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Review Article

Abrasive water jet machining of fiber reinforced polymer composite materials: A review

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Abstract

Fiber reinforced polymer composites (FRPC) have become integral to material systems due to their exceptional performance in specific applications. The existence of fiber inclusion and the heterogeneous composition of composites present challenges for machining using traditional methods. Due to the heterogeneous and inhomogeneous behavior of fiber-reinforced composite materials, severe damage can occur while using traditional machining methods. The most common damage is delamination, which also leads to a reduction in the composite's strength. Nontraditional machining techniques including laser machining, ultrasonic machining, electric discharge machining and abrasive waterjet machining have Developed as viable alternatives for Machining fiber reinforced polymer composite materials. Abrasive water jet machining (AWJM) has emerged as the most effective and preferred approach for machining fiber-reinforced polymer composite materials compared to other non-traditional methods. This review paper seeks to outline and clarify the effect of AWJM parameters on machining performance, damage characteristics and mechanical properties of fiber reinforced polymer composites.

I. INTRODUCTION

Composite materials are used widely in several industries because of their outstanding qualities[1-4]. The composite materials provide benefits such as high strength to weight ratios, high resistance against corrosion, high modulus, high resistance against thermal deterioration, superior electrical characteristics, design flexibility, and high fatigue endurance[5]. Fiber reinforced polymer composites (FRPC), particularly those incorporating carbon and glass fibers, are commonly favored materials in the space and aviation industries. Secondary machining processes must be conducted after the fabrication of composite materials to meet their functional requirements [6]. Machining composite materials, particularly those with continuous fibers, can be challenging due to the risk of damaging the fiber reinforcement despite the advantages it offers. Traditional machining frequently leads to elevated tool wear and significant material degradation because of the diverse composition of composites[7].

Non-conventional machining methods have been created and utilized to address these obstacles. Various methods like, abrasive water jet machining (AWJM), ultrasonic machining[8], laser machining[9], and electric discharge machining have been utilized to machine composite materials[10]. AWJM is a favored technique for machining FRPC[11]. AWJM provides benefits such as fast cutting rates, operating without heat generation, and clean machining[12], making it ideal for cutting, drilling, and milling composites without causing any harm to the material.

Despite its advantages, abrasive water jet machining (AWJM) presents several challenges when applied to composite materials. Issues such as delamination, moisture absorption, and surface degradation can negatively impact the overall integrity and performance of the material. These challenges arise primarily due to the heterogeneous and anisotropic nature of composites, which make them more susceptible to defects during the machining process. In particular, delamination at the machined edges can reduce structural strength, while moisture absorption and surface degradation may affect long-term durability and dimensional stability. Addressing these issues requires careful optimization of AWJM parameters to minimize adverse effects and ensure high-quality machining outcomes. Nevertheless, these difficulties have not reduced the significance of AWJM in machining composite materials, particularly in industries where strong connections, accurate holes, and excellent surface quality are crucial.

Many machining variables in AWJM can influence various machining parameters, both individually and in combination. Choosing the right machining parameters is crucial for preventing issues such as burrs, fractures, and delamination, as well as for maintaining good surface quality and kerf behavior.

Extensive research has been done to comprehensively examine the effect of AWJM factors on a wide range of machining responses. Researchers have generally aimed to identify the optimal cutting settings to prevent failures as fiber rupture, resin fiber debonding, micro-crack formation, and delamination. This paper will specifically concentrate on studies that explore how different AWJM parameters affect various machining responses on FRPC.

II. RESEARCH METHODOLOGY

2.1. AWJM parameters and Composite machining responses.

AWJM is a process that relies on several machining factors, each of which has different levels of impact on the machining responses. Certain parameters exert a substantial impact, while others possess a lesser degree of influence. Furthermore, some factors can be easily modified, while others provide challenges when attempting to make changes. Various composite machining responses are essential for accurately measuring machining quality and assessing the validity of the machined composite component. Table.1 summarizes the most studied parameters and machining responses from several researches.

2.2. Effect of AWJM factors on damage characteristics of FRPC.

Multiple investigations have been done to analyze the influence of AWJM factors on the danage characteristics of machined regions. Hashish[13] stated that the careful choice of AWJ parameters is crucial for minimizing burrs, delamination, and cracks, as well as for enhancing Kerf taper, wall straightness, surface roughness, and waviness.

