A study on machinability of polymer composite by abrasive water jet machining

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Abstract. The aim of this work is to study the effect of input parameters such as abrasive flow rate, standoff distance and transverse rate on the output process parameters taper angle and circularity in machining of polymer composite(E-glass fiber reinforced with polypropylene) by abrasive water jet machining. The polymer composite was prepared by compression molding. A circular hole of size 5mm is machined in the composite plate having a thickness of 4.8 mm by AWJM using granite of size 80μ as abrasive. Taper angle and circularity of machined hole was measured by machine vision. Experiments were conducted based on L16 orthogonal array. Effect of input parameters was individually analyzed on corresponding output parameters using taguchi method. Analysis of Variance (ANOVA) was done and the output was optimized using Grey relation analysis. Results indicate that standoff distance and abrasive flow rate has high influence on the taper angle and circularity respectively.

Keywords. AWJM, Polymer composite, ANOVA, Grey relation analysis

1. Introduction

Abrasive water jet machining (AWJM) process is a mechanical nontraditional machining process which uses abrasive particle and pressurized water for machining. In AWJM material removal in case of brittle material is due to the crack initiate by abrasive grain and its penetration into the material. Polymer composites find its application in various fields due to their high specific stiffness and strength. Polypropylene resins have good toughness and it is used in manufacture bullet proof vest and helmet. Compared to conventional drilling, AWJM gives an improved output results [1]. Kalairasu.S et al.[2],evaluated the machinability of jute/polyester composite by AWJM process and concluded thattraverse rate has high influence on delamination and types of abrasive has less effect on the surface roughness and taper angle of the hole produced., Aiazmiret al. [3], described the influence of machining parameters on kerf ratio and results indicate standoff distance and traverse rate has high influence on kerf width. They also concluded that hybrid composite can be processed effectively by AWJM. J.schwartzentrber et al [4], predicted the surface roughness by developing model considering the interaction of particle on the prepared composite, it is concluded that the particle velocity has significant

influence on the surface roughness of the CFRP composite. M.A. Azmir et al [5], optimized the parameters of AWJM in machining glass fibre/epoxy composites. Effectiveness of various abrasive materials like granite and Sic were analyzed to achieve better R_a in machining. Kamlesh Phapale [6] did experimental work on machinability of CFRP and optimized the parameters for getting less delamination. From the results they inferred that abrasive flow rate is a critical factor affecting the delamination of the composites. D.H. Ahmed et al.[7] did a numerical study on the effect of particle impact velocity on the surface finish, material removal rate and delamination. Using finite element method, they validated the experiment results and checked the effectiveness of the developed model. C. Narayanan et al [8], developed a mathematical model to predict the surface roughness in AWJM incorporating particle size and velocity. Azmir et al [9], worked on machining the aramid fibre composite by AWJM and examined the effect of input parameters on roughness and delamination. Akkurt et al [10], studied the influence of feed rate on the surface finish obtained in cutting a polymer composite. According to author's knowledge, lot researchers have analyzed surface roughness, delamination and kerf width in AWJM. So, an attempt had been made to check the effect of process parameters on circularity and taper angle in AWJM of polymer composite.

2. Preparation and testing of composites

In this work e-glass fiber is used as reinforcement and polypropylene as matrix and it is fabricated using compression molding machine. Five layers of polypropylene sheets of thickness 0.75mm were cut to required size and it is reinforced with four layer of glass fiber. The fiber to resin ratio is kept as 30:70. The prepared laminate of size 300x300x5 mm is kept in the mould for 30 minutes which is preheated to 210ºC. Then pressure of 0.75 tonne/sq.inch was applied and after two hours the composite plate is ejected out from the mould. The tensile test and flexural test were performed on the prepared composite. For tensile test, according to ASTM D638standard test specimen of overalllength 250mm and width is 25 mm was prepared(figure-1) and ASTM D790 standard was followed for flexural test specimen size 127mm length and 12.7 mm width(figure-2). These tests were conducted on universal testing machine and the results were tabulated in table-1.

