Abrasive Water Jet Machining Studies on Kenaf/E-Glass Fiber Polymer Composite

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Abstract

The aim of the present work is to synthesis Kenaf/E-glass fibers reinforced hybrid polymer composite and assesses its machinability through Abrasive Water Jet Machining (AWJM) process. The polymer matrix composite (PMC) was synthesized using kenaf and E-glass fibers reinforcement with bisphenol resin polymer matrix. Combination of hand layup and cold press molding method are used to process the composite plate of 1feet x 1feet x 10mm. Machining is a process used to make the processed composite in to a real product. But conventional machining of PMC leads various fractures like peel out, pull out, rupture, delamination etc. Hence, AWJM is the most suitable process used for machining of PMCs. AWJM was carried out on fabricated composite with 16 cuts of length 10mm by varying parameters namely, Water jet Pressure, Abrasive flow rate, Standoff distance (SOD) and Traverse rate as per Taguchi's L_{16} array. Top and bottom Kerf width were measured and average kerf readings were calculated. The surface roughness (Ra) of machined surfaces was measured and micro-structure of best and worst surfaces were analyzed. From the experimental results, it was found that, Ra values were varied from 3.141 to 6.538μm and Kerf width varied from 0.205 to 0.575mm. The optimized AWJM parameters have been obtained for getting minimum Ra of 3.254μm and minimum kerf width of 0.255mm for the parameter combination of water jet pressure: 255MPa, abrasive flow rate: 0.275kg/min or 4.6g/sec, SOD: 1.9mm and traverse speed of 0.26mm/min.

Keywords: Kenaf/E-glass fiber polymer composite, AWJM studies, Taguchi's L_{16} orthogonal array, Surface roughness, Kerf width.

1. INTRODUCTION

Polymer matrix composites (PMCs) are composite materials consisting of polymers (resin, Bisphenol, unsaturated polyester) combined with fibers (fiberglass, graphite, glass-kenaf hybrid, etc.) reinforcements in the form of laminates. Natural fiber composites are often poorer in properties, mostly mechanical, compared to synthetic fiber composites. A possible solution to this issue is the use of natural fiber/synthetic fiber combination in polymer hybrid composites. Although the biodegradability of the composites is compromised by synthetic fibers, this is compensated by the improvement in their mechanical and physical properties. Hybrid composites use more than one kind of fibers in the same matrix and the idea is to get the synergistic effect of the properties of both fibers on the overall properties of composites. There has been a significant increase in research on natural fiber/synthetic fiber hybrid composites in recent years. Some studies, however, have been done on hybridization of natural fibers with the more expensive carbon and aramid fibers. The natural fibers mostly used in these studies are hemp, jute, coir, flax, sisal, and ramie. Conventional thermosets and thermoplastics and biodegradable polymers have been used as matrix material for these composites. There is a considerable improvement in mechanical properties of these composites following hybridization, especially when synthetic fiber plies are used as skin and natural fiber plies are used as core. Hybrid composites can be designed by the combination of a synthetic fiber and natural fiber (biofiber) in a matrix and a combination of two natural fiber / biofiber in a matrix. Hybridization with glass fiber provides a method to improve the mechanical properties of natural fiber composites and its effect in different modes of stress depends on the design and construction of the composites.

Machining is a secondary manufacturing process which is used to make the processed composite in to a real product with correct shape, size, accuracy and build assemblies. But conventional machining of PMCs leads various fractures like fibers peel out, pull out, rupture, delamination, etc. Among different machining processes, abrasive water jet machining (AWJM) is the most suitable machining process used for machining of PMCs since it does not cause chatter, has no thermal effects, impose minimal stresses on the workpiece, and has high machining versatility and high flexibility. AWJM is a nonconventional machining process where material is removed by impact erosion of high pressure high velocity of water and entrained high velocity of grit abrasives on a work piece. AWJM was developed in 1974 to clean metal prior to surface treatment of the metal. Addition of abrasives to water jet enhanced MRR and produced cutting speeds between 51 and 460 mm/min. Generally, AWJM cuts 10 times faster than the conventional machining methods of composite materials. It has been found that the abrasive water jet is hundreds of times more powerful than the pure water jet. From the year 2000 onwards, AWJM is used to cut PMCs, granites, wood, metal matrix composites (MMCs), ceramics, etc. Lemma et al. [1] used AWJM with oscillating head for cutting glass fiber reinforced polymer (GFRP) composite. They found that The improvements in surface quality (more than 20% than normal AWJM) was better when high values of the frequency of oscillation and angle of oscillation are used. Azmir and Ahsan [2] did experimental studies on AWJM of glass/epoxy composite laminate. They concluded that high hydraulic pressure and Al_2O_3 abrasive were identified as the best

