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EXPERIMENTAL INVESTIGATION ON ABRASIVE WATERJET MACHINING OF FIBRE VINYL ESTER COMPOSITE

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ABSTRACT

Abrasive water jet machining (AWJM) is one of the most developed non-traditional machining processes. It is generally used to cut difficult to cut materials like composites. The present study is focused on machining of carbon fiber vinyl ester composite with AWJM. The effect of process parameters namely water pressure, standoff distance and traverse speed on surface roughness and kerf tapper is studied. Design of experiment is done by using Taguchi L16 orthogonal array. It is observed that water pressure is the most significant parameter followed by traverse speed. It is found that with the increase in water pressure and decrease in traverse speed of AWJM, surface roughness and kerf tapper of machined samples decreases.

Key words: *Abrasive Water Jet Machining, Carbon fibre vinyl ester composite, Process Parameters, Surface Roughness and Kerf Taper.*

1. Introduction

Abrasive water jet machining (AWJM) is one of the most developed non-traditional machining processes. It is generally used to machine difficult to cut materials. It is widely used in industries due to its several advantages on other unconventional machines such as high material removal rate, no thermal effect, minimal stresses, no chatter and high flexibility. AWJM process is suitable for machining composites [1]. Carbon fibre vinyl ester composite is used in aerospace industries, automotive industries, sport goods, marine vehicle and pressure vessel parts because of its durability, high strength to weight ratio, and good mechanical properties. Vinyl ester has better chemical resistance and mechanical properties than polyesters. Considering a similar fiber content, the carbon fiber vinyl ester pressure vessel had a blasted weight 20% higher than the vessel made of carbon strands and epoxy matrix. Carbon fiber vinyl ester composite is generally machined by AWJM.

Worldwide researchers have made efforts to investigate AWJM for machining various composites like glass epoxy composites, aramid epoxy composites, graphite epoxy composites, carbon epoxy composites and ceramic composites to minimize surface roughness and kerf taper. For example, Arora and Ramul [2] studied the kerf characteristic of AWJM of graphite/epoxy composite. They also investigated the effect of process parameters on kerf taper. Khan and Haque [3] studied the performance of different abrasive materials in AWJM of glass. They found that the garnet is the best abrasive for machining glass. Kumar and Kant [4] investigated the surface roughness of AWJ machined samples and also developed a regression model to predict it. Çaydaş and Hascalık [5] studied the influence of parameters on kerf taper angle and surface finish of AWJ machined samples of glass epoxy composite. They found that the abrasive-type and water pressure are most significant factors. Azmir and Ahsan [6] studied influence of traverse rate and water pressure on kerf taper while machining granite by AWJM. It was found that kerf taper graph goes down with increase in water pressure and decrease in traverse speed. Karakurt et al. [7] investigated the kerf width in AWJM of granitic rocks. They found that the stand-off distance and traverse speed have significant effect on kerf width. Kerf width increases with increase in stand-off distance and traverse speed. Karakurt et al. [8] studied trends of kerf taper and surface finish with the variation in process parameters for AWJM of carbon epoxy composite material. It was found that the graph of kerf taper and surface finish goes down when we increase the water pressure and decrease in traverse rate. Dhanawade et al. [9] described the experimental study on kerf properties in abrasive water jet machining of lead zirconated titanite ceramic material. It is concluded that traverse rate and water pressure are the most significant factors followed by stand-off distance to control kerf properties. Further, Dhana wade et al. [10] investigated defects

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including delamination; abrasive embedment and fibre pull out in machined samples of carbon epoxy composite.

Delamination was observed at the lower region of machined samples. Abrasive embedment was prominent in samples cut with high abrasive mass flow rate and low stand-off distance. Abdullah et al. [1] studied surface quality of marble machined by AWJM and it was found that the nozzle traverse speed is the most significant factor followed by standoff distance. Dhanawade and Kumar [11] concluded that AWJM is the most developed and effective machining for fiber reinforced polymer composites. Vigneshwaran et al. [12] studied the influence of process parameter on kerf taper and surface roughness.

From the review of available literature, it can be concluded that many researchers have made efforts to study AWJM of carbon epoxy composite, granite hybrid composites and glass epoxy composite etc. for improving surface finish, kerf taper, material removal rate and depth of cut. Researchers have also optimized process parameters and developed mathematical models for response measures. But very less work has been reported on AWJM of carbon fiber vinyl ester composite. Along these lines, there is sufficient scope in this area. In the present study, the influence of process parameters on surface roughness and kerf properties in AWJM of carbon fiber vinyl ester composite is investigated. In the present study, three process parameters namely stand of distance (SOD), water pressure (WP) and traverse speed (TS) are considered. The process parameters are selected on the basis of available experimental setup, reviewed literature [10] and their influence on response characteristics. The paper is organized as follows: Section 2 describes experimental setup; section 3 presents experimental design; section 4 describes results and discussion and finally concluding remarks of present study are given in section 5.