Table. 1: AWJM factors and Composite machining responses.

AWJ composite machining Factors	Composite machining responses
Water Pressure (WP)	Surface roughness
Abrasive mass flow rate (AMFR)	Material removal rate
Stand off distance (SOD) (Fig. 1)	Kerf characteristics
Traverse speed (TS)	Delamination (Fig. 3)
Abrasive type	Tensile Strength
Abrasive size	Fatigue endurance limit
Nozzle diameter	
Composite thickness	
Fiber orientation (Fig. 2)	
Matrix and fiber type	

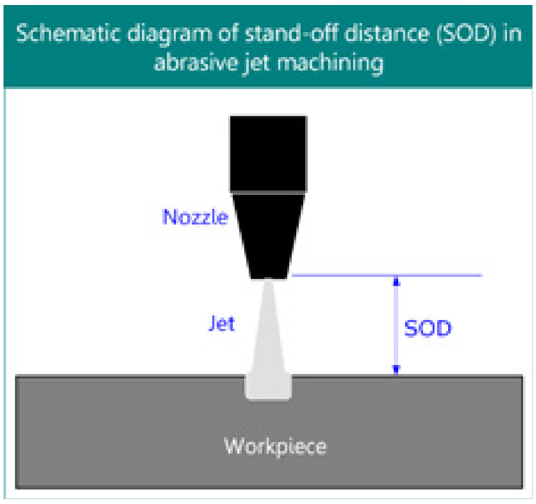

Fig. 1: Stand-off distance

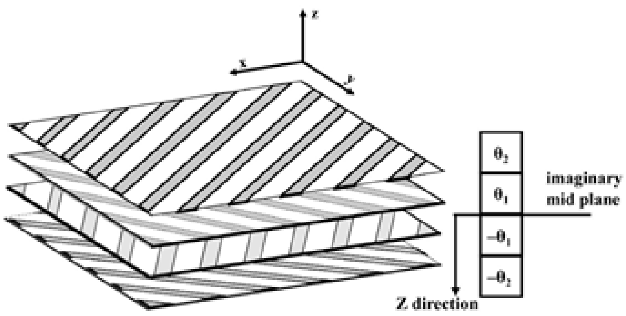

Fig. 2: Fiber orientation

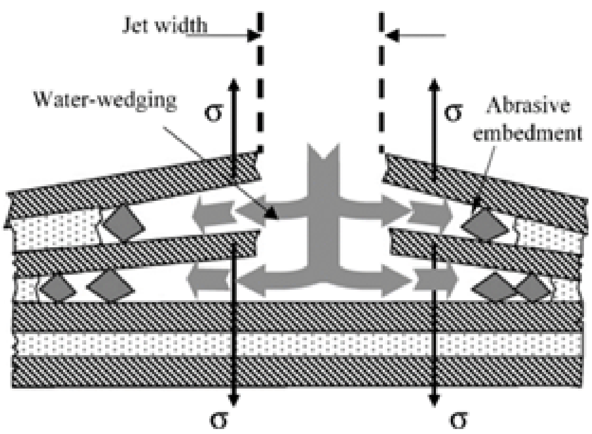

Fig. 3: Delamination

An experimental study was done to explore the impact of cutting parameters on kerf taper angle and surface roughness of graphite epoxy composites machined with AWJ[14]. The Taguchi method was employed to systematically evaluate how machining parameters influence these characteristics. Scanning electron microscope (SEM) was used to recognize wear zones on machined surfaces. Profilometry measurements and microscopy investigations revealed three distinct surface topography regions on the specimens. Analysis of variance approach (ANOVA) demonstrated that the influence of machining parameters on surface roughness varied with cutting depth. It was found that SOD and grit size were the key variables influencing surface roughness at low cutting depths, whereas TS, grit size, and WP had greater influence at deeper cutting depths. The study also concluded that high WP and low TS are essential for achieving high surface roughness when machining thick laminate specimens. Mathematical models had been developed to predict kerf taper and surface roughness for graphite epoxy laminates up to a cutting depth of 16 mm.

