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Optimizing the Machining Parameters of Abrasive Water Jet Machining for Polymer Nano composite Containing Tungsten Carbide Nanoparticles

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ABSTRACT

In this present work experimental investigations were conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on surface roughness (Ra) of glass fiber reinforced epoxy composites. The approach was based on Taguchi's method and multiple linear regression analysis to optimize the AWJM process parameters for effective machining. It was found that the type of abrasive materials, water jet pressure, standoff distance and abrasive flow rate were the significant control factors and the cutting orientation was the insignificant control factor in controlling the Ra. The models successfully predicted the surface roughness of an AWJ machined glass fiber and epoxy laminate within the limit of this study. The optimal parameters combination was determined. Analysis of variance (ANOVA) and F-test were used to check the validity of Multiple Linear Regression mathematical model and to determine the significant parameter affecting the surface roughness. The statistical analysis showed that the mass flow rate was a most dominating parameter on surface roughness in waterjet machining process.

Keywords: Tungsten Carbide Filled Polymer Composite- Abrasive Water Jet Machine- Surface Roughness- Taguchi's Method- Multiple Linear Regression Analysis.

1. INTRODUCTION

Polymer matrix composite is widely used in many product manufacturing industries because of its distinct advantages such as lower weight, higher strength and stiffness, ability to mould into complex shapes, better corrosion resistance, and damping properties. In recent days, Nano fillers such as graphite particles are impregnated with glass fiber reinforced polymer (GFRP) to enhance specific properties. The incorporation of Nano ceramics such as layered silicate clays, calcium carbonate or silica Nanoparticles arranged on the nanometer scale with a high aspect ratio and/or an extremely large surface area into polymers improves their mechanical performances significantly. The properties of Nano composites depend greatly on the chemistry of polymer matrices, nature of Nano fillers, and the way in which they are prepared. The uniform dispersion of Nano fillers in the polymer matrices is a general prerequisite for achieving desired mechanical and physical characteristics. Polymer composite is used in product manufacturing due to its distinct advantages such as lower weight, higher strength and stiffness, ability to mold into complex shapes, better corrosion resistance, and damping properties. In recent days, Nano fillers such as graphite particles are impregnated with glass fiber reinforced polymer (GFRP) to enhance specific properties. Shivamurthy et al. [1], found that mechanical properties of glass/epoxy composite, namely, Young's modulus, tensile strength, flexural strength, impact strength, and wear resistance, show improvement with addition of graphite flakes. Such composites are highly suitable for manufacturing of bearing liners, gears, seals. Li et al. [2] discussed that AWJ machining is a fairly new manufacturing process which has been realized to address limitations mentioned earlier. In AWJ machining process, the machined surface does not affect from thermal damage due to water that acts as coolant and also it is generated low heat during the machining process. Wang et al. [3] they were studied about in AWJ machining process, the mixture of abrasive and water is directed on the target material. The nozzle is attached to CNC control to produce required profiles on Work piece. Material removal rate (MRR) in AWJ machining process is depends on operating parameters of the machine. Khan et al. [4] studied that abrasive particles with higher hardness have better machining capability, but they have limitations like accelerating the wear of machine components on cut surface. Hence, AWJ machining industry uses garnet abrasive due to its specific advantages like low nozzle wear rate, good machinability, and economical availability. Junkar et al. [5] by finite element analysis they were noticed that the maximum material removal occurs at jet impact angle of 90. Azmir et al. [6] Author has investigated on the glass fiber reinforced epoxy composites and they were noted that abrasive hardness, operating pressure, standoff distance, and jet traverse rate were significant control factors which affect surface roughness and a mathematical model was developed to predict surface roughness. Ulas caydas et al. [7] studied about the machining process of AWJ by ANN method and regression analysis and compared the both results which is obtained from the analysis and found that the waterjet pressure was the most dominating process parameters in the AWJ machining process. In this work fully devoted to finding out the most dominating parameters of AWJ machining process by Taguchi (9 set of experiment) and Multiple Linear Regression analysis.

2. MATERIALS USED

In the present work, Tungsten Carbide of 100 µm size in the particulate form was used as filler in glass fiber reinforced epoxy laminate. And epoxy resin was used as matrix. Machining is carried out by using garnet abrasive of the size 80 mesh.

3. FABRICATION OF POLYMER COMPOSITE

The following step has been followed to fabricate the polymer composite.

