0	5	4	0.002321	1.5845
27	2.0	5	5	0.002151	1.1599

III. MATHEMATICAL MODELING

In many problems two or more variables are related, and it is of interest to model and explore this relationship. In general, suppose that there is a single dependent variable or response y that depends on k independent or regressor variables, for example, $x_1, x_2, \ldots, x_k$. The relationship between these variables is characterized by a mathematical model called a regression model.

Here, Linear Regression Model is used for modeling machinability parameters of GFRP using abrasive jet machining and the first order linear equations for each parameter are obtained as follow:

MRR (mg/sec) = - 0.000575 + 0.000741 Thickness (mm) + 0.000416 Pressure (bar) - 0.000223 SOD (mm)

Taper (mm) = 2.83 + 0.023 Thickness (mm) + 0.124 Pressure (bar) - 0.436 SOD (mm)

A. Graphical Analysis of Residuals Using Normal Probability plots

Graphical methods have an advantage over numerical methods for model validation because they readily illustrate a broad range of complex aspects of the relationship between the model and the data.

Figures 4 and 5 show the normal probability plots for residuals of all four responses. It is observed that the residual nearly follows a straight line and there are no unusual patterns or outliers. As a result, the assumptions regarding the residual were not violated and the residuals are normally distributed. Also the pattern in all the graphs suggests that the results obtained are unbiased, therefore, indicates that the model and results are valid.

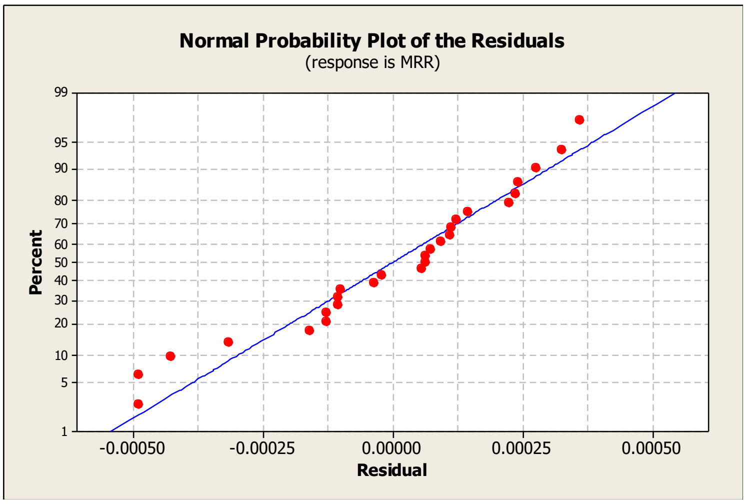

Figure 4: Normal Probability Plot for Residuals of MRR

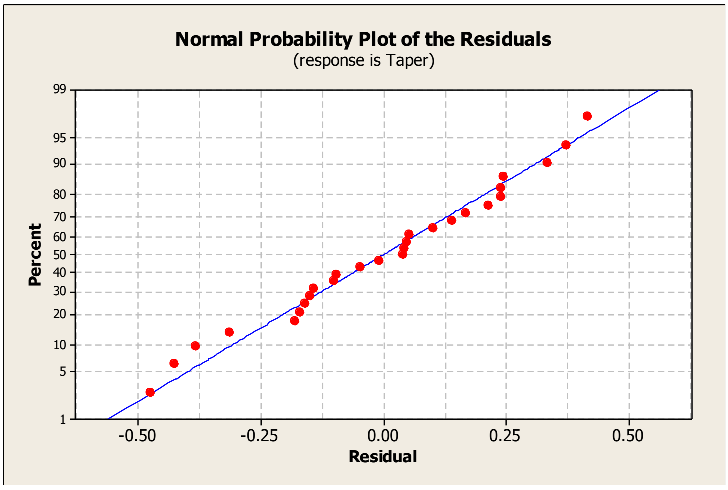

Figure 5: Normal Probability Plot for Residuals of Taper

IV. RESULTS AND DISCUSSION

A. Main Effect Plots

1) Main Effects Plot for MRR

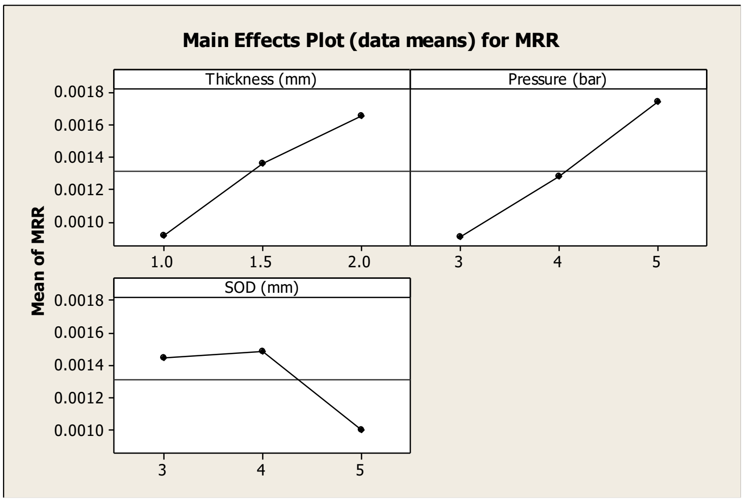

Figure 6: Main effects plot for MRR

From figure 6, it is observed that thickness of the work piece is the most significant parameter for MRR. The material removal rate increase linearly with increase in workpiece thickness. The rate of increase is rapid from lower thickness level to intermediate thickness level but then the rate of increase from intermediate thickness to highest thickness is slightly slow. The increase in MRR is due to the increasing collision of impinging particles in the working zone.