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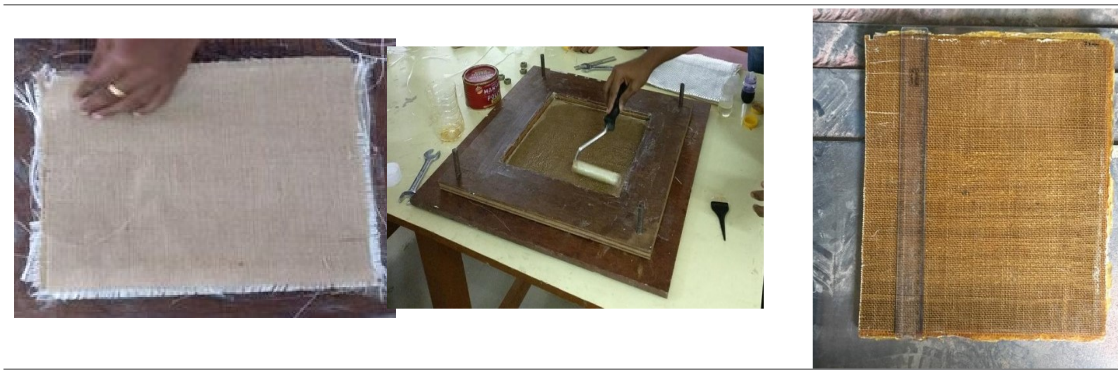

Fiber hand laying | Spreading of resin on the mould cavity | Final PMC laminate~300x300x10 mm

Fig. 1. Stages of PMC preparation

condition for getting high surface finish and low kerf. Comparative study of various processes for cutting cotton fiber polyester composite was attempted by Shaikh and Jain [3] using CO_2 laser, water jet and diamond saw cutting. Their conclusion was Laser cutting is better over water jet cutting and diamond saw cutting. Kalla et al. [4] carried review on AWJM of Fiber Reinforced Composites. They discussed briefly on effect of cutting parameters on surface quality and kerf along with modelling of AWJM process parameters and kerf geometry prediction. In the year 2013, a study of the effect of the AWJM process parameters on the quality of cut was carried out on Carbon FRP (CFRP) [5]. Deepak Doreswamy et al. [6] Investigated AWJM on Graphite/Glass/Epoxy composite and concluded that the kerf width increased with an increase in operating pressure and standoff distance. But kerf decreased with increase in feed rate. Recently in 2017, Karunamoorthy et al. [7] from Anna university carried a investigation on performance of abrasive water jet in machining hybrid composites (E-glass+carbon fiber with Epoxy resin). They identified optimal cutting parameters for getting minimum kerf and surface roughness. From the literature, it is observed that machining of polymer based composites by AWJM is immature stage and still it is a continuing problem to minimize the kerf, taper, delamination, surface finish, particle or fiber pull out. Hence the present the study investigates the effect of AWJM parameters on kerf and surface roughness of Kenaf/E-glass fiber with polyester resin matrix polymer composite.

2 EXPERIMENTAL DETAILS

2.1 PMC preparation

The detailed procedure used to make PMC laminate is given below. A combination of hand lay-up and cold press method was used in the fabrication of the composites laminates.

Three kenaf fibers were arranged inside the mold and layered by fiber E-glass in a sandwich pattern. Two mats of fiber glass with size of 300 mm x 300 mm used in each layer. The fiber glass was put in upper and lower part of a composite laminate. The matrix material was prepared from the unsaturated polyester resin and the accelerator at the weight ratio of 100 to 2 and stirred. The polyester matrix was poured onto the Kenaf and glass fibers in the mould and spread to the entire area. The fiber is placed over that area and the resin is poured with correct proportion and spread. Once the fibers are placed inside the mould, top portion of the mould is placed above it and covered and cold press method (10kN load) was applied to the laminate at room temperature to ensure the specimen has no air bubble and also the homogeneity of the specimen. Finally, the specimen was removed from the mold after 24 hours curing to ensure the specimen was hard. Nowadays, Kenaf/E-Glass Fiber polymer composite is used in car tire, ceiling, wall profiles, etc.. Figure 1 shows the different stages of PMC preparation.