Machining performance and material removal mechanisms of polymer matrix composites machined by AWJ were studied by J. Wang *et al.*[15]. The study's results demonstrated that selecting appropriate machining parameters can produce high quality kerfs at a high production rate. Key parameters influencing kerf taper angle and depth of cut were identified as TS, AMFR, and WP, while TS and AMFR have a significant impact on kerf width. Analyzing the cut surfaces with a Scanning Electron Microscope (SEM) reveals that the erosion mechanism for the matrix material involves shearing, intergranular cracking, and ploughing. Shearing or cutting is the primary mechanism for fiber failure in the upper machined region, while fibers are predominantly pulled out in the lower machined region. Mathematical models were created and validated to extrapolate the values of depth of cut and kerf taper angle.

Chelikani. S. *et al.* studied the suitability of using AWJM for reinforced plastics[16]. A diverse selection of plastics with varying matrices and fiber thicknesses was chosen as representative samples. Subsequently, SEM was used to inspect the machined surfaces. Additionally, some samples roughness was measured using a profilometer with stylus, Confirmed through laser holography. The SEM analysis revealed that high cutting speeds, high SOD, low WP, and small nozzle diameter are the main causes for fiber debonding, fiber pull out, chipping of the matrix, and delamination. The roughness measurements indicated that larger-diameter nozzles and lower TS contributed to an enhancement in surface quality.

Kunlapat Thongkaew *et al.*[17] conducted a study that showed that AWJM can produce high quality holes in CFRP composites when the process parameters are selected correctly. Additionally, it has been discovered that optimal process parameters are a WP of 200 MPa, a nozzle TS of 2 mm/s, and an AMFR of 7.0 g/s. Empirical models were developed to precisely predict hole diameter variability, roundness error, and wall inclination angle.

A study on delamination in AWJ cutting of Gr/Ep composite[18] revealed that delamination damage is created by the shock wave produced by impacting the waterjet on the surface of the workpiece. Delamination region propagates due to jet slurry penetration through the crack tips. A mathematical model was developed to predict maximum crack length, which is verified using experimental data.

A preliminary investigation was done to assess the impact of AWJM parameters on the occurrence of delamination in Carbon Fiber composite plates[19]. The study focused specifically on straight cuts. They found that AMFR, abrasive size and delay time for mixing the abrasives into the jet are the most important factors that significantly affects the occurrence of delamination.

Machining parameters such as WP, TS, SOD, and AMFR were evaluated for their effects on delamination, kerf top width, and kerf taper ratio[20]. Delamination in the machined samples was assessed using a scanning electron microscope. ANOVA was employed to clarify the most significant process parameters affecting the responses. The results indicated that delamination damage decreases with higher WP and AMFR, and lower SOD and traverse speed. The kerf taper ratio decreases with higher pressure and lower traverse speed and SOD. The kerf top width decreases with lower SOD and higher traverse speed. They also developed Mathematical models to predict the responses at various process parameter levels. Additionally, multi-response optimization was performed to minimize these responses.

Irina Wong *et al.* conducted a study on the kerf taper angle and delamination in FRP hybrid composites during AWJM[21]. They used response surface approach to experimentally study the influence of AWJM parameters on both responses. Experimental results revealed that SOD and TS are the most significant parameters affecting kerf taper angle. Delamination on both sides was affected by the AMFR, TS, and WP. It was also revealed that it is necessary to increase the kinetic energy of the jet when it impacts the workpiece at a lower cutting speed to reduce the kerf ratio and delamination.

An investigation was conducted to assess the quality of the machined region in hybrid composite material machined by AWJ technique. The quality of the machined region was represented by kerf taper angle and surface roughness[22]. Several cutting factors were considered, including WP, AMFR, SOD, and TS. The study demonstrated that WP, TS, and AMFR are the most significant parameters affecting kerf taper. On the other hand, surface roughness is significantly affected by TS.

M.A. Azmir *et al.*[23] examined surface roughness and kerf taper ratio of glass fiber epoxy composite machined by AWJ. The machining parameters included in the study are WP, AMFR, abrasive material, SOD and TS. Results showed that abrasive material type and WP significantly influenced Ra and TR respectively. Aluminum oxide abrasive material performed better than graphite. Increasing WP and AMFR while decreasing the SOD and traverse rate improve machining performance for both responses.