2. Experimental Setup

The machine used to machine carbon fibre vinyl ester composite is flying arm AWJM (Model – DARDI, DWJ1525-FA). Specifications of the machine are given in table 1. The machine is equipped with intensifier to pressurize water up to 240MPa. Gravity based abrasive hoper feeding system is attached to the machine.

Table 1. Specifications of AWJM Setup

Structure		Flying Arm
Cutting table size	X Axis	1600 mm
	Y Axis	2600 mm
Travel	X Axis	1500 mm
	Y Axis	2500 mm
	Z Axis	150 mm
Max. traverse speed		3 m/min
Cutting head		3 Axis
Accuracy	Cutting Accuracy	±0.10 mm
	Linear Accuracy	±0.10 mm
	Repeatability Accuracy	±0.05 mm
Drive system	Drive Motor	AC stepper
	Drive Mode	Ball screw & Guider Rail

Table 2. Properties of work material [7]

Properties	Value
Volume Fraction	40%
Tensile strength (MPa)	938 ± 11.4%
Density	1.56
Traverse Tensile strength (MPa)	17.8 ± 5.7%
Compression strength (MPa)	328 ± 11.5%

The properties of the carbon fibre vinyl ester composite material is listed in Table 2. Thickness of the work piece material used in present work is 20 mm. Machining of carbon fibre vinyl ester composite by AWJM is shown in Fig.1.

Fig. 1. Machining of carbon fibre vinyl ester composite by AWJM

3. Experimental Design

To study the influence of process parameters on surface roughness and kerf taper, three process parameters namely standoff distance, traverse rate and water pressure are considered in present work. Four levels of these process parameters as given in table 3 are selected based on the availability of the machine setup and literature review. Trial experiments are also conducted to select levels of process parameters.

Table 3. Levels of process parameters

Process parameters	Level 1	Level 2	Level 3	Level 4
Surface Roughness				
Standoff Distance (mm)	2	2.5	3	3.5
Traverse Rate (mm/min)	50	100	150	200
Water Pressure (MPa)	180	200	220	240
Kerf Taper Angle				
Standoff distance (mm)	2	2.5	3	3.5
Traverse Rate (mm/min)	70	125	175	225
Water Pressure (MPa)	150	175	200	225

In full factorial design, 64 experiments are required for each response parameter. Therefore, total 128 experiments are required which is neither practical nor economical and also time consuming. Therefore, experiments for present work are designed using Taguchi's L_{16} orthogonal array. Total 32 experiments are carried out i.e. 16 numbers of experiments for surface roughness and 16 numbers of experiments for kerf taper. Surface roughness of machined samples is measured by using surface roughness tester (Model – Mitutoyo SJ-310) as shown in Fig. 2 at three regions i.e. top, middle and bottom and average roughness is taken into consideration. Kerf taper angle is calculated by measuring top kerf width and bottom kerf width by keeping 0.5 mm margin from edge to nullify the effect of jet entry and jet exit.

Table 4. Experimental design with response values

Sl. No	Control factors for roughness			Avg. SR (μm)	Control factors for kerf taper angle			Kerf taper angle
	SOD	WP	TR		SOD	WP	TR	
1	2	180	50	5.182	2	150	70	0.3430
2	2	200	100	5.032	2	175	125	0.3240
3	2	220	150	4.835	2	200	175	0.3200
4	2	240	200	4.753	2	225	225	0.3178
5	2.5	180	100	5.287	2.5	150	125	0.3840
6	2.5	200	50	4.590	2.5	175	70	0.3150
7	2.5	220	200	5.339	2.5	200	225	0.3296
8	2.5	240	150	4.850	2.5	225	175	0.3112
9	3	180	150	5.825	3	150	175	0.4270
10	3	200	200	6.037	3	175	225	0.4620
11	3	220	50	4.677	3	200	70	0.2960
12	3	240	100	4.203	3	225	125	0.2760
13	3.5	180	200	6.670	3.5	150	225	0.6385
14	3.5	200	150	5.756	3.5	175	175	0.3980
15	3.5	220	100	5.621	3.5	200	125	0.2950
16	3.5	240	50	3.926	3.5	225	70	0.2533