Table 1. Mechanical Properties of the prepared composites

Sample No.	Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
1	51.70	147.40
2	37.21	224.23
3	50.21	163.60

3. Experimental setup

The Machining is done on the CNCEZ-AWJM Techmoon make and the specifications of the machine was given in table-2

Table 2. Specification of AWJM

X Axis Travel	3000 mm
Y Axis Travel	2000 mm
Z Axis Height	150 mm
Max. Taper Cutting Angle	3˚ at 100 mm Job Height
M/C Tool Size(L×W×H)	4000×2000 mm
Max. Cutting Speed	60 mm/min
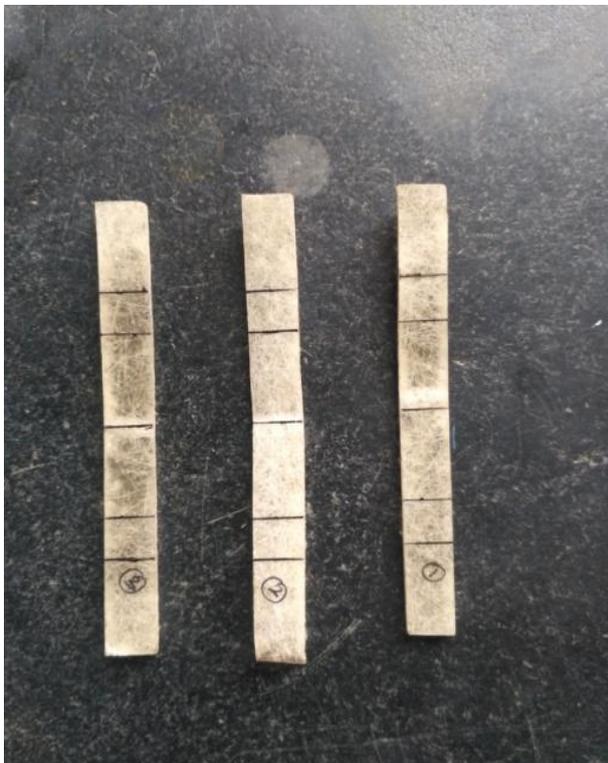
Figure 1. Tensile test sample

Figure 2. Flexural test samples

Due to constraint of the machine abrasive flow rate, stand-off distance and traverse rate each with four levels were considered in this work.

Table 3. Parameters and its levels

| Levels | Parameters | | |
	Abrasive Flow Rate (g/min)	Standoff Distance (mm)	Traverse Rate (mm/min)
1	70	2	100
2	80	3	200
3	90	4	300
4	100	5	400

Based on Taguchi design of experiment, L_{16} array was selected to conduct the experiment. Lot of researchers have planned their work by using L_{16} array effectively [11]. Trail run was conducted to fix the levels for each parameter and it is listed in table-3. Hole of diameter 5 mm is machined on the prepared polymer composites which give in figure-3.

4. Measurement of response

Circularity and taper angle was measured using machine vision setup (figure-4). Circularity value gives the deviation from the actual circular shape and smaller the values better the form of the hole. Taper angle of the hole is due to sliding of abrasive after it entering the material[2] and it is calculated by the equation(1).

$$\theta = \tan^{-1}(D_{top} - D_{bottom})/2T \qquad\qquad (1)$$

Where,
T= Thickness of the plate (4.8mm)
D_{top}=Diameter on top side where abrasive particle enter the material
D_{bottom}=Diameter on bottom side where abrasive particle exit the material.

Smaller taper angle will result in a straight cut hole and it exhibits better characteristic of the product in machining. The measurements were done in machine vision with 0.7x magnification and the values were presented in table-4. Figure 5(a) and 5(b) are the machine vision image of best and worst hole machined in the polymer composite by AWJM

Table 4. Measured responses

| Trail No. | Input Factor | | | Output Factor | |
	Abrasive Flow Rate	SOD	Traverse Rate	Circularity	Tapper Angle
1	1	1	1	0.321	0.595
2	1	2	2	0.215	0.489
3	1	3	3	0.256	0.625
4	1	4	4	0.566	0.840
5	2	1	2	0.254	0.926
6	2	2	1	0.426	0.700

7	2	3	4	0.210	0.484
8	2	4	3	0.325	0.599
9	3	1	3	0.368	0.642
10	3	2	4	0.211	0.465
11	3	3	1	0.287	0.561
12	3	4	2	0.261	0.924
13	4	1	4	0.342	0.616
14	4	2	3	0.323	0.597
15	4	3	2	0.371	0.645
16	4	4	1	0.366	0.640