2.2 AWJM

A computer numerical control (CNC) AWJ Machine (MAXIEM 1530, USA) was used to machine the fabricated laminate in the experiment. Figure 2 shows the experimental setup with laminate. Garnet (silicate mineral- $X_3Y_2(SiO_4)_3$-X -- Mg, Y - Al) abrasives with 150 to 170 micron size were used as abrasive. 16 cuts/slots were carried out with length of 10mm by varying the controllable parameters using Taguchi L_{16} orthogonal array and is shown in figure 3. Figure 3 (b & c) shows the comparison between saw cutting and AWJ machined surface in which figure 3b shows smooth surface.

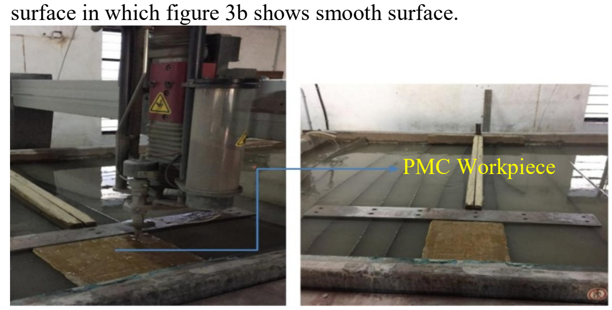

Fig. 2. AWJM setup

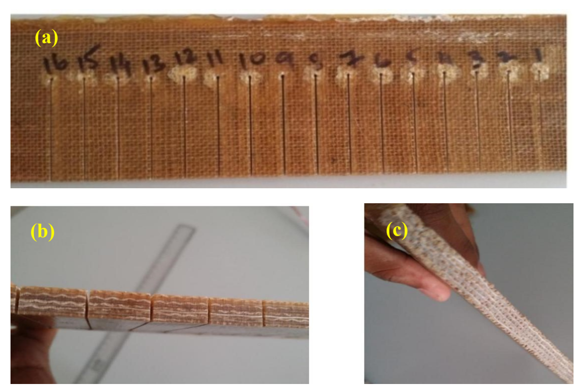

Fig. 3. (a) 16 cuts using AWJM (b) AWJM cutting (c) Saw cutting

After machining, surface roughness (Ra) value of the machined surfaces were measured using Mitutoyo surftest SJ210 model having stylus diameter of 5 µm and kerf was measured using profile projector (Figure 5.a and 5.b). Average of 3 Ra and kerf values are taken and considered for further analysis.

2.3 Experimental design

Four AWJM parameters were selected as controllable factors and are listed on table 1. Parameters levels and values were taken from literature [2].

Table 1. AWJM parameters and their levels

AWJM parameters	Level 1	Level 2	Level 3	Level 4
Jet pressure (MPa)	227	241	255	269
Abrasive flow rate (g/sec)	4.4	4.5	4.6	4.7
Stand-off distance (mm)	1.5	1.9	2.3	2.7
Traverse speed (mm/min)	0.24	0.26	0.28	0.30

3. RESULTS AND DISCUSSIONS

Experimental results are shown in Table 2.

3.1 Effect of AWJM parameters on kerf

Water jet pressure: From figure 4.a, it is observed that kerf width decreased with increase in water jet pressure. This is due to the influence of increased kinetic energy (KE) on increasing pressure cuts the material and flow turbulence of the water jet at a higher pressure [8]. Further, as the jet proceeds through the fibers filled glass resin polymer composite, it loses part of its KE. Also, the abrasive particles impacting on the surface lose their sharpness and few abrasive particles penetrate into the surface while few other particles retard towards the top surface.

Abrasive flow rate: Figure 4.b shows the effect of abrasives flow rate on kerf width. At lower flow rate, larger number of abrasive particles participate in the cutting action and hence produce wider kerf. As the feed is increased, less number of abrasive particles participate in cutting action and tend to reduce the possibility of interaction of rebounding of particles on machined surface. Hence, kerf width reduced with increase in abrasive flow rate [2].

Stand-off distance (SOD): Figure 4.c represents the effect of SOD on kerf width. Increase in SOD results in slight increase in kerf widths. As the jet is discharged through the nozzle, expansion and disintegration of the jet takes place due to outside boundary interaction. This leads to increase in top kerf width [9]. The jet expansion increases with increase in the distance of jet traverse in air after ejecting from nozzle. Higher jet expansion leads to increase in kerf width and also higher loss of jet kinetic energy. Hence, at higher SOD, the machining capability of the jet also decreased.