Step 1: Preparation of steel mould with square shape f 350 x 350 mm

Step 2: Applying the releasing agent on the mould.

Step 3: Mix the catalyst and accelerator with

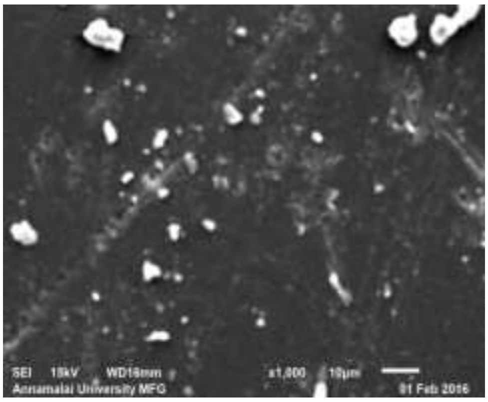
the polyester resin in a beaker by using the mechanical stirrer.

Step 4: Place the glass fiber on the plate and apply the resin over the fiber

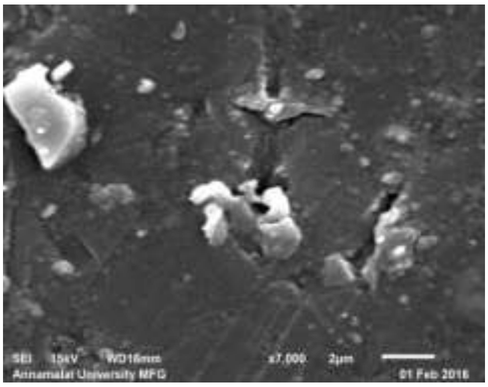
Step 5: Then place another layer of glass fiber and repeat this process up to six layers. Then this specimen is allowed to cure at room temperature for 3days

(a)

Tungsten Carbide filled GFRP laminates were prepared using hand lay-up process as shown in Figure 1. The material compositions for composite were Tungsten Carbide 3% by weight; glass fiber and the epoxy resin are taken as equal weight. Square shape of 300 mm × 300 mm polymer composite with tungsten carbide has been fabricated for six layers.



(b)



(c)

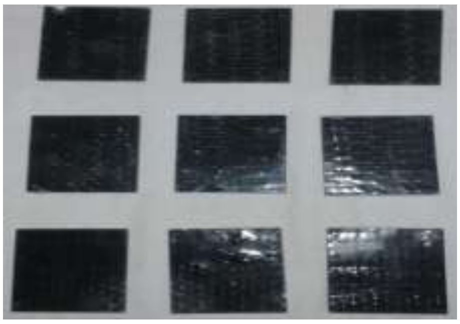
Figure 1 (a) 3% of Tungsten Carbide filled polymer composite (b) and (c) SEM image

Figure 1 (b) and (c) shows that the uniform presence of tungsten carbide in the fabricated polymer matrix composite.

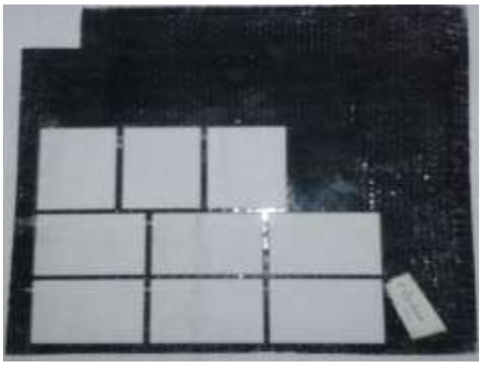
4. EXPERIMENTAL SETUP

Excel-CNC abrasive water jet cutting machine was used for to conduct the experimentation. The experimental setup is shown in Figure 2. The abrasive water jet was directed at 90^0 on to the surface of tungsten carbide epoxy composite through a carbide nozzle of orifice with 1.1mm diameter and granite & natural sand used as abrasive materials.

(a)



(b)



(c)

Figure 2 (a) Machining Process (b) Machined Plate and (c) Machined Piece

5. OPTIMIZATION

In this present work has been concentrated to optimize the machining characteristics of AWJ by two DOE techniques (I) Taguchi's method with L9 orthogonal array (II) multiple linear regression analysis. DOE is the powerful and economical tool for optimizations and most of author has followed this DOE method to optimize the machining characteristics.

Table 1 Machining parameters.