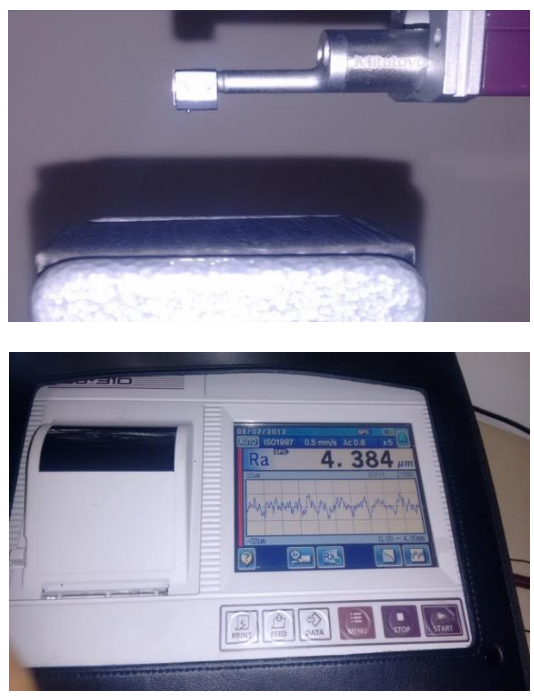
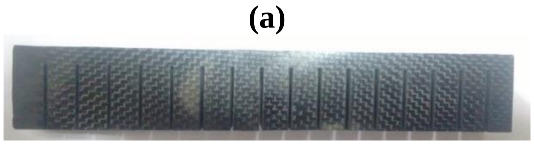


Fig. 2 Surface roughness tester (Model – Mitutoyo SJ-310)

Kerf widths are measured with the help of vision measurement system (Model – Sipcon SDM-TRZ 5300) as depicted in Fig. 4. The experimental design along with measured value of surface roughness and kerf taper angle are shown in Table 4. Machined samples of fibre vinyl epoxy composite for surface roughness and kerf taper angle are shown in Fig. 3 and Fig. 5. The size of machined samples is 20 mm×36 mm×300 mm.

Fig. 4.Vision measurement system

(a)



(b)

Fig. 5. Machined samples for kerf taper angle (a) top view (b) bottom view

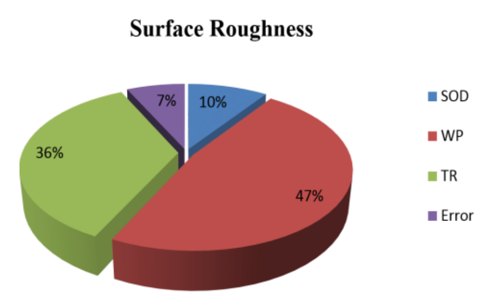
4. Results and Discussion

Influence of process parameters namely standoff distance (SOD), traverse rate (TR) and water pressure (WP) on response characteristics namely kerf taper angle and surface roughness are examined using Analysis of Variance (ANOVA). ANOVA is widely used statistical technique to measure the influence and percentage contribution of process parameters on response characteristics. Analysis is carried out at 95% confidence level. ANOVA for surface roughness and kerf taper as given in table 5.

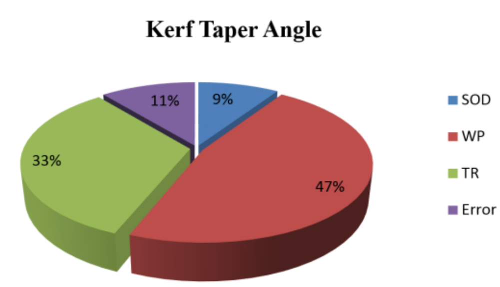
Table 5. ANOVA table for surface roughness and kerf taper angle

Parameters	DO F	Surface Roughness			Kerf taper angle		
		F	P	%P	F	P	%P
SOD	3	2.74	0.135	9.73	1.71	0.264	9.24
WP	3	13.40	0.005	47.49	8.64	0.013	46.79
TR	3	10.06	0.009	35.67	6.12	0.030	33.13
Error	6			7.09			10.83
Total	15						

Where DOF – Degree of Freedom, F – F value, P – P value, %P – Percentage contribution of respective parameters. It is found that percentage contribution of water pressure is highest for both response characteristics while percentage contribution of standoff distance is least among three process parameters.



(a)



(b)

Fig. 6. Percentage contribution of process parameters on surface roughness and kerf taper angle

Consequence of traverse rate lies between the effect of water pressure and standoff distance. Contribution of water pressure, traverse rate and standoff distance for surface roughness is 47.49%, 35.67% and 9.73% respectively and for kerf taper angle, it is 46.79%, 33.13% and 9.24% respectively. Figure 6 (a) and (b) shows percentage contribution of each parameter on surface roughness and kerf taper angle.

5. Conclusion

In the present study, the influence of four process parameters namely water pressure, stand-off distance and traverse rate for machining of carbon fibre vinyl ester composite with AWJM has been investigated. It is found that water pressure and traverse rate are significant process parameters influencing surface roughness and kerf taper. Surface finish improves and kerf taper decreases with increase in water pressure and decrease in traverse rate.

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