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An Experimental Investigation of AWJ Parameters on Banana Fiber Reinforced Composite

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Abstract- **Machining of natural fiber composite using abrasive waterjet has been proven better technology over other non-conventional processes nowadays. Identification and control of key factors is very essential for obtaining quality of machined component. The present investigation deals with developing banana fiber reinforced composite using general-purpose polyester resin and carrying abrasive waterjet cutting on composite plate. The surface roughness (R_a) and kerf tapper ratio (T_R) parameters are focused during abrasive water jet machining. Full factorial design of experiments is applied to determine influence of machining parameters such as hydraulic pressure (P), traverse speed (S) and standoff distance (D) on output response R_a and T_R. It is observed that surface roughness (R_a) and taper ratio (T_R) are reduced by increasing the hydraulic pressure. It is also observed that traverse speed and standoff distance are significant parameters for output response. It is felt that increase in traverse speed and standoff distance leads to increase in both R_a and T_R increases.**

Key words- Banana fiber reinforced composite, water jet machine, polyester resin, surface roughness, Standoff distance.

I. INTRODUCTION

In a recent era, the uses of natural fiber composites are getting much more attention in structural, construction and automotive applications [1]. A natural fiber enjoys many advantages compared to glass fibers, for example they have low density, recyclability and biodegradability. Additionally, they are renewable raw materials and have relatively high strength and stiffness. Their low density values allow producing composites that combine good mechanical properties with a low specific mass [2]. Banana fiber at present is a waste product of banana cultivation. Hence, without any additional cost input, banana fiber can be utilized for industrial application. Composite materials are replacing conventional materials in so many fields due to their lightweight and easy processing, but the use of natural fiber is also alternative for synthetic reinforcements [3].

Natural fibers such as cotton, jute, banana, bamboo, wood and pineapple leaf fiber have enough properties, which could be used in automotive applications, construction as well as in packaging industries with few disadvantage [4-7]. In India about 1.5 million acres of land is cultivated with banana farming, which yield about 3 x 10^5 tons of fiber [8].

Nowadays, abrasive waterjet machining technology is widely used by manufacturing industries for cutting of variety of materials like glass, cast iron, titanium alloy and composite materials. The abrasive waterjet machine consisting various machining parameters such as hydraulic pressure, jet traverse speed, standoff distance, abrasive mass flow rate and abrasive size can be adjusted to influence the depth of cut and surface quality of the cut material [9]. Chen et al. (1996) have investigated kerf characteristics of alumina-based ceramics for determination and optimization of abrasive waterjet cutting performance [10]. Arola and Ramulu (1996) have studied the kerf geometry, kerf wall features and cutting front characteristics of machining of graphite/epoxy composites by abrasive waterjet [11]. Most of such studies are limited to specific material and not applicable for dissimilar materials. The machining of composite such as drilling of FRP causes more wear of the drill compared to drilling on conventional materials due to heterogeneity of the work material, which leads the drill bit to experience variable forces resulting in damage of work material such as delamination, fiber pull out and poor hole quality [12]. Owing to these limitations of conventional machining processes, alternative techniques that utilize non-conventional energy sources for material removal such as electrical discharge machining (EDM), laser cutting, ultrasonic machining, water jet and abrasive water jet machining has attracted much interest and has been studied the viability of the processes [13]. Among these non-conventional machining processes, abrasive water jet machining is widely used method in industry today for trimming fiber reinforced composite materials as laser machining suffers from the problem of a large heat-affected zone, while EDM suffers from extremely low cutting rates [14]. Machining of natural fiber composite cannot be done

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by laser cutting as fiber gets burnout due to high heat generation. There are numerous associated parameters and factors of AWJM process that can influence the surface quality of the AWJ machined surfaces [15]. It has various different advantages over other cutting and machining technologies, such as the ability to cut almost all materials, ability to conduct multi-directional machining, absence of both a heat-affected zone and thermal distortion [16]. An abrasive waterjet machine consist: booster pump, ultrahigh pressure generation system, gravity feed abrasive delivery system, catcher, cutting head with nozzle and orifice as demonstrated in Fig. 1. Booster pump increase the pressure up to 8 bars from the atmospheric pressure. The supply of water to intensifier which produce pressure up to 300MPa as hydraulic energy of oil transferred to water as ratio of cross-sectional areas of two cylinders is different.