Machining parameters	Level 1	Level 2	Level 3
Pressure in MPa	138	207	276
Standoff distance in mm	1.5	3.0	4.5
Abrasive-mass flow rate in g/s	2.5	5.0	7.5

5.1. Taguchi's method

The AWJ machining parameters and levels of the experiments were chosen based on the literature review followed by trial experiments. Table 1 shows the machining parameters that were chosen to study the performance of AWJ machining of tungsten carbide GFRP composite.

Table 2 Experimental design orthogonal array

Abrasive Material	Pressure MPa	SOD mm	Abrasive-Mass Flow Rate (g/s)	Surface Roughness µm	S/N Ratio
Granite & Natural Sand 80 Mesh	138	1.5	2.5	2.8	-8.94316
	138	3.0	5.0	2.4	-7.60422
	138	4.5	7.5	2.1	-6.44439
	207	1.5	2.5	2.7	-8.62728
	207	3.0	5.0	2.4	-7.60422
	207	4.5	7.5	2.6	-8.29947
	276	1.5	2.5	2.7	-8.62728
	276	3.0	5.0	3.0	-9.54243
	276	4.5	7.5	2.6	-8.29947

Table 3 Response Table for S/N ratio

Level	Pressure	Standoff Distance	Mass Flow Rate
1	-7.664	**-8.733**	**-8.98**
2	-8.177	-8.250	-8.177
3	**-8.823**	-7.681	-7.559
DELTA	-1.159	-1.051	-1.370
RANK	2	3	1

Table 4 the optimum control parameters of values for S/N ratio analysis

Pressure (MPa)	276
Standoff distance (mm)	1.5
Abrasive mass flow rate (g/s)	2.5

From the above table it can be noted that Mass Flow Rate has the rank 1 followed this pressure and standoff distance. From this MFR is the most affecting parameters in AWJ machining process.

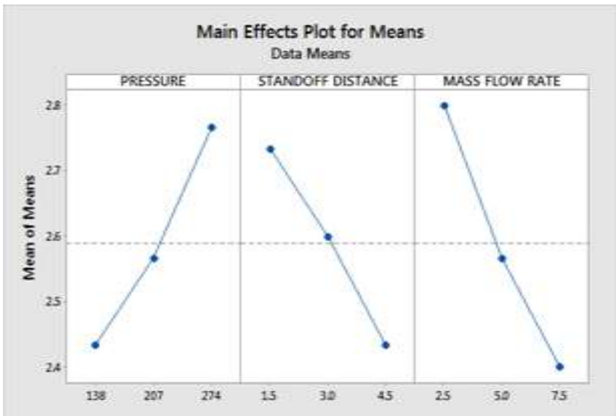


Figure 3 Main effects plot for means

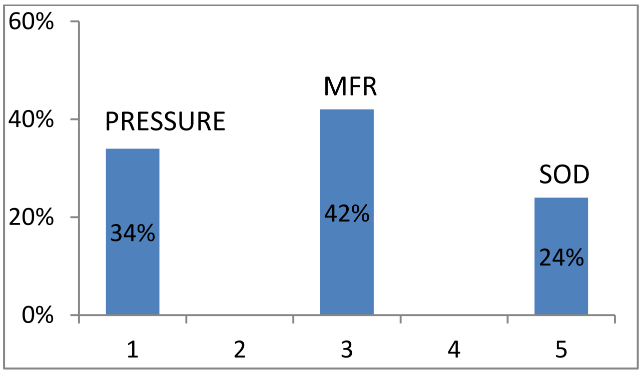


Figure 4 Bar Chart of Estimated percentage of Contribution

5.2 Multiple linear regression modeling

Since the study is about the determination of more dominant process parameter out of three parameters namely pressure, standoff distance and abrasive mass flow rate. All the machining parameters are considered as independent variables and hence L9 Orthogonal Array is selected for this study. The numerical results obtained by varying pressure, standoff distance and abrasive mass flow rate are fitted to quadratic polynomial model using MINITAB 17 in the general equation (1).

$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 \quad (1)$$

Where Y is predicted response, here it is surface response (Ra) and $\beta_o, \beta_1, \beta_2, \beta_{11}, \beta_{22}, \beta_{12}$ is model co-efficient parameters.

The Multiple linear regression analysis is carried out using MINITAB 17 software taking Pressure, SOD and MFR as input parameters and a second order polynomial type regression equation is fitted with values of correlation co-efficient (R^2) and adjusted correlation co-efficient (R^2 adj) are 99.60% and 98.38% respectively and the fitted equation is given in equation (2). Correlation co-efficient (R^2) is a measure of degree of fit i.e., how close the data are to the fitted regression line. If R^2 approaches unity, the better the model fitted with the actual data.