Figure 3. Machined polymer composite
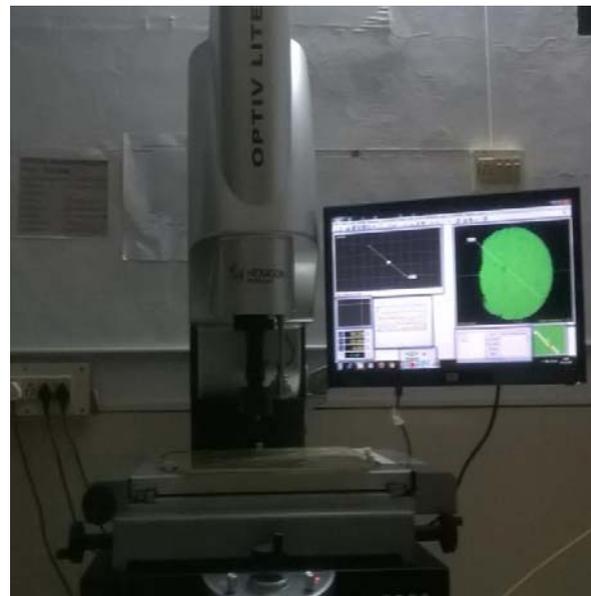
Figure 4. Machine vision setup

(a)   **(b)**
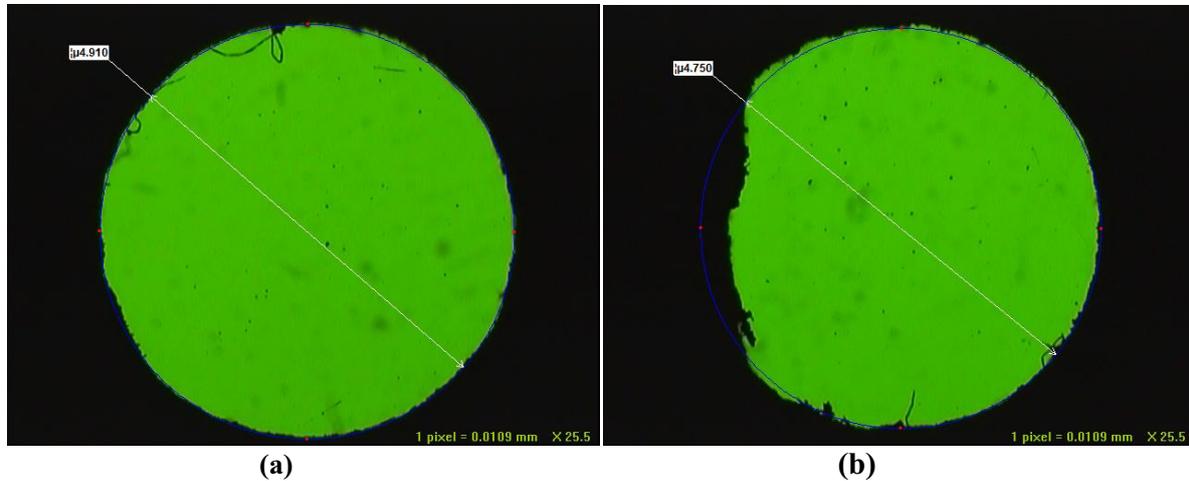
**Figure 5.** Machine vision images **(a)**Best hole with Ø4.910mm and **(b)**worst hole Ø4.750mm

