

An Assessment of Single- and Three-Layer Wood-Plastic Composite Hole-Machining Using Abrasive Waterjet Cutting

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ABSTRACT

Wood-Plastic Composites (WPCs) are commonly used in furniture and structural applications. However, forming-based fabrication limits the production of complex shapes. Therefore, post-machining operations, such as hole machining, are required for WPCs, and achieving high machining quality remains challenging owing to the unique properties and layered structures of materials. Therefore, the novelty of this study lies in assessing the machinability of Abrasive WaterJet (AWJ) cutting as an effective non-traditional machining method for hole fabrication in single-layer and three-layer WPCs, comparing its performance with WaterJet (WJ) cutting and conventional drilling. The effects of water pressure, traverse speed, abrasive mass flow rate, and hole diameter on the roundness and machined surface quality were investigated experimentally. The results show that AWJ successfully produced through-cut holes in both WPC structures, whereas pure WJ achieved complete cuts mainly at 350 MPa water pressure due to insufficient cutting energy at lower pressure to surpass the material's hardness. According to response optimization, the proposed AWJ parameters are an abrasive mass flow rate of 6.67 g/s, a water pressure of 350 MPa, and a traverse speed of 30 mm/s, yielding a high desirability index of 0.848. A regression model was developed to predict roundness, and its validation revealed a small difference of 3.19% between the predicted and actual values. Compared to traditional hole drilling, AWJ offers shorter processing times and greater flexibility in hole size without requiring tool changes, although it results in larger hole roundness quality, which remains acceptable for clearance-fit applications. These findings highlight the potential of AWJ as an attractive option for machining WPCs.

Keywords-wood plastic composites; hole-machining; abrasive waterjet cutting; drill bit

I. INTRODUCTION

WPCs have been used in various industries, such as furniture and construction, for their sustainability, environmental friendliness, and durability. WPCs can be fabricated by using forming processes that combine wood flour or wood fibers with plastic, leading to low density, good specific material properties, and eco-efficiency [1]. WPCs are mainly fabricated in simple shapes due to the limitations of the molds. Therefore, post-machining operations, particularly cutting and hole machining, are still required for applications such as assembly. Traditional machining techniques have been employed for WPCs; however, challenges exist, including tool wear, heat degradation, delamination, and dimensional inaccuracy because of their anisotropic material structure and properties [2, 3]. These issues emphasize the necessity for alternative non-traditional machining methods.

Non-traditional machining techniques, including laser cutting and AWJ cutting, have shown potential for difficult-to-cut materials such as composites. In laser machining, the parameters of feed rate and gas power significantly affect the penetration energy and the cut quality. Optimum cutting parameters of low feed rate and low gas power can minimize thermal deterioration and enhance cutting consistency. Nevertheless, heat-affected zones still exist, causing thermal damage to WPCs [4, 5]. In contrast, AWJ cutting can eliminate the effect of heat damage due to its erosion mechanism for material removal, resulting in less thermal generation [6]. The cutting parameters of water pressure, abrasive mass flowrate and traverse speed have a significant impact on the kerf quality and surface roughness in WPCs [7, 8]. AWJ can produce good kerfs and surface roughness by adjusting the cutting conditions to the unique characteristics of each composite [9, 10]. Tool wear and adhesion problems, which are typical of traditional machining, can be minimized using AWJ cutting [11].

AWJ can generate holes by deploying two different methods: drilling (or piercing) and circular cutting (or trepanning). AWJ drilling attains greater roundness compared to circular cutting, but the hole size is limited by the dimensions of the jet nozzle [12, 13]. Delamination typically occurs through drilling operations owing to the initial jet impact; thus, circular cutting is proposed for AWJ hole machining as it enables flexibility in the hole size and reduces the initial shockwave impact [12]. Authors in [14] indicated that the hole characteristics are influenced by kerf profile variations along the hole depth, and proposed post-milling to remove extra lumber and improve hole geometry. Predictive models for AWJ machining performance, such as penetration depth and surface roughness models [8, 12, 15] based on material properties, can help manufacturers understand the AWJ machining process and reduce costs related to trial experiments.