The increasing demand for natural fiber-reinforced composites (NFRCs) is attributed to their great advantages, such as affordability, biodegradability, eco-friendliness, strong mechanical properties. Natural fibers are used nowadays due to the its great impact on the environmental and sustainability aspects[24]. Natural fibers are sourced from plants, animals, or minerals. One of the main plant natural fibers is banana fiber. A study was conducted on banana/polyester composites using Taguchi's method in order to optimize the AWJM parameters with the goal of minimizing kerf width and kerf taper. The study concluded that using Garnet 120 abrasive, a feed rate of 20 mm/Sec, a SOD of 2mm, and a WP of 250 MPa were optimal for improving kerf quality.

The utilization of abrasive waterjet for machining natural fiber composites has been established as a superior technique compared to other non-conventional procedures in contemporary times . Jignesh K. Patel *et al.*[25] work focused on creating a composite material by combining banana fiber with general purpose polyester resin, and then subjecting the composite plate to abrasive waterjet cutting. Full factorial design was utilized as a design of experiment method. The study focused on assessing the impact of machining parameters, including WP, TS, and SOD on surface roughness and kerf taper ratio. they concluded that an increase in WP leads to a reduction in surface roughness and taper ratio. Additionally, it was noted that TS and SOD play a crucial role in determining the output response. An increase in TS and SOD is believed to result in a rise in both responses.

An experimental study was done to analyze the kerf characteristics of two different types of fiber polymer composites, graphite epoxy and glass epoxy composites[26]. The study advises using a combination of high WP, low TS, and low SOD to minimize the kerf taper angle. Additionally, a semi-analytical model was created to predict kerf taper angles at different values of controlling parameters levels.

S. Madhu *et al.*[27] conducted a comparative study on two types of nozzles (one with internal threads and one without) to evaluate their impact on the surface roughness (Ra) of holes machined by AWJ. The study investigated the effects of SOD, abrasive air jet pressure, nozzle diameter, and abrasive size on surface roughness (Ra) for both nozzle types. Results showed that the internal threaded nozzle produces a superior surface finish.

Experiments were done to evaluate the impact of AWJM parameters on surface roughness of GFRP composites[28]. Taguchi's technique was utilized as a design of experiment method. ANOVA was also used to determine the most significant parameters to fulfill efficient machining. The study revealed that abrasive material type, WP, SOD, and TS were the most influential control parameters affecting surface roughness (Ra). On the other hand, the cutting orientation was found to have no statistically significant impact on controlling surface roughness.

To improve machining quality and mechanical properties of composite materials, filler materials are added alongside natural fibers.

A comparative study was conducted to examine hybrid natural fiber composites in two forms (with and without filler materials) machined by AWJM[29]. Three cutting parameters were used: WP, TS, and SOD. The machining responses studied were kerf inclination angle, material removal rate, and surface roughness. The study found that TS is the most significant parameter affecting material removal rate and surface roughness. Additionally, it revealed that hybrid fiber composites with filler materials produce high-quality components with low delamination and minimal fiber pullout.

Mustafa Arma ˘gan *et al.*[30] conducted a study to analyze the machining performance of vinyl ester composite plates reinforced with glass fiber under different cutting parameters of AWJM using Taguchi method as an experimental design. The controlled parameters in the study were SOD, AMFR, TS, WP and material thickness. Each parameter has three levels. The study aimed to assess cutting performance by analyzing the width of top kerf and surface roughness. ANOVA was used to analyze the data and Linear regression was used to develope mathematical models to predict the responses at different levels of the controlled variables. Main effects plots were constructed to study the correlation between controlled parameters and responses. The SOD was found to be the most crucial parameter, and the optimum levels were determined using major effects plots.

Ajit Dhanawade *et al.*[31] presented an empirical investigation of the AWJM applied to carbon polymer composites. The study included the following parameters: WP, TS, SOD, and AMFR. Taguchi technique was used as a design of experiment design approach and analysis of variance method is employed to examine the impact of machining parameters on surface roughness and kerf taper ratio. The study revealed that WP and TS are the most significant factors that affect surface roughness and kerf taper ratio. They also found that delamination damage is high in machined samples that are machined with low AMFR and high TS.