5. Results and discussion

The direct effect of abrasive flow rate, pressure and standoff distance on circularity and taper angle were examined by plotting the graph using Minitab-15 software. Based on the trend of plot from figure-6, the circularity decreases upto the abrasive flow rate of 90 g/min and increase beyond it. In case of SOD it decreases till 3 mm and then increasing the SOD beyond 3 mm the value increases. This is attributed to the fact that increasing the SOD will cause the abrasive particle to flare and it will result in poor circularity [12]. Hence it is desired to keep the SOD within 3 mm and in case of transverse rate the.
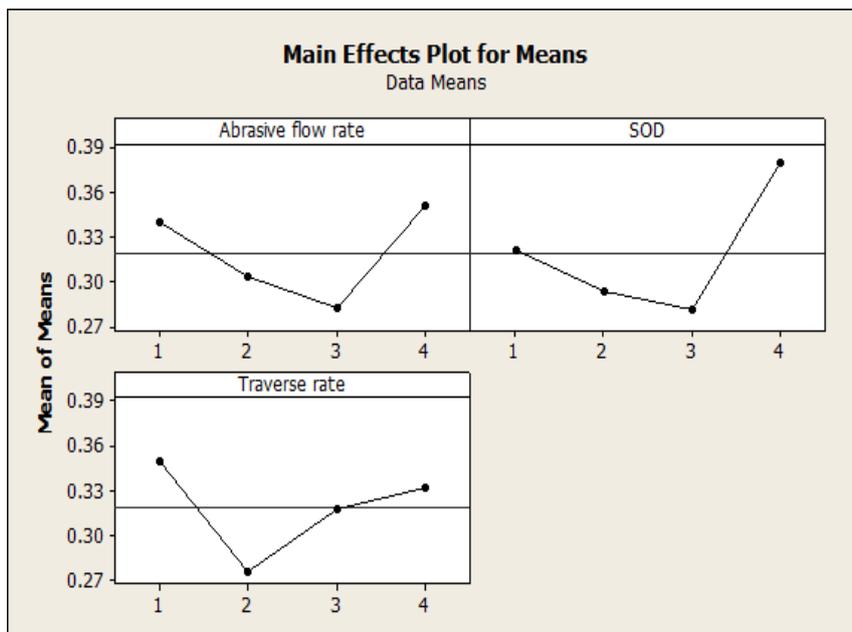

Figure 6. Direct effect of input parameter on circularity

circularity is lowest for level 2 and increasing the feed value circularity increases. The value is lowest for the transverse rate of 200 mm/min
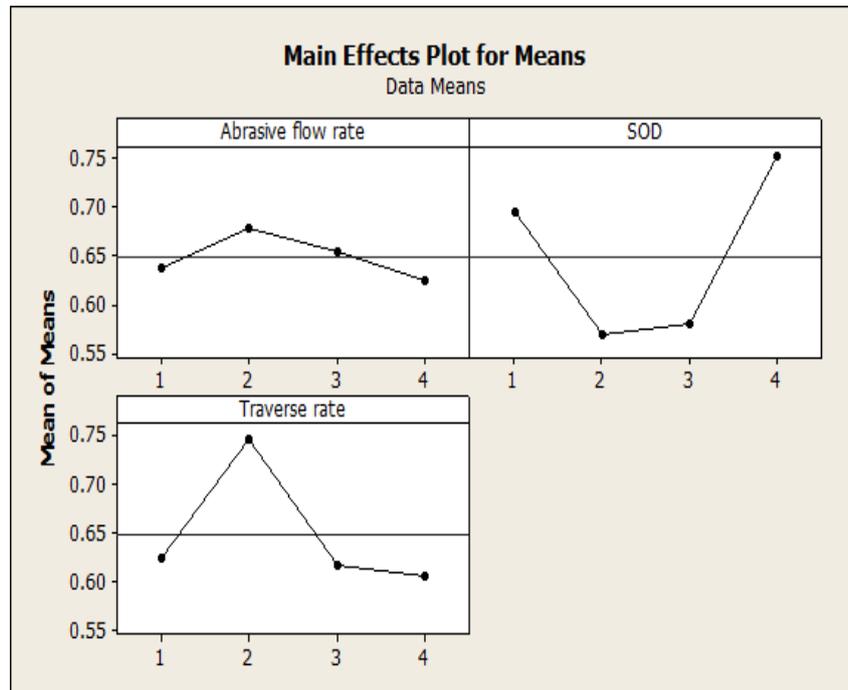

Figure 7. Direct effect of input parameter on Taper angle

From the figure-7 it is clear that the taper angle increases upto level 2 of abrasive flow rate and it decreases beyond it and it is also maximum at 80 g/min of abrasive flow rate and it is clear by reducing the flow rate result in more taper hole. Trend observed for SOD exhibits taper angle is less for level 2 and increasing the SOD beyond 2mm result in more taper hole. In case of transverse rate for level 2 the taper is high and by increasing the transverse rate the taper deceases. Hence it is desired to operate at higher traverse rate so that taper angle can be reduced.