Prior studies have focused on AWJ linear cutting of WPCs, with limited research on hole machining. Existing AWJ hole machining studies have mainly concentrated on carbon fiber composites with different material properties, leaving the effect of WPC structural configuration unclear. Therefore, this study experimentally investigated AWJ hole machining for WPCs

with single-layer and three-layer structures. The effects of water pressure, traverse speed, abrasive mass flow rate, and hole diameter on the hole characteristics, roundness, and surface quality were analyzed. Comparison with conventional drilling was conducted to evaluate practical applicability. A predictive model for hole roundness was also developed and validated, providing new insights into AWJ hole machining for WPCs.

II. METHODOLOGY

A. Wood-Plastic Composites

WPCs were fabricated using the process and formulation developed in [16]. The process commenced with the extrusion of the composite strands into pellets, followed by sheet formation through compression molding. The components comprised a Polypropylene (PP) matrix, Rubberwood Flour (RWF), a UV stabilizer, Maleic Anhydride-Grafted Polypropylene (MAPP), and paraffin with weight ratios of 44.5:50.4:3.9:0.2:1, respectively [16]. Two WPC structures were produced with a thickness of 10 mm (Figure 1): a single-layer WPC and a three-layer WPC-PP-WPC configuration with layer thicknesses of 2–6–2 mm. The properties of WPCs, including hardness, tensile strength, impact resistance, and water absorption, were evaluated following the method discussed in [17], with the findings reported in Table I [8]. Authors in [8] investigated the linear cutting of these WPCs, concentrating on kerf characteristics and surface roughness, without addressing hole machining performance.



Fig. 1. Structure of WPCs: (a) single-layer and (b) three-layer WPCs.

TABLE I. WPS PROPERTIES [8]

WPC	Thickness (mm)	Hardness (N/m ²)	Tensile strength (MPa)	Impact resistance (J)	Water absorption (%)
1-layer	10	64.30	6.57	0.09	19.53
3-layers	10 (2-6-2)	79.24	24.26	0.21	3.70

B. Experimental Design

Two types of hole generation processes were investigated: hole drilling (piercing) and hole cutting, as shown in Figure 2. Hole drilling was conducted on a CINCINNATI ARROW machine utilizing 6-, 8-, and 12-mm high-speed steel long straight drill bits (D_b) with straight shanks and a 118°-point angle [18]. The drilling parameters were set as follows: 6 mm (2,100 min⁻¹ revolution and 0.23 mm/rev), 8 mm (1,600 min⁻¹ revolution and 0.28 mm/rev), and 12 mm (1,000 min⁻¹

revolution and 0.38 mm/rev) without using coolant [18]. Circular hole cutting using pure WJ and AWJ processes was conducted on an SQ1313 Sunrise CNC WJ cutting machine (Jiangsu Sunrise Intelligent Equipment Co.). The experimental parameters, including three levels of water pressure (P), traverse speed (V_t), and hole diameter (D_w), are summarized in Table II. The designated D_w values were employed to generate the corresponding cutting paths (Figure 2). Fixed parameters of AWJ cutting included an 80-mesh garnet abrasive with a flow rate (m_a) of 6.67 g/s, a 2 mm standoff distance, a 0.33 mm orifice diameter, and a 1.02 mm nozzle diameter (d_j), as proposed by the manufacturer, based on the selected water pressures. A full factorial design of three cutting parameters at three levels and two WPC structures (3×3×3×2) was executed with 54 experimental conditions, each performed in triplicate to obtain mean and standard deviation values. The experimental setups for hole drilling and AWJ hole machining are depicted in Figure 3.