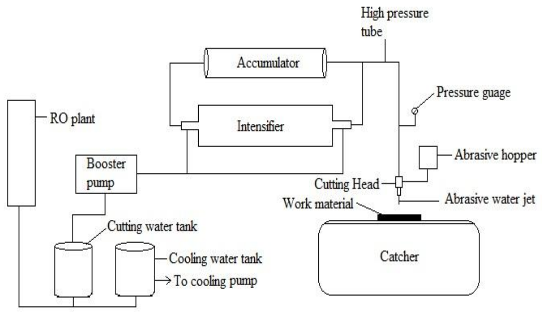

Fig. 1. Schematic diagram of an abrasive waterjet cutting system

The area of AWJ machining is very interesting for natural fiber reinforced composite. Therefore, in continuation of this research, banana fiber reinforced composite is produced using general-purpose polyester resin. The quality of machining is focused by, surface roughness (R_a) and kerf tapper ratio (T_R) during abrasive water jet machining. The experiments are planned using full factorial design of experiments to determine influence of machining parameters on R_a and T_R.

II. EXPERIMENTAL METHODOLOGY

2.0 General

Unsaturated polyester resin of grade ECMALON 4411 was purchased from S.K. Enterprises and the banana fibers were obtained from Man-Made Textiles Research Association (MANTRA) Surat, Gujarat, India.

2.1 Materials and Methods

2.2.1 Materials

In the present study, banana fibers have been used as reinforced materials, with the form of continuous long filament fibers, chopped in to small particulate length of 2-5 mm. Mechanical properties of banana fibers are as depicted in Table 1. The matrix used was unsaturated polyester resin of grade ECMALON 4411 that is mixed with hardener and accelerator for curing at room temperature. Physical property of resin is also shown in Table 2.

TABLE 1. MECHANICAL PROPERTIES OF BANANA FIBER

Diameter of Fiber (μm)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation at Break (%)	Density (Kg/m^3)
80-250	325	6.524	3.10	1350

TABLE 2. PHYSICAL PROPERTIES OF RESIN

Density Kg/m^3	Viscosity (CPS)	Strength (MPa)	Breaking Load (N)	Elastic Modulus (GPa)	Strain
1258	500 at 25^{0}C	26.5	689	2.32	0.01147

2.2.2. Methods

2.2.1. Sample fabrication procedure

Banana fiber reinforced composite plate is fabricated using compression molding process as shown in Fig. 2. The fibers are cut into small 2-5 mm length from the large fibers. Coped fibers are mixed with resin, which is prepared by adding hardener and accelerator. The mixture is poured into the mould cavity, and allow to post cure for 24 hours for at ambient temperature. The fibers are placed in mould so as they are distributed randomly in all the direction, and the thickness of composite plate is arrived as 10 mm, with the volume fraction of fiber in composite plate has been obtained as 20% (weight basis).

Fig. 2. Banana fiber reinforced composite plate prepared from banana fiber and unsaturated polyester resin

2.2.2. Equipment

The experiments are performed on abrasive water jet machine (Model DWJ1313-FB1, Make – A innovative international ltd. India) which is equipped with DARDI-DIPS6D-2230 ultrahigh pressure pump. The machine is working on maximum pressure of 300 MPa, traverse speed 6000 mm/min and jet of angle fixed at 90^0. The orifice used was from material sapphire and having diameter 0.25 mm, along with tungsten carbide nozzle having diameter 0.7 mm. The machine is equipped with abrasive gravity feed system which is controlled by pneumatic valve and a work piece table with dimension of 1300 mm x 1300 mm. The experimental set up of abrasive waterjet machining of banana FRP composite is illustrated in Fig. 3.