SR = 3.122 - 0.00048P- 0.0556SOD - 0.1333MFR + 0.000007 P*P- 0.0074SOD*SOD + 0.00533 MFR*MFR (2)

Table 5 Experimental values from AWJ

Machining parameters			Surface Roughness (R_a) Values	
Pressure MPa	Stand Off Distance mm	Abrasive-Mass Flow Rate g/s	Experi mental	Predicted
200	8	2.5	2.8	2.78889
200	16	5.0	2.4	2.42222
200	24	7.5	2.1	2.08889
400	8	2.5	2.7	2.68889
400	16	5.0	2.4	2.38889
400	24	7.5	2.6	2.62222
600	8	2.5	2.7	2.72222
600	16	5.0	3.0	2.98889
600	24	7.5	2.6	2.58889

Table 6 ANOVA for the multiple linear regression models

Source	Degree of Freedom (DF)	Adjusted Sum Square (Adj SS)	Adjusted Mean Square (Adj MS)	F – value	P – value
Regression	6	0.546667	0.091111	82.00	0.012
Pressure	1	0.000061	0.000061	0.06	0.836
SOD	1	0.000850	0.000850	0.77	0.474
MFR	**1**	**0.013605**	**0.013605**	**12.24**	**0.073**
Pressure*Pressure	1	0.002222	0.002222	2.00	0.293
SOD*SOD	1	0.000556	0.000556	0.50	0.553
AMFR * AMFR	1	0.002222	2.00	0.293	0.293
Error	2	0.002222	0.001111		
Total	8	0.548889			

From the ANNOVA table MFR has the lowest P-value of 0.073 and it is infer that MFR is the most dominating parameters than the other parameters.

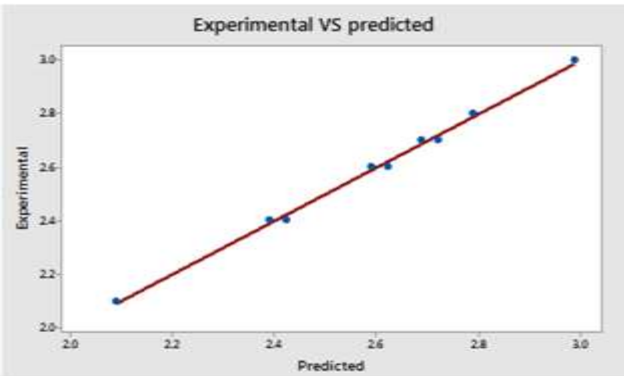


Figure.5 Experimental Vs Predicted

The Experimental Vs Predicted for present regression models are shown in Fig. 6.The points in the plot should generally form a straight line if the residuals are normally distributed. Since in the present model, the residuals falls near the straight line, there is no indication of non- normality of experimental results.

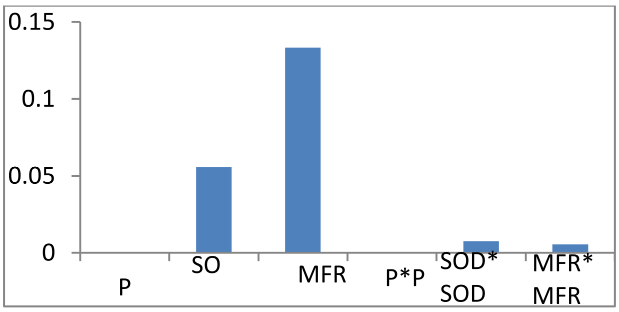


Figure 6 Bar Chart of Estimated Regression Coefficient Values hence it can be concluded that the MFR is more dominant factor than other parameters.

6. CONCLUSIONS

The following conclusions are derived from this work.

- From the Taguchi's orthogonal array and analysis of variance the best level of the machining parameters of AWJ is determined by ANOVA.
- Based on the ANOVA and F-test, the most dominant parameter on the surface roughness was found as mass flow rate(MFR) while the second ranking factor was pressure(P) followed by standoff distance(SOD).
- From the Multiple linear regression analysis, the predicted process parameters on validation were found to be close correlation with the actual performance results. And from the ANOVA table the most dominant parameter on the surface roughness was found as MFR

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