A methodology needs to be developed to adjust AWJM Factors for each GFRP and CFRP materials. as manufacturers currently do not offer comprehensive databases for composite machining. A. Alberdi *et al.*[32] focused on investigating the machinability model of composite materials. They determined the machinability index experimentally for different types of fiber reinforced polymer composites (FRPC) with different thicknesses, the study revealed distinct results for different materials. Additionally, studying the effect of machining factors on cut quality (kerf taper and surface roughness) was also included in the study.

Hussein Mohammed *et al.*[33] work aimed to evaluate how AWJM parameters affect the hole quality in woven laminated GFRP material, with the goal of determining the optimal drilling parameters values. A statistical approach was used to assess the effects of machining parameters on surface roughness, dimensional accuracy, tensile strength, cost, and productivity. ANOVA was conducted to clarify the effects of machining parameters on hole-quality. The results indicated that the optimal values for TS, fiber density, WP, SOD, and AMFR on the response variables are 0.3 m/min, 0.82 g/cm³, 150 MPa, 2 mm, and 100g/min, respectively.

K. Siva Prasad *et al.*[34] conducted an experimental investigation to assess the impact of various abrasive water jet (AWJ) machining process variables such as abrasive grain size, standoff distance (SOD), abrasive flow rate, hydraulic pressure, material thickness, and fiber orientation on dimensional quality features. The experiment was designed using the Taguchi L27 orthogonal array. Taguchi's ANOVA and SEM images were employed to statistically analyze the relationship between the Abrasive Water Jet Machining (AWJM) process parameters and response parameters. The results indicate that material thickness and standoff distance are the two most significant factors influencing dimensional accuracy.

Investigating how process parameters interact to influence machining responses and mechanical properties is as crucial as studying the parameters' individual effects (main effects).

An experiment was conducted to investigate how the interaction between water jet process parameters and stack up arrangement affects machining responses on titanium and CFRP stacks[35]. The study is aiming to investigate how water-jet process factors affect drilled hole size and surface quality. The studied machining parameters included WP, TS, AMFR, and stack arrangement. Two material configurations were tested: CFRP over titanium (CFRP/Ti) and titanium over CFRP (Ti/CFRP). The responses were taper ratio, hole bore surface roughness, hole quality, and overall surface condition. Statistical analysis was employed to create mathematical models that consider variable interactions and quadratic terms, resulting in highly correlated and predictive models. Models were Validated with confirmation experiments demonstrating the models' accuracy. The findings highlight the significant impact of material configurations and its interaction with other parameters.

Deepak Doreswamy et al.performed a research to assess the impact of AWJM parameters including WP, traverse rate, SOD, and abrasive concentration on kerf width of graphite-filled glass fiber reinforced epoxy composites[36]. They employed Taguchi's L27 orthogonal arrays as a design of experiment method. ANOVA was used to assess the significance of the main and interaction effects of the controlled parameters. regression models were developed in order to predict kerf width at different levels of significant parameters. Results indicated that WP, SOD, and traverse rate significantly affect top kerf width, Additionally, it was found that there is no significance for the interaction effects of the process parameters.

Abrasive water jet technology is versatile, as it can be utilized not just for cutting, trimming, or drilling, but also for turning and milling processes.

A single pass radial mode abrasive waterjet (AWJ) turning experiment (Fig. 4) was conducted on a short carbon fiber reinforced polyetheretherketone specimen[37]. The objective of the study was to evaluate the effects of AWJ turning variables WP, feed speed, nozzle tilting angle, AMFR, and rotational speed—on machining performance indicators: material removal rate (MRR), depth of cut, and surface roughness. The findings suggest that high WP, a normal nozzle impact angle, and high rotational speed, combined with an optimal feed speed and AMFR, can achieve a high MRR without significantly compromising surface roughness. Mathematical models were developed to predict these three cutting performance responses.

Delamination is a common damage characteristic in fiber-polymer composite during drilling process using AWJ, reflecting the challenges in machining composite laminates. It is crucial to develop an advanced drilling techniques to overcome these challenges.