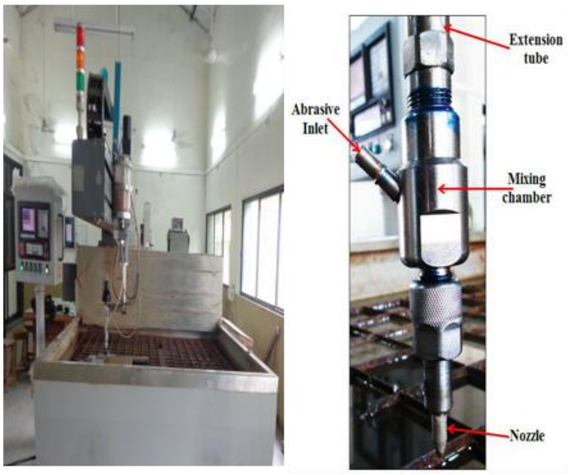

Fig. 3. Experimental set up for machining of banana FRP composite and nozzle assembly

2.2.3. Experimental Design (DOE)

Abrasive water jet machine possess the large number of process parameters, which all affect the quality of cutting. It is decided to select three machining parameters during cutting. Preliminary experiments are conducted to find out the working limit of the independent process parameter for banana fiber reinforced composite. The independent process parameters are shown in Table 3, which describes the three levels of selected parameters namely water pressure **(P)**, Traverse speed **(S)** and standoff distance **(D)**.

Table 3. Process parameters and their levels

Factors	Units	Notations	Factors levels		
			Minimum	**Average**	**Maximum**
Water Pressure	MPa	P	96	120	144
Traverse Speed	mm/min	S	100	200	300
Standoff Distance	mm	D	2	3	4

2.2.4 Experimental procedure

To initiate investigation Full-factorial design of experiment is applied, where total 27 nos of experiments are conducted. Throughout the experiments garnet particle used as abrasive material with mesh size of #80 and constant abrasive flow rate of 5 grams/s. All samples are machined from banana fiber reinforced composite plate having dimensions of 300 x 300 x 300 mm^3 in small of 40 x 10 x 5 mm^3. Surface roughness is measured along the cut. Surface roughness *(R_a)* is measured using stylus surface roughness tester (Model: Mitutoyo SJ-400; Make: Japan), equipped with cone-shaped diamond stylus having the radius of 5µm and tip angle 90^0. A sample length of 0.8 mm is chosen with measuring length of 4 mm and evaluation length 3.2 mm for all specimens.

III. RESULTS AND DISCUSSION

The full-factorial design of experiment for run of total 27, cutting is carried out and then pieces of 40 mm x 10 mm x 10 mm are cut from 300 mm x 300 mm x 10 mm banana FRP composite plate. Specimens after machining are shown in Fig. 4.

Fig. 4. Specimen after AWJ cutting

3.1 Influence of machining parameters on surface roughness (Ra)

The effect of hydraulic pressure on surface roughness is shown in Fig. 5 for standoff distance of 2 mm, 3 mm and 4 mm. During this study the three sets of traverse speed is tried that is 100 mm/min, 200 mm/min and 300 mm/min. The pattern of roughness variation is almost same in all the three cases of standoff distance i.e as the pressure increases the surface roughness decreases this is obvious as increase in pressure leads to increase kinetic energy of abrasive particles and increase of more amount of material removal. This may also be due to retaining good amount of energy to cut the material without striation marks.

