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EXPERIMENTAL STUDY OF ABRASIVE WATER JET MACHINING OF KEVLAR EPOXY COMPOSITE

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ABSTRACT

The present paper describes an experimental study of abrasive water jet machining (AWJM) of Kevlar epoxy composite. Influence of process parameters namely stand-off distance, water pressure, traverse speed and abrasive mass flow rate on surface roughness and kerf taper is investigated. Taguchi orthogonal approach is applied to plan the design of experiments; and subsequent analysis of experimental data is done using analysis of variance (ANOVA). It is found that water pressure and traverse speed are most significant parameters followed by stand-off distance and abrasive mass flow rate influencing surface roughness and kerf taper. With increase in water pressure and decrease in traverse speed, kerf taper and surface roughness decreases.

Key words: *Abrasive Water Jet Machining, Kevlar Epoxy Composite, Water Pressure, Traverse Speed, Kerf Taper and Surface Roughness.*

1. Introduction

Kevlar epoxy composite which is known as aramid fiber reinforced composite is an extremely strong and light weight composite these composite known for their superior performance. It is widely used for making life jackets for army soldier, sports goods, sports shoes, gloves etc. Conventional cutting techniques in Kevlar epoxy composite are possible but it results in to impermissible kerf properties, fibre pullout, delamination and surface damage etc. [1]. Abrasive water jet machining (AWJM) is a most popular process amongst the latest non-conventional machining methods being utilized for machining of composite materials. AWJM is widely used to cut wide variety of materials, ranging from metals to non-metals such as composites, alloys, glass, ceramics, granite and marble. In AWJM process, machining of work piece material takes place when a high speed water jet mixed with abrasives impinges on it. AWJM process is characterized by various process parameters including stand-off distance, water pressure, traverse speed, abrasive mass flow rate, type of abrasive, size of abrasives and nozzle diameter. While machining with AWJM, major challenges are to minimize kerf taper and surface roughness of machined work piece. In AWJM kerf taper is the one most important output characteristics to be addressed. Formation of kerf taper during AWJM cannot be eliminated due to the inherent characteristics of water jet. The water jet diverging from the nozzle may be converging or diverging in nature. Due to this factor it is

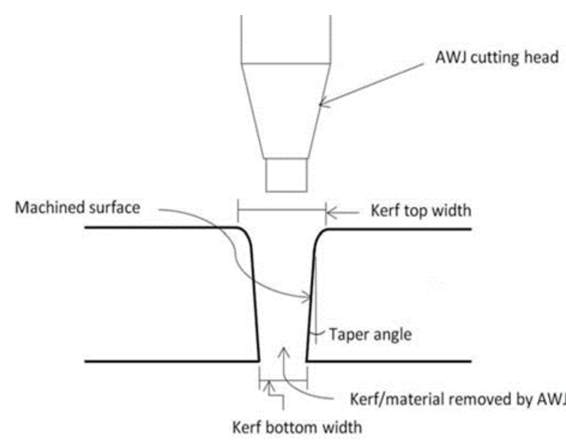

Fig. 1 Kerf taper generated by AWJM

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impossible to form a straight cut in AWJM. Kerf taper generated by AWJM is shown in Fig. 1.

Worldwide researchers have studied AWJM of various composite materials including graphite epoxy, glass epoxy, ceramic matrix and natural fibre composite materials to improve kerf properties and surface quality. For example, Arora and Ramulu [2] studied the kerf characteristics of abrasive water jet (AWJ) machined graphite epoxy composite. It was found that entry kerf width was more affected by standoff distance as compared to exit kerf width. Saleem et al [3] investigated machinability of polymer matrix composites under AWJM. The mathematical models are developed to find out the influence of process parameters namely transverse speed, water pressure and standoff distance on kerf geometry. Lemma et al [4] studied oscillation cutting and normal AWJ cutting of glass fibre reinforced polymer composite. They concluded that there was a significant reduction in surface roughness produced by oscillation than normal cutting. Azmir and Ahsan [5] investigated the surface of glass epoxy composite machined by AWJM. It was identified that the quality of cut can be improved by increasing abrasive hardness and water pressure. Further, they studied the influence of hydraulic pressure, type of abrasive material, stand-off distance (SOD) and traverse speed on the surface roughness and kerf taper of GFRP laminate machined by AWJM. It was found that the roughness and kerf taper decrease with increase in water pressure and hardness of abrasives.