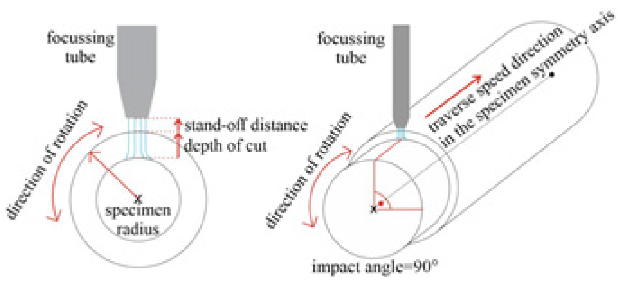

Fig. 4: Rradial mode abrasive waterjet (AWJ) turning

A study was done to understand the impact of AWJ drilling parameters on delamination of carbon fiber reinforced polymer (CFRP) composites. The study was performed by Kamlesh Phapale *et al.*[38]. Process parameters in the study were SOD, WP and AMFR. They concluded that SOD and WP have more significant impact on delamination than AMFR. The study also discussed the development of various techniques to eliminate delamination induced by abrasive water jet drilling. Those techniques includes using a pre-drilled hole technique, a backup plate technique and water immersion drilling technique. Analysis indicated that AWJ drilling using a backup plate technique results in the least delamination, the least hole size variation, and the least surface roughness.

Prasad D. Unde *et al.*[39] focused on experimentally investigating the AWJM process. Their aim was to assess the technological and material-related parameters that influence the machining quality of CFRP composites and optimize the results using response surface method. SOD, feed rate, WP and fiber orientation were identified as controlling factors. They studied the effect of the controlling factors on kerf taper ratio, delamination, surface roughness and material removal rate. Results showed that fiber orientation and WP were found to significantly influence surface roughness.

A comparative study was performed to study the impact of AWJ process parameters, WP, AMFR and quality level (QL) on kerf taper ratio and surface roughness[40]. The study employed three levels for each parameter to analyze their effects and determine the optimal settings using Taguchi L27 orthogonal array. The results indicated that higher levels of WP and QL, along with a lower level of AMFR, are preferable for achieving minimal surface roughness and kerf taper ratio.

Kerf taper ratio (TR) and surface roughness were also studied by M.A.Azmirand *et al.*[41]. Taguchi method was employed as the design of experiment approach. ANOVA was used to analyze the resulting data. Results revealed that TS was the most significant factor affecting both surface roughness (Ra) and kerf taper ratio (TR). Higher WP and Lower SOD and TS led to reduction in Ra and TR. However, the effect of AMFR on Ra and TR was not significant. Mathematical models were developed to predict both Ra and TR using Multiple linear regression analysis.

New techniques have been developed to improve the performance of AWJM. One of these techniques is AWJ cutting with head oscillation, which involves a back and forth motion of the cutting head along its normal linear motion. This technique is designed to optimize the loading of cutting forces on the workpiece.

E. Lemma *et al.*[42] conducted a comparative study to determine the impact of normal AWJM and head oscillation AWJM on GFRP composites. The results of the comparison indicate a significant improvement in surface quality achieved by the head oscillation technique compared to normal AWJ cutting. In some samples, surface quality improvement, as measured by Ra values, was found to be up to 20%.

Prasad D. Unde *et al.*(2015) discovered that although delamination in glass fiber-reinforced polymer composites cannot be eliminated after using AWJM, it can be minimized by adjusting AWJM parameters such as WP, SOD, and feed rate. They also observed that delamination damage is higher on the top side compared to the bottom one.

Dharmagna *et al.*[43] outlined the influence of control variables like AMFR and TS on material removal rate (MRR) during AWJM of GFRP composites. They employed Taguchi methodology for the experimentation and found that TS is the most significant variable affecting MRR. They found that the optimum values for parameters to maximize MRR are 100 cm/min TS and 300 gm/min AMFR respectively.

2.3 Effect of AWJM parameters on mechanical properties of FRP composites

Studying the impact of machining parameters on mechanical properties of composite materials is as crucial as investigating their effects on damage characteristics such as delamination, kerf taper angle, surface roughness, and dimensional accuracy as it can help clarifying the structural behavior and load-carrying capacity of the machined part. Unfortunately, there is limited literature examining the influence of parameters on the mechanical properties of FRP composites.