The air pressure is the second significant parameter affecting MRR. With increase in air pressure, the MRR is observed to increase. The rate of increase is slower from lower pressure to intermediate pressure and then increases. The nozzle converts pressure energy into kinetic energy. The increase in pressure leads to increased velocity at the exit of the nozzle causing the particles to impinge on the work surface with larger momentum.

There is slight increase in the MRR with increase in SOD from lower value to intermediate value. The abrasive carrying jet tends to expand as it travels and impinges on larger area due to expansion causing slight increase in MRR with increase in SOD. Further increase in SOD takes the work surface away from nozzle exit and the internal friction and air resistance causes reduction in jet energy before striking the work surface. This causes reduction in the MRR with increase in SOD from intermediate level to highest level.

2) *Main Effects Plot for Top Taper*

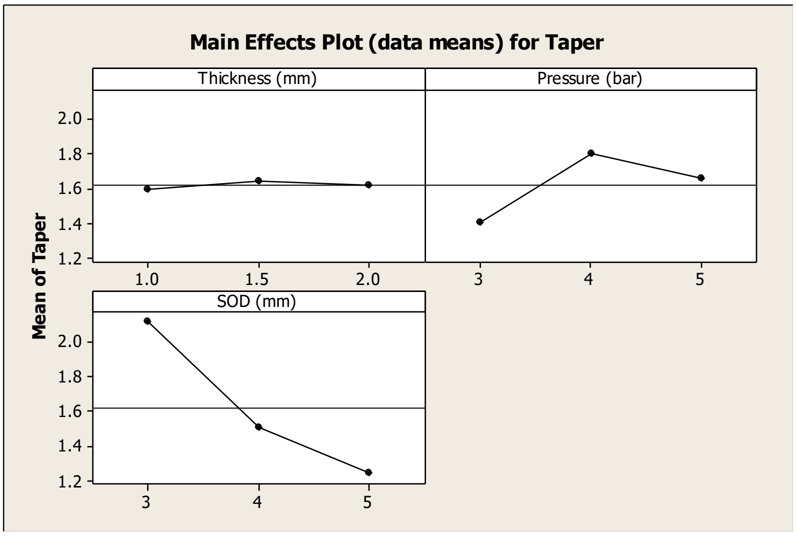

Figure 7: Main effects plot for Taper

As shown in figure 7, it is clearly observed that the thickness is the least significant parameter affecting the taper. The value of taper almost remains same except a small increase at the intermediate level of thickness.

Also, from the main effect graph, it is clearly seen that taper increases with increase in pressure upto the intermediate level of pressure; whereas it decreases from the intermediate to higher level of Pressure

There is a decrease in the taper with increase in SOD. The decrease rate from lower to intermediate level of SOD is higher than that of intermediate to higher level of SOD.

B. *Analysis of Variance*

1) *Analysis of Variance for MRR*

Table 3: ANOVA Table for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Thickness	2	0.0000025	0.0000025	0.0000013	26.02	0.000	31.65
Pressure	2	0.0000031	0.0000031	0.0000016	32.59	0.000	39.24
SOD	2	0.0000013	0.0000013	0.0000007	13.56	0.000	16.46
Error	20	0.0000010	0.0000010	0.0000000			12.65
Total	26	0.0000079					100.00
S = 0.000219220			R-Sq = 87.83%			R-Sq(adj) = 84.18%	

The important information that can be obtained from the table is the percentage influence of all factors over responses. P value less than 0.0500 indicate model terms are significant. In this case all three parameters are significant model terms. The percentage contribution by each of the process parameter in the total sum of squared deviation can be used to evaluate the importance of the process parameter change on the quality characteristic. Here, the contribution of Pressure for MRR is highest: 39.24%.

2) *Analysis of Variance for Taper*

Table 4: ANOVA Table for Taper

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Thickness	2	0.01014	0.01014	0.00507	0.11	0.892	00.19
Pressure	2	0.70900	0.70900	0.35450	8.02	0.003	13.62
SOD	2	3.60307	3.60307	1.80153	40.74	0.000	69.20
Error	20	0.88450	0.88450	0.04422			16.99
Total	26	5.20670					100.00
S = 0.210297			R-Sq = 83.01			R-Sq(adj) = 77.92%	

From ANOVA table 4, it is observed that for taper, SOD and pressure are the significant factors as P value for these factors is less than 0.05. The percentage contribution of significant factors SOD and pressure are 69.20% and 13.62% respectively. Values greater than 0.1000 indicate the model terms are not significant. Therefore, in this case, thickness is not a significant parameter affecting the taper.

V. CONCLUSION

The effect of selected input parameters using abrasive jet machining on the output responses like MRR and taper are studied by experimentation performed using full factorial design of experiment on GFRP material.

First Order Linear Model is obtained for all the parameters using Linear Regression Model which helps to predict the values of response parameters for any combination of selected input parameters.

The pattern of residuals observed in normality plots indicates that the results are unbiased as the residuals nearly follow a straight line and thus it shows that the model and results are valid.

From the analysis of variance, it can be concluded that the most significant abrasive jet machining process variable influencing material removal rate of GFRP is pressure followed by the stand off distance and thickness, whereas for taper, the significance order of parameters is stand off distance and pressure. It is also observed that the thickness does not affect the taper significantly. These models can be effectively utilized by the process planners to select the level of parameters to meet any specific abrasive jet machining requirements of GFRP with SiC as abrasive within the range of experimentation.

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