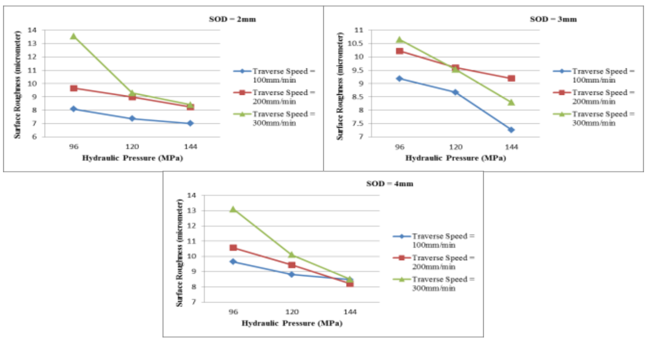

Fig. 5. Influence of hydraulic pressure on surface roughness for SOD 2 mm, 3 mm and 4 mm

The effect of traverse speed on surface roughness is shown in Fig. 6 for hydraulic pressure 96 MPa, 120 MPa and 144 MPa. During this study the three sets of standoff distance is tried that is 2 mm, 3 mm and 4 mm. The pattern of roughness variation is almost same in all the three cases of hydraulic pressure i.e as the traverse speed increases the surface roughness increases this is obvious as increase in traverse speed leads to decrease in cutting time. This may also be due to less amount of time is available of cutting so jet produce rough surface at exit. Ma and Deam (2006) have demonstrated in their investigation on prediction of the kerf profile shape under different traverse speed in AWJM of acrylic, it is found that the roughness of the cut profiles increasing with traverse rate [17].

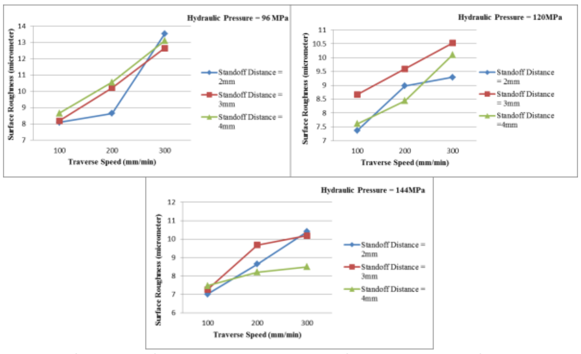

Fig. 6. Influence of traverse speed on surface roughness for Hydraulic Pressure 96 MPa, 120 MPa and 144 MPa

The effect of standoff distance on surface roughness is shown in Fig. 7 for hydraulic pressure 96 MPa, 120 MPa and 144 MPa. During this study the three sets of traverse speed is tried that is 100 mm/min, 200 mm/min and 300 mm/min. The pattern of roughness variation is almost same in all the three cases of hydraulic pressure i.e as the standoff distance increases the surface roughness increases this is obvious as increase in standoff distance leads to increase loss of useful energy owing to interaction with the environment. Ramulu and Arola (1994) have described in their investigation that, higher standoff distance allows the jet to expand before impingement and lowers the densities of abrasive particles in the outer perimeter of the expanding jet [18]. This generally results in lower penetration depth as well as a higher surface roughness.

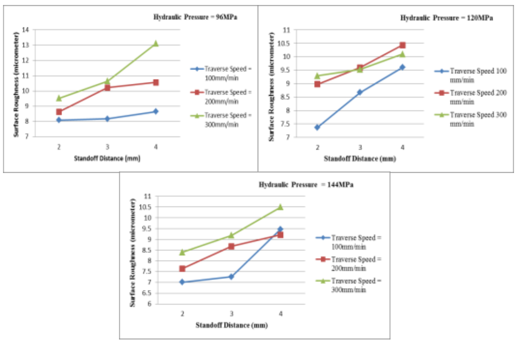

Fig. 7. Influence of standoff distance on surface roughness for Hydraulic Pressure 96 MPa, 120 MPa and 144 MPa

3.2 Influence of machining parameters on Taper Ratio (Ta)

The term kerf tapper ratio is considered by taking ratio of top width to bottom width of kerf. The variation in kerf taper ratio observed for various runs are shown Fig. 8, which highlights kerf from jet exit obtained during AWJ cutting. The variation in kerf taper ratio observed for kerf from jet entry to jet exit. Top width and bottom width of kerf tapper are measured by Vision measuring system (Model: Sipcon SDM-TRZ-5300). Workpieces as per the standard run order for Kerf taper width analysis.