Çaydaş and Hascalık [6] reported that the quality of machined surface is improved with increase in water pressure. Azmir and Ahsan [7] examined the effect of AWJM parameters on kerf taper and roughness of aramid fiber reinforced plastic composite. They concluded that kerf taper and surface roughness decrease with increase in water pressure and decrease in SOD and traverse speed. Cosansu and Cogun [8] studied the cutting process outcomes of AWJM such as surface roughness, surface waviness and kerf-taper angle using colemanite powder as abrasive in AWJM with variable abrasive flow rate and traverse speed. It was concluded that kerf tape angle, surface roughness and surface waviness increase with increase in traverse speed. Alberdi et al [9] studied the influence of process parameters of AWJM on CFRP and GFRP composites. It was observed that with the increase in traverse speed, surface quality deteriorates. Karakurt et al. [10] studied the influence of process parameter of AWJM on kerf width while machining granite. It was concluded that small SOD and high traverse speed are preferred for narrow kerf widths. Dhanawade et al .[11] investigated the effect of abrasive flow rate, traverse speed, abrasive mass flow rate, SOD and water pressure of AWJM on carbon epoxy composite. It was concluded that with the increase in water pressure and decrease in traverse speed, kerf taper and surface roughness decreases. Sasikumar et al [12] studied the effect of abrasive water jet machine on kerf taper angle of hybrid aluminum 7075 metal matrix composites. It was found that water pressure is inversely proportional to the kerf taper angle. Vigneshwaran et al [13] studied machining performance of AWJM on the fiber-reinforced composites. It was concluded that with increase in water pressure and decrease in traverse speed, machining surface improves.

Critical review of literature reveals that the research efforts have been made to study AWJM of various composite materials to improve kerf properties and surface quality of machined parts. But very less work has been reported on AWJM of Kevlar epoxy composite. The present experimental work is focused on studying the influence of AWJM process parameters on surface roughness and kerf taper of machined parts of Kevlar epoxy composite. Subsequent sections of this paper describe experimental work, results and discussion, and concluding remarks.

2. Experimental Work

In the present work, Kevlar 49 epoxy composite material is machined by a computer controlled flying arm AWJ machine. The composite material is prepared at M/s Ahmedabad Textile Industries Research Association (ATIRA), Ahmedabad, India by using Kevlar 49 as reinforcement and epoxy resin as matrix. This epoxy resin work as a hardening agent as well as bonding material. The final size of work piece material is 300 mm × 300 mm × 14 mm. The mechanical properties of work piece material are given in Table 1.

Table 1 Mechanical Properties of Kevlar 49 Epoxy Composite

Property	Value
Volume fraction of Kevlar fiber	70%
Tensile modulus -in plan	18.03GPa
Tensile strength-in plan	428.44MPa
Compressive strength - in plan	59.42MPa
Compressive modulus	5.05 GPa
Shear strength-in plane	22.720N/mm^2
Density	1.44 gm/cm
%Elongation (%)	5.59

The AWJM machine is fitted with automatic abrasive filling system (hoper) along with abrasive metering system and a high-pressure pump with maximum pressure up to 300 MPa. Water pressure is controlled by dial indicator. The positional and repeat accuracy of the machine is ± 0.05 mm. Garnet is used as abrasives with mesh size # 80. The levels of process parameters namely water jet pressure, traverse speed, stand-off distance and abrasive mass flow rate are selected based on literature review and available AWJM setup. The levels are given in Table 2. Some other parameters which are kept constant during experimentation including orifice diameter, nozzle diameter, focusing length and impact angle are 0.25mm, 70mm, 0.76mm, and 90^0 respectively.

Table 2 Levels of process parameters

Process parameter	Level 1	Level 2	Level 3	Level 4
Standoff distance (SOD) (mm)	1	1.5	2	2.5
Water jet pressure (P) (MPa)	150	165	180	195
Traverse speed (TS) (mm/min)	50	100	150	200
Abrasive mass flow rate (AMFR) (g/min)	200	300	400	500

In the present work, the Taguchi approach-Orthogonal arrays is used to plan the experiments and subsequent analysis of the collected data. Total 16 number of work piece samples of thickness 14 mm are machined using AWJM. Machined work piece samples are shown in Fig. 2.