TABLE II. PROCESS PARAMETERS FOR AWJ HOLE MACHINING

Parameters	Units	Level		
		1	2	3
Water pressure, P	MPa	150	250	350
Traverse speed, V_t	mm/s	30	40	50
Hole diameter, D_w	mm	6	8	12

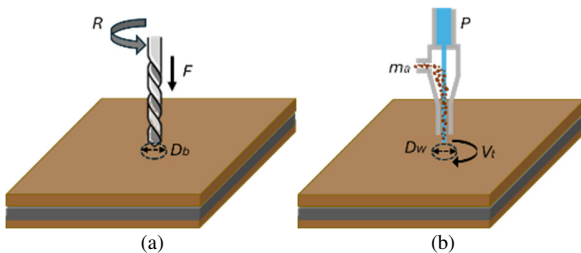


Fig. 2. Characteristics of: (a) hole drilling and (b) hole cutting using AWJ.

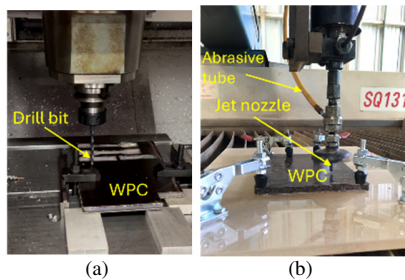


Fig. 3. Experimental setup for: (a) hole drilling and (b) hole cutting using AWJ.

C. Hole Characteristic Measurement

This study evaluated the hole characteristics in terms of surface roughness, roundness, and material structure. The procedures for measuring the roundness (R_h) and surface roughness (R_m) are illustrated in Figure 4. Roundness measurements followed the form tolerance criteria specified in ASME Y14.5:2018 Dimensioning and Tolerancing Standard [19]. Roundness was determined by fitting two concentric

circles, an inner circle (D_{min}) and an outer circle (D_{max}), such that all points on the measured circular profile were enclosed between them. The surface roughness (R_m) was evaluated using the maximum height parameter (R_z) in accordance with ISO 21920-2:2021 [20], with a measurement length (L) of 8 mm, a cut-off length of 2.5 mm, a measuring speed of 0.15 mm/s, and a sampling pitch of 0.0010 mm. The hole roundness and surface roughness were measured using a PJ-A3000 profile projector and a CONTOURECORD 2600E contour measurement tester, respectively, as illustrated in Figure 5.

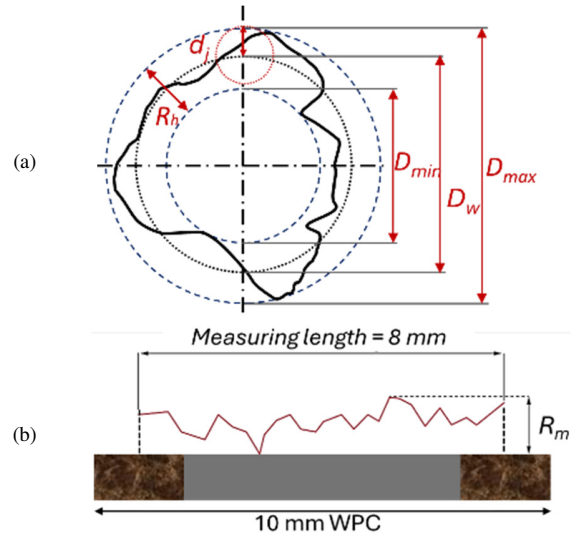


Fig. 4. Measurements of: (a) hole roundness and (b) hole surface roughness.

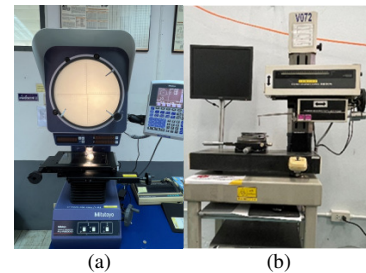


Fig. 5. Measuring equipment: (a) PJ-A3000 profile projector and (b) CONTOURECORD 2600E contour measurement.