Traverse speed: From figure 4.d, it is evident that the kerf width decreased slightly with increase in traverse rate. The reason is that high traverse rate causes less overlapping of machining action and less abrasive particles to impinge on the work piece surface which reduced the cutting ability of jet [9].

3.2 Effect of AWJM parameters on surface roughness

Water jet pressure: The Ra decreased with increase in jet pressure (Fig. 5.a). The reason is that the increase in pressure caused increase in particle velocity at nozzle exit and particle fragmentation inside the nozzle. This fragmentation reduces the size of impacting particle. Also an increase in pump pressure increases abrasive water jet KE and enhances their capability for material removal with minimum roughness [2].

Table 2 Experimental results using L_{16} Orthogonal array

S. No	Water Jet Pressure (MPa)	Abrasive flow rate (kg/min)	stand-off distance (mm)	Traverse speed (mm/min)	Surface roughness (µm)	Kerf (mm)
1	227	4.4	2.7	0.3	3.612	0.54
2	227	4.5	2.3	0.3	3.266	0.28
3	227	4.6	1.9	0.3	4.756	0.56
4	227	4.7	1.5	0.3	5.549	0.24
5	241	4.4	2.7	0.28	6.312	0.535
6	241	4.5	2.3	0.28	5.334	0.25
7	241	4.6	1.9	0.28	6.538	0.475
8	241	4.7	1.5	0.28	5.512	0.535
9	255	4.4	2.7	0.26	5.721	0.24
10	255	4.5	2.3	0.26	3.739	0.205
11	255	4.6	1.9	0.26	3.254	0.255
12	255	4.7	1.5	0.26	4.244	0.245
13	269	4.4	2.7	0.24	3.298	0.575
14	269	4.5	2.3	0.24	4.316	0.49
15	269	4.6	1.9	0.24	3.141	0.305
16	269	4.7	1.5	0.24	3.168	0.485

Abrasive flow rate: In case of abrasive mass flow rate, the higher the abrasive mass flow rate, the higher the number of particles involved in the mixing and cutting processes. An increase in abrasive mass flow rate leads to a proportional increase in the depth of cut. When the abrasive mass flow rate is increased, the jet can cut through the laminate easily and as a result the cut surface becomes smoother with less Ra value [2].

Stand-off distance: Increase in SOD decreased the surface finish ((Fig. 5.c). If SOD is increased, the process will no longer cut but will efficiently clean and de-scale surfaces. Generally, higher stand-off distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment. Therefore, increase in the standoff distance results an increased jet diameter as cutting is initiated and in turn, reduces the kinetic energy density of the jet at impingement. It is desirable to have a lower standoff distance to produce smoother surface [2].

Traverse speed: With increase in traverse rate, there is less overlapping of machining action and also reduced number of abrasive particles to impinge on surface [2]. It results in increase in surface roughness (Fig. 5.d).

Optimum AWJM conditions: Optimum AWJM parameters have been obtained from 11^{th} exp. for getting minimum Ra of 3.254µm and kerf width of 0.255mm for the parameter combinations of water jet pressure: 255MPa, abrasive flow rate: 4.6g/sec, SOD: 1.9mm and traverse speed of 0.26mm/min.

Microstructure of machined surface: Figure 6 shows the optical micrographs of machined surfaces (500 X) with 3 different cutting conditions. Fig. 6(a) is shows low Ra (from 15^{th} exp.) in which WJ pressure is high and shine surface is observed without fibers protrusion/deflection. Figure 6.b and 6.c shows the surfaces of high roughness. This is because of low AWJ pressure, abrasive flow rate with more SOD. In these conditions, the jet is unable to cut a hard component of fiber reinforced in the matrix and fiber could be deflected and eroded the matrix which is the soft components of the material.

As a result, the typical appearance of matrix washout and protruding fibers with deflection can be seen clearly especially in case of figure 6(b) where there is a lack of KE of the jet. This caused the fiber pullout and greater disruption in the plies. Figure 6(c) shows higher amount of fiber pullout indicated by white region compared to Figure 6(a) and this contributes to a rougher surface.