Fig. 2 Machined work piece samples of Kevlar epoxy composite

Response characteristics namely surface roughness and kerf taper of machined samples are measured using surface roughness test and vision measurement system respectively.

Surface roughness tester (Model -Mitutoyo SJ-210) is shown in Figure 3. The cut off length for measurement is set as 0.8mm and total sampling length as 4 mm. Traverse speed of the stylus on the work piece is kept as 0.5 mm/s throughout the measurement of surface. For measuring the roughness value, stylus is traversed in horizontal direction of the work piece. Surface roughness is measured at three regions (top, middle and bottom) of machined samples and average surface roughness is considered for analysis.

Fig. 3 Surface roughness tester (Model -Mitutoyo SJ-210)

Kerf widths of machined surfaces are measured using vision measurement system (Model- Sipcon SDM-TRZ 5300) as shown in Fig. 4. In this measurement process, video edge detection with pointer is used for selecting point on cut edge with active crosshair**.**

Fig. 4 Vision measurement system (Sipcon SDM-TRZ 5300)

The L_{16} design of experiments along with measured values of kerf taper and surface roughness are given in Table 3.Analysis of variance (ANOVA) has been done using Minitab software to find out the significant process parameters

Table 3 L_{16} design of experiments and measured values of surface roughness and kerf taper

Expt. No.	SOD (mm)	P (MPa)	*TS (mm/min)*	AMFR (g/min)	Surface roughness (R_a) μm	Kerf taper angle (degree)
1.	1	150	*50*	200	0.788624	0.2234
2.	1.5	150	*100*	300	0.661828	0.2818
3.	2	150	*150*	400	0.864099	0.4468
4.	2.5	150	*200*	500	0.889066	1.167
5.	1	165	*100*	400	0.638529	0.0793
6.	1.5	165	*50*	500	0.603703	0.0438
7.	2	165	*200*	200	0.748303	1
8.	2.5	165	*150*	300	0.737326	0.3445
9.	1	180	*150*	500	0.56265	0.3278
10.	1.5	180	*200*	400	0.565085	0.5391
11.	2	180	*50*	300	0.503132	0.0584
12.	2.5	180	*100*	200	0.546641	0.0751
13.	1	195	*200*	300	0.6306	0.5662
14.	1.5	195	*150*	200	0.445001	0.1294
15.	2	195	*100*	500	0.406645	0.0981
16.	2.5	195	*50*	400	0.339166	0.0041

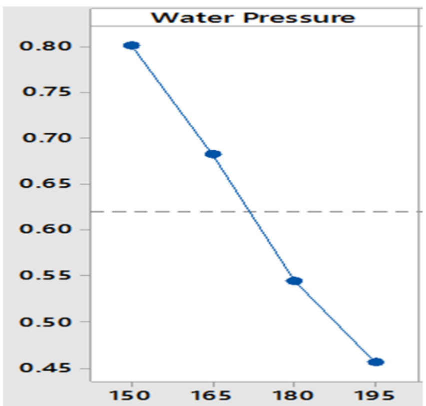
3. Results and Discussion

After experimentation, ANOVA is performed to identify the significant variables and to quantify their effects on the response characteristics. Table 4 depicts the ANOVA for kerf taper and surface roughness. The analysis is carried out at 95% confidence level. As depicted in Table 4, major process parameters which influence kerf taper and surface roughness are traverse speed and water pressure. The percentage contribution of these two parameters is 46.90 and 44.49 respectively. Influences of other two parameters namely stand-off distance (SOD) and abrasive mass flow rate (AMFR) is negligible.

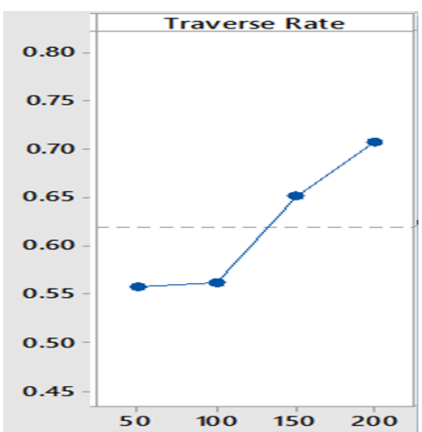
The effect of process parameters on response characteristics (i.e.kerf taper andsurface roughness) are depicted in Fig. 5 and Fig. 6.