Table 5. ANOVA result for circularity

Source of Variation	Sum of Squares	DOF	FAo	Contribution on %
SSA	0.004045	3	2.83	43.25
SSB	0.001930	3	1.25	20.63
SSC	0.002134	3	1.52	22.81
SSE	0.001243	9		13.29
SST	0.009352	18		

The analysis of variance was performed using minitab-15 software and it was performed at 95% confidence limit. The ANOVA result for circularity and taper angle were tabulated in table-5 and table-6 respectively. The R-square value of the circularity is 94.27% and 95.72% for the taper angle. This shows the model is fit and it has significance. From these results the abrasive flow rate has the highest influence on the circularity; SOD is the dominant factor for taper angle.

Table 6. ANOVA results for taper Angle

Source of Variation	Sum of Squares	DOF	F-Ratio	Contribution on %
SSA	0.002405	3	1.12	20.280
SSB	0.005893	3	3.31	49.710
SSC	0.002134	3	1.35	18.010
SSE	0.001423	9		12.009
SST	0.011855	18		

6. Grey Relation Analysis

The following steps was following in performing the grey relation analysis

- For all the selected output parameters, Smaller the best S/N ratio equation (2) is used as less circularity and taper angle is required,

$$S/N \text{ ratio} = -10\log(y^2) \tag{2}$$

Where, y - Corresponding value of the output factor

- Compute normalized S/N ratio using smaller the better equation(3)

$$Z_{nj} = (\min Y_{nj} - Y_{nj}) / (\max Y_{nj} - \min Y_{nj}) \tag{3}$$

- Calculate the grey relational grade using equation(4)

$$GC_{nj} = (\Psi_{min} + \delta\Psi_{max}) / (\Psi_{nj} + \delta\Psi_{max}) \tag{4}$$

Where, GC_{nj} is the grey co-efficient for n^{th} trail for j^{th} dependent response, δ is the quality loss and Ψ is the distinctive co-efficient which has value from 0 to 1. Here 'Ψ_{min}' value is the minimum value of Normalized S/N Ratio.'Ψ_{max}'value is the maximum value of Normalized S/N Ratio. δ is taken as 0.5

- Calculate grey relation code from equation(5)

$$G_n = (1/Q) \sum GC_{nj} \tag{5}$$

Where, Q is number of responses, GC_{nj} is the grey co-efficient for n^{th} trail for j^{th}dependent response.The results were listed in table-7. Rank is awarded according to the grey code obtained.

Table 7. Grey relation analysis results

S.No	S/N Ratio		Normalized S/N Ratio		Grey Relation Grade	Rank
	Circularity	Taper Angle	Circularity	Taper Angle		
1	09.8698990	4.509661	0.119453912	0.423100944	0.271277	13
2	13.3512300	6.213823	0.709840789	0.336891167	0.523366	5
3	11.8352000	4.082400	0.225183291	0.452107130	0.338645	8
4	04.9436710	1.514414	0	0.768950069	0.384475	7
5	11.9033300	0.667780	0.232310870	1	0.616155	3
6	07.4118080	3.0980039	0.075258066	0.538008322	0.306633	9
7	13.5556100	6.3030930	1	0.333333333	0.666667	1
8	09.7623333	4.4514640	0.116461038	0.426449539	0.271455	12
9	08.6830440	3.8492990	0.093065322	0.469520796	0.281293	10
10	13.5143500	6.2851650	0.923764981	0.333333333	0.628549	2
11	10.8423600	5.0207430	0.155605596	0.333333333	0.244469	14
12	11.6671900	0.6865610	0.209343043	0.987521500	0.598432	4
13	09.3194780	4.2083860	0.105571288	0.456674410	0.281123	11
14	09.8159500	4.4805130	0.117933859	0.333333333	0.225634	15
15	08.6125220	3.8088060	0.091859548	0.752410000	0.422135	6
16	08.7303780	3.8764010	0.094625775	0	0.047313	16

7. Conclusion

From this study, following conclusions were drawn:
- Increasing the abrasive flow rate beyond 90 g/min, circularity increases and circularity is lowest for SOD 3mm and beyond it circularity increases.
- For the transverse rate of 20 mm/min, circularity is lower. From the ANOVA abrasive flow rate has a contribution of 43.25% and SOD has least contribution of 20.63% on circularity
- In case of taper angle higher abrasive flow rate 100g/min and SOD of 3mm result in less taper and for the transverse rate of 40 mm/min taper at its lowest.
- From the grey relation analysis the optimal combination identified were abrasive flow rate- 80 g/min, SOD–4mm and transverse rate-40 mm/min.

8. References

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