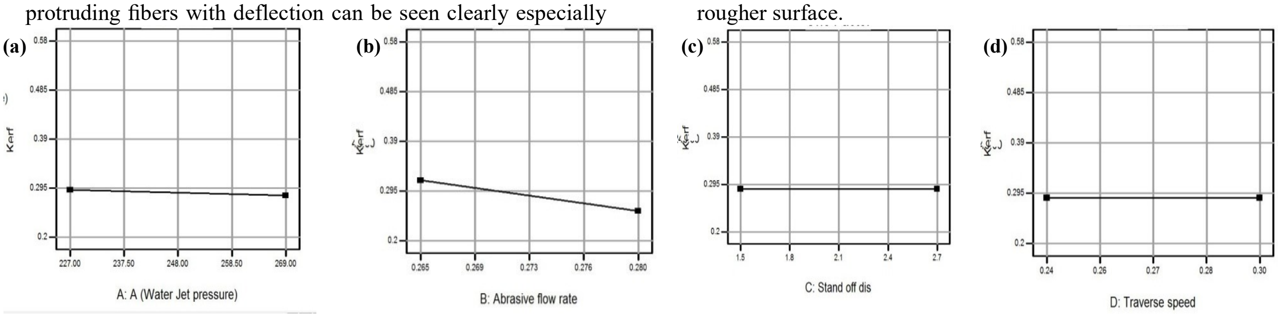

Fig. 4. Effect of AWJM parameters on kerf width

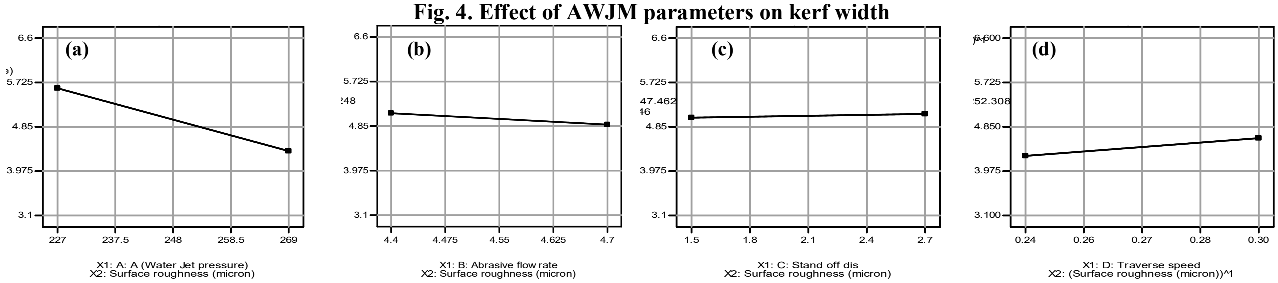

Fig. 5. Effect of Water Jet Pressure on Surface Roughness

4. CONCLUSIONS

- Hand lay-up and cold press methods are used to make hybrid Kenaf/E-Glass Fiber + polyester resin PMC laminate and was effectively cut using AWJM.
- Abrasive water jet pressure and abrasive flow rate are most significant parameters to control surface roughness and kerf.
- Kerf width decreased with increase in water jet pressure, abrasive flow rate and traverse rate. Increase in water jet pressure and abrasive flow rate decreased the surface roughness value.

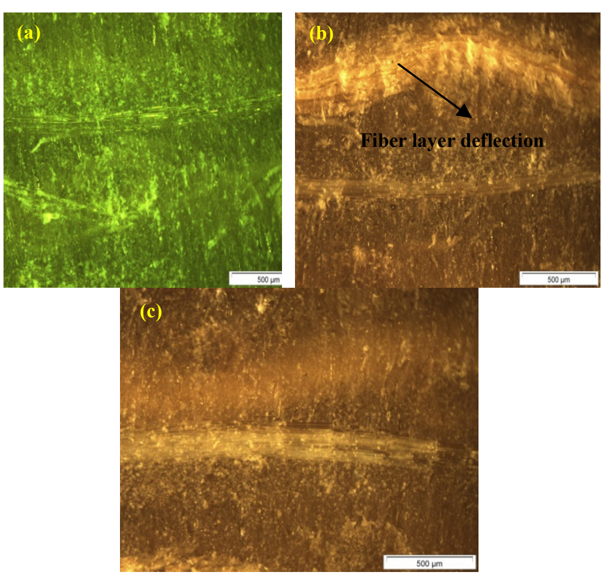

Fig. 6. Microstructure of machined surfaces: (a) Low Ra (b) Medium Ra (c) High Ra

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