Table 4 ANOVA table for kerf taper and surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%P
Water jet Pressure	3	79.549	79.549	26.5164	73.23	0.003	44.49
SOD	3	3.980	3.980	1.3268	3.66	0.157	4.08
Traverse speed	3	81.825	81.825	27.2749	75.32	0.003	46.90
AFR	3	2.515	2.515	0.8384	2.32	0.254	1.61
Residual Error	3	1.086	1.086	0.3621			2.89
Total	15	168.956					100

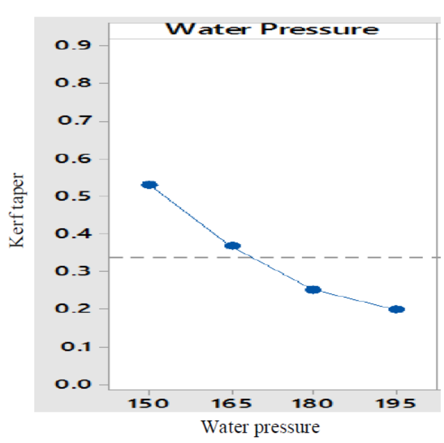


(a)

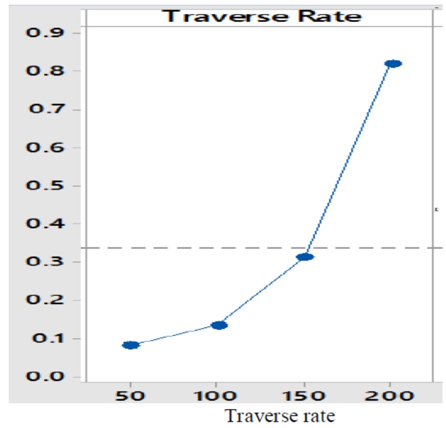


(b)

Figure 5 (a) Effect of water pressure on surface roughness, (b) Effect of traverse rate on surface roughness



(a)



(b)

Fig. 6 (a) Effect of water pressure on kerf taper, (b) Effect of traverse rate on kerf taper

As depicted in Fig. 5, the surface roughness (R_a value) decreases with increase in water pressure and decrease in traverse speed. With increase in water pressure, kinetic energy of abrasive-water jet (AWJ) increases. This increased kinetic energy results in machining of surface with minimum roughness. Besides this the increase in water pressure causes fragmentation of abrasives. AWJ with small size abrasives also helps in machining with minimum roughness. With decrease in traverse speed, more number of abrasives strike on lesser area of work piece surface which results in decrease in surface roughness

As shown in Fig. 6, kerf taper decreases with increase in water pressure and decrease in traverse speed. With increase in water pressure, kinetic energy of AWJ also increases and the jet cuts the bottom part of kerf effectively. It results in minimum kerf taper. Decrease in traverse speed causes more overlapping of machining action and more abrasive particles strike on the work piece surface. It results in decrease in kerf taper

To examine the microscopic features of AWJ machined surfaces, two work piece samples are machined by using the following set of process parameters

P - 195 MPa, TS – 50 mm/min, AMFR – 400 g/min, SOD - 2.5 mm,

P – 150 MPa, TS – 200 mm/min, AMFR- 500g/min, SOD - 2.5 mm.

Thereafter, machined surfaces of work piece samples are examined by the scanning electron microscope (SEM) as shown in Figure 7 (a) and 7 (b). By using the first set of process parameters, a smooth machined surface is obtained without fibre-pull off, and abrasives embedment. The surface roughness (R_a value) of AWJ machined samples varies from 4.381 to 7.468 μm.

The above work piece samples are also machined by conventional machining (diamond edge cutter). SEM images of work piece samples machined by diamond edge cutter are shown in Fig. 8 (a) and 8 (b). It is found that the surface roughness (R_a value) of these samples varies from 12.434 to 14.342 which are comparatively higher than that of sample surfaces machined by AWJM. Another observation is that fibres are fractured with matrix pull out in machining; and damages are observed on whole machined surface of samples cut with diamond edge cutter. However in AWJM, damages take place only at the bottom region of machined surface.