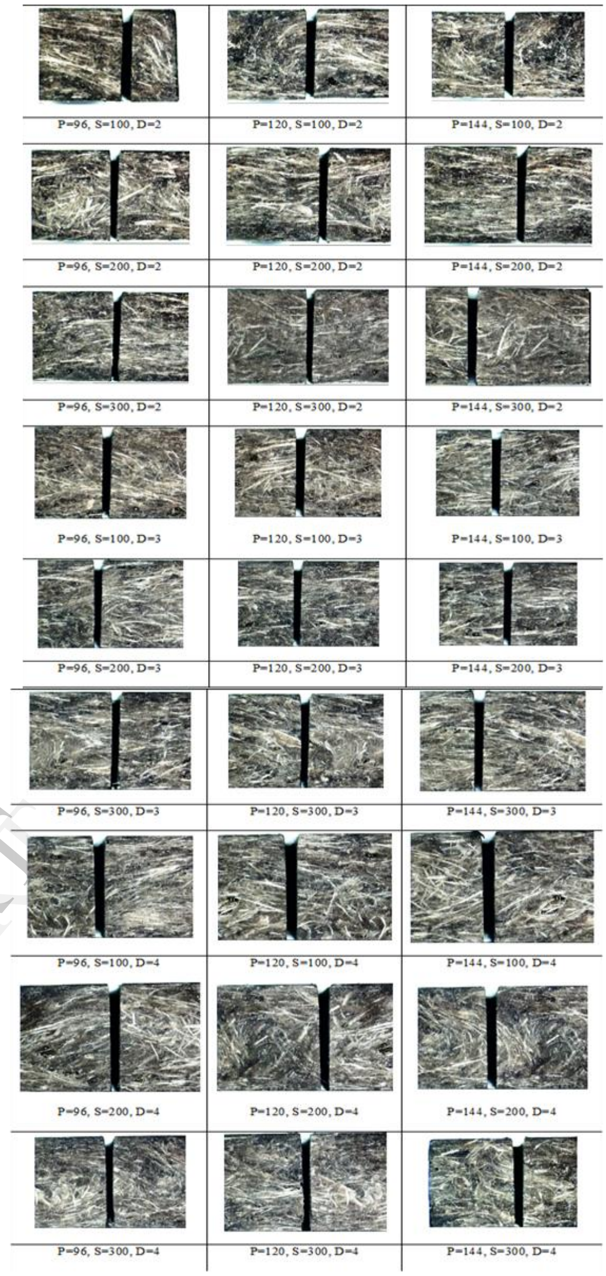

Fig. 8. Cross sectional view of kerf profile for 27 nos. specimens

Fig. 9 shows the effect of hydraulic pressure on kerf taper ratio for standoff distance of 2 mm, 3 mm and 4 mm. During this study the three sets of traverse speed is tried that is 100 mm/min, 200 mm/min and 300 mm/min. Results indicate that, within the operating range selected, increase of water pressure results in decrease of kerf taper. When water pressure is increase, the jet kinetic energy increases that leads to a high momentum transfer of the abrasive particles, generating a wider-bottom kerf. Therefore, the difference in top and bottom kerf width is reduced. According to Momber and Kovacevic (1992), a general trend of AWJM parameters shows that the taper increases with an increase in the traverse rate and the standoff distance while it decreases with an increase in the pump pressure [19]. These results suggest that the taper reduces with an increase in the abrasive water jet kinetic energy. This trend for kerf taper ratio can be explained by the strength zones in a water jet proposed by Hashish [15] and further developed by Wang and Wong [20].