III. RESULTS AND DISCUSSION

A. Hole Characteristics

The experimental results revealed that complete hole penetration was achieved for all WJ and AWJ cutting conditions in single-layer WPCs. However, some cutting conditions were inadequate for achieving a through cut in three-layer WPCs. This is due to the high hardness and tensile strength of the material, as shown in Table I. Figures 6 and 7 illustrate the hole characteristics produced by WJ and AWJ cutting for single-layer and three-layer WPCs for through cuts, whereas Figure 8 exhibits non-through cuts. Figures 6(a) and 7(a) show the holes created by conventional drilling for

comparison with the AWJ cutting. It can be noticed that the drilled holes have better shape with negligible burr development. The WJ and AWJ cutting generated rougher edges, exhibiting noticeable burrs and chip fiber pull-out around the perimeter. However, AWJ cutting offers better hole roundness than WJ cutting because of the additional cutting energy provided by the abrasive particles. A jet initial zone (d_{jz}) is visible at the hole entrance, caused by the initial shockwave impact that induces a damage zone at the point of entry [12]. Overcut in this zone can be minimized by starting and stopping the cutting path within the hole. From (1), the actual machined hole diameter (D_{aw}) exceeds the programmed diameter (D_w) by a deviation (d_f).

$$D_{aw} = D_w + d_f \tag{1}$$

In this study, the maximum diameter at the top hole, D_{max} (Figure 4(a)), was collected as D_{aw} . Thus, the d_f was calculated as the difference between D_{aw} and D_w . The mean d_f with corresponding standard deviation for WJ and AWJ cutting were 0.886 ± 0.185 mm and 1.066 ± 0.182 mm for single-layer WPCs, and 0.976 ± 0.136 mm and 0.882 ± 0.130 mm for three-layer WPCs, respectively. All measured values were below the nozzle diameter of 1.020 mm, in agreement with previous studies, indicating that the hole deviation is constrained by the nozzle size [12, 14]. Compensation for the deviation from the programmed diameter (d_f) is proposed to reach the target hole diameter [12]. As demonstrated in Figure 8, a machined groove is formed on the entry surface, representing the initiation of material removal; however, the jet lacks sufficient penetration capability to achieve through hole. Consequently, the reflected jet rebounds toward the top surface, enlarging the groove at the entry side (Figure 8(b)), and resulting in fiber full-out at the top surface (Figure 8(a)). This behavior is attributed to jet energy attenuation caused by material resistance, particularly in thick and high-strength materials and structures [6].

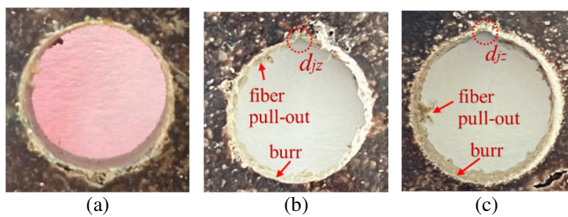


Fig. 6. Hole characteristics (12 mm) in single-layer WPCs: (a) drilled with a 12 mm drill bit, (b) WJ at $P = 350$ MPa and $V_i = 30$ mm/s, and (c) AWJ at $m_a = 6.67$ g/s, $P = 350$ MPa, and $V_i = 30$ mm/s.

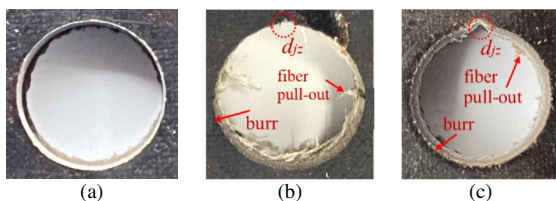


Fig. 7. Hole characteristics ($D_w = 12$ mm) in three-layer WPCs: (a) drilled with a 12 mm drill bit, (b) WJ at $P = 350$ MPa and $V_i = 30$ mm/s, and (c) AWJ at $m_a = 6.67$ g/s, $P = 350$ MPa, and $V_i = 30$ mm/s.

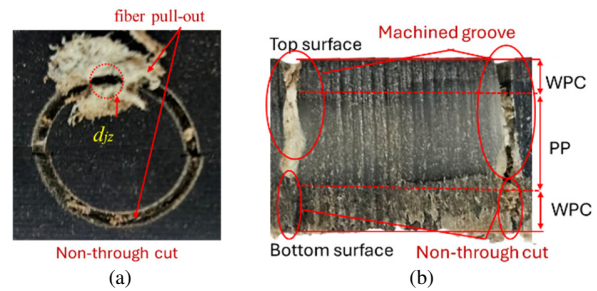


Fig. 8. Non-through cut holes in three-layer WPCs at $D_w = 12$ mm, $m_a = 6.67$ g/s, $P = 150$ MPa, and $V_i = 50$ mm/s: (a) top view and (b) side view.