Comparative study was performed to explore the defects caused by various machining processes (AWJM, burr tool, abrasive diamond cutter 'ADS') on CFRP and their effects on its mechanical properties evaluated by quasi-static and tension-tension fatigue tests[44]. Different cutting conditions are applied to achieve different levels of material degradation. The analysis includes characterizing the machined surface using roughness measurement devices and SEM observations. Findings indicated that defects like fiber pull out and resin degradation occur primarily in layers oriented at 45 and 90 degrees during trimming with a cutting tool. In contrast, AWJM and ADS processes produce streak-like defects that are not influenced by fiber orientation. Quasi-static tests demonstrate that AWJM specimens exhibit superior compression resistance, while ADS samples display higher inter laminar shear strength. Fatigue tests showed that specimens machined using a burr tool have a higher endurance limit.

M. Saleem *et al.*[45] conducted a comparative study to explore how different types of machining processes impact the mechanical performance of CFRP composite plates under cyclic loading. They used conventional drilling and AWJM to create holes in the specimens. They used thermographic infrared camera to observe temperature variations during fatigue test. Temperature variations can then be related to stiffness reduction and damage progression in the plates. The results of the fatigue tests revealed that the accumulation of damage in specimens drilled using conventional drilling process was greater than in those drilled using abrasive waterjet machining (AWJM). Additionally, the endurance limit of a composite plate drilled with conventional drilling was found to be approximately 10% lower than that of specimens drilled with AWJM. They concluded that the selection of the machining process significantly affects the mechanical performance of CRFP.

Mechanical properties represented by tensile strength, flexural strength, and impact strength were examined for thermoset composite specimens reinforced with glass mat (synthetic) and coconut sheath (natural) fibers made by compression-molded process. The examination compare between tow conditions before and after machining the composites[46]. The study found that there was a slight decrease in tensile strength which was observed after machining the composite in each condition. Taguchi method was used to design the experiment and ANOVA was used to analyze the data. It was found that the abrasive particles size is the most significant parameters affecting the mechanical properties of both composites.

Akshay Hejjaji *et al.*[47] conducted a study to investigate the damage induced in CFRP laminates by AWJ milling and its effect on the static and fatigue strength of the machined specimens. Controlled parameters in the study were WP, SOD, scan step (mm), and TS. The ultimate static tensile strength and endurance limit of the specimens were related to surface quality and damage level. Damage level is characterized by crater volume (Cv). The results demonstrated a clear relationship between surface quality degradation and mechanical properties, showing that both static strength and endurance limit decreased as surface quality decreased.

Akshay Hejjaji *et al.* conducted another study on controlled depth AWJ milling on CFRP specimens[48]. The study was aiming to find the correlation between damage characteristics represented by (surface roughness and crater volume) and the mechanical properties of the specimens represented by static tensile strength. Results indicated that static tensile strength of machined specimens is affected by crater volume more than surface roughness.

III. CONCLUSION

This paper extensively investigates the impact of abrasive water jet machining on fiber reinforced polymer composites. The literature is divided into two main groups according to machining responses. The first group focuses on the damage characteristics of the machined features, such as delamination, kerf characteristics, dimensional accuracy, and surface roughness. The second group examines the mechanical properties of the machined composite parts, including ultimate static strength and fatigue endurance limit. The findings of this study lead to the following conclusions:

• The delamination response is primarily influenced by the abrasive flow rate and water pressure. on the other hand, kerf characteristics such as kerf taper angle

and kerf width are most affected by traverse speed, abrasive mass flow rate, and stand-off distance.

• Reducing the stand-off distance (SOD) and increasing the water pressure and abrasive mass flow rate can reduce surface roughness. However, further increase in SOD and traverse speed will lead to an increase in surface roughness.

• Limited research has been conducted on the impact of AWJM parameters on mechanical properties. Further research is needed in this area to establish a connection between machinability and the functionality of composite components. There has been limited research on studying the interaction effects between AWJM process parameters, which are crucial for controlling the decision-making process at the operator level.

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