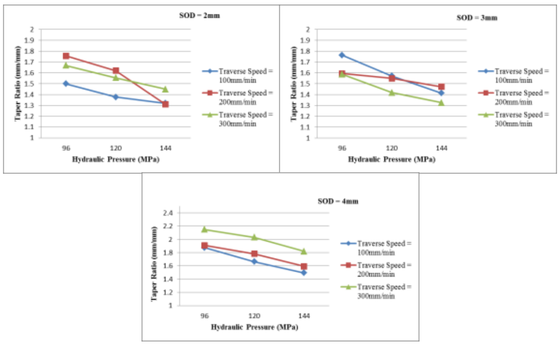

Fig. 9. Influence of hydraulic pressure on taper ratio for SOD 2 mm, 3 mm and 4 mm

The effect of traverse speed on kerf taper ratio is shown in Fig. 10 for hydraulic pressure 96 MPa, 120 MPa and 144 MPa. During this study the three sets of standoff distance is tried that is 2 mm, 3 mm and 4 mm. Looking to Fig. 10 taper ratio is increasing as jet speed increasing. The increase in kerf taper is a direct result of the exposer time because at higher traverse, less time is available for cutting, leading to less overlapping of the jet on the target material. It may be concluded that the negative effect of traverse rate on the kerf width is due to the fact, that a faster passing of abrasive water jet allows fewer particles to strike on the target material and, hence, generates a narrower slot [20].

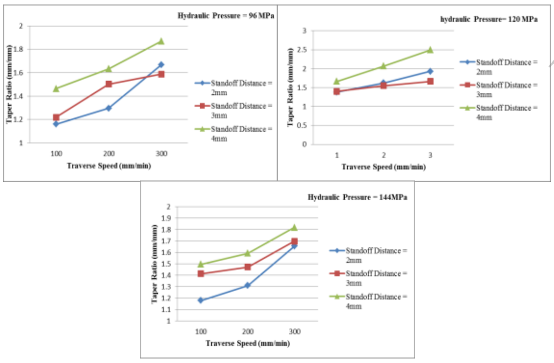

Fig. 10. Influence of traverse speed on taper ratio for Hydraulic Pressure 96 MPa, 120 MPa and 144 MPa

The effect of standoff distance on kerf taper ratio is shown in Fig. 11 for hydraulic pressure 96 MPa, 120 MPa and 144 MPa. During this study the three sets of traverse speed is tried that is 100 mm/min, 200 mm/min and 300 mm/min. With increase in standoff distance, the kerf taper increase within the range 1-3 mm as shown in Fig. 11. By increasing the standoff distance the material is exposed to the downstream of the jet. At downstream, the jet starts to diverge losing its coherence thereby reducing the effective cutting area that directly affects the kerf taper. Thus, increasing the standoff distance between the nozzle and workpiece is expected to result in higher difference between top and bottom kerf widths, which eventually gives higher kerf taper ratio. Moreover, the result is also believed to be produced by the jet divergence [21].

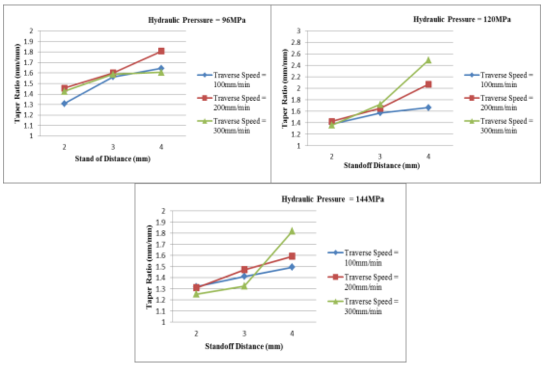

Fig. 11. Influence of standoff distance on taper ratio for Hydraulic Pressure 96 MPa, 120 MPa and 144 MPa

IV. CONCLUSION

1. The short random banana fiber-polyester composite having volume fraction (20%) as reinforcement is considered for abrasive water jet cutting.
2. Increasing in hydraulic pressure surface roughness (R_a) and taper ratio (T_R) is decreasing.
3. It is confirmed that increasing hydraulic pressure of water that increase the kinetic energy of jet may produce better kerf quality.
4. Surface roughness (R_a) and taper ratio (T_R) is increasing as traverse speed increasing which clearly shows the less overlapping of abrasive and water particles with work material.
5. With increase in standoff distance increases surface roughness (R_a) and taper ratio (T_R). Owing to loss of jet energy increase as distance between work piece and jet increase.

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