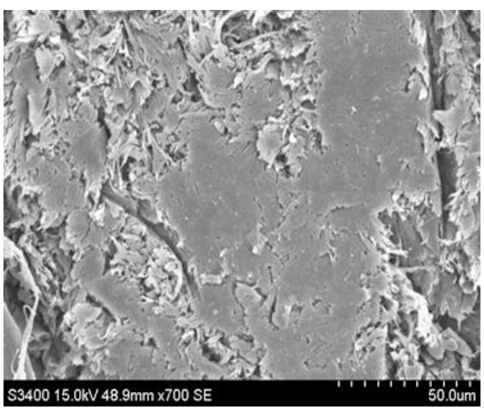


Fig. 7a. SEM of AWJ machined surfaces of work piece (vertical surface at 700 SE)

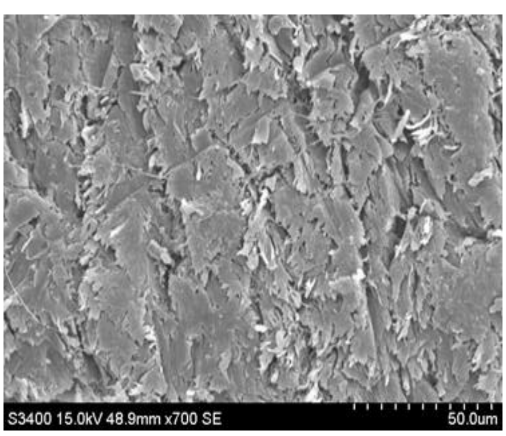


Fig. 7b. SEM of AWJ machined surfaces of work piece (vertical surface at 700 SE)

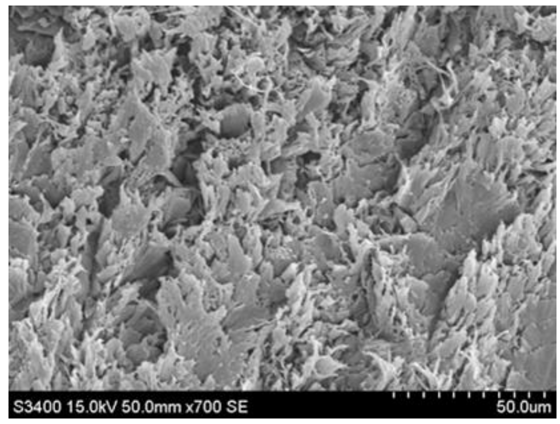


Fig. 8a. SEM of diamond edge cutter machined surfaces of work piece (vertical surface at 700 SE)

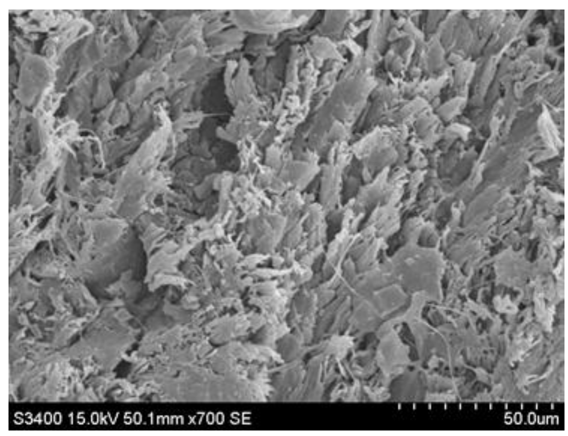


Fig. 8b. SEM of diamond edge cutter machined surfaces of work piece (vertical surface at 700 SE)

4. Conclusions

In the present experimental work, influence of process parameters namely stand-off distance, water pressure, traverse speed and abrasive mass flow rate on surface roughness and kerf taper in AWJM of Kevlar epoxy composite has been studied. The followings are the findings of present study.

(i) Water pressure and traverse speed are dominant factors influencing both the response characteristics i.e.kerf taper and surface roughness.

(ii) With increase in water pressure and decrease in traverse speed, kerf taper and surface roughness decrease.

Further, microscopic features of AWJ machined samples are examined by using scanning electron microscope (SEM). It was found that with high water pressure and low traverse speed, smooth surface is obtained having less kerf taper. AWJ machined surfaces of work piece samples are having good surface finish with less defects as compared to conventional machining method (i.e. diamond edge cutter).

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