In terms of operational period, the AWJ cutting took less time per hole (about 9 s) than drilling (around 12 s). Moreover, AWJ cutting can function continuously without interruption for tool changes, but drilling requires additional time for changing drill bits when varying hole sizes are needed. Consequently, AWJ cutting appears to be more flexible and efficient in operation than drilling while maintaining acceptable machined hole quality.

B. Hole Roundness

Table III presents the mean roundness from three repetitions, with the standard deviations provided in parentheses.

TABLE III. ROUNDNESS RESULTS FOR SINGLE-LAYER AND THREE-LAYER WPCs

WPC	P (MPa)	Vi (mm/s)	WJ-roundness (mm)			AWJ- roundness (mm)		
			6	8	12	6	8	12
1-layer	150	30	0.854 (0.037)	1.082 (0.115)	0.693 (0.178)	0.862 (0.082)	0.496 (0.069)	0.626 (0.161)
		40	0.985 (0.289)	0.930 (0.156)	0.877 (0.253)	0.724 (0.173)	0.654 (0.175)	0.657 (0.156)
		50	0.411 (0.206)	0.871 (0.216)	1.000 (0.294)	0.502 (0.222)	0.641 (0.180)	0.647 (0.105)
	250	30	0.949 (0.239)	0.903 (0.316)	0.479 (0.045)	0.411 (0.107)	0.788 (0.114)	0.513 (0.118)
		40	0.806 (0.194)	0.412 (0.214)	0.401 (0.316)	0.566 (0.150)	0.919 (0.035)	0.582 (0.046)
		50	0.689 (0.201)	0.610 (0.182)	0.729 (0.079)	0.552 (0.156)	1.087 (0.056)	0.560 (0.087)
	350	30	0.857 (0.236)	0.920 (0.348)	0.804 (0.257)	0.239 (0.018)	0.488 (0.049)	0.351 (0.125)
		40	0.419 (0.217)	0.144 (0.117)	0.744 (0.117)	0.838 (0.192)	0.711 (0.098)	0.425 (0.123)
		50	0.614 (0.080)	0.497 (0.149)	0.873 (0.205)	1.055 (0.035)	0.949 (0.035)	0.454 (0.072)
3-layer	150	30	-	-	1.127 (0.173)	0.491 (0.207)	0.288 (0.315)	0.258 (0.086)
		40	-	-	-	0.482 (0.103)	0.676 (0.270)	0.710 (0.072)
		50	-	-	-	-	-	-
	250	30	-	0.996 (0.130)	1.102 (0.447)	0.680 (0.342)	0.890 (0.294)	0.653 (0.214)
		40	-	0.767 (0.583)	-	0.407 (0.299)	1.270 (0.379)	0.901 (0.011)
		50	-	-	-	-	-	-
	350	30	0.874 (0.460)	0.627 (0.317)	1.215 (0.384)	1.040 (0.092)	0.982 (0.231)	0.216 (0.035)
		40	0.504 (0.253)	-	-	0.517 (0.133)	0.445 (0.158)	0.349 (0.089)
		50	-	-	-	1.205 (0.093)	0.826 (0.087)	0.413 (0.118)

AWJ cutting achieved greater roundness than WJ cutting, particularly at high water pressure and low cutting speeds. Incomplete penetration data for the three-layer WPCs were excluded from the evaluation of hole quality. The relationship between the cutting parameters and roundness is displayed in Figures 9 and 10 for single-layer and three-layer WPCs, respectively. For single-layer WPCs, higher pressure and lower cutting speeds improved roundness, with AWJ cutting outperforming pure WJ cutting (Figure 8). This is consistent with the research on CFRP composites in [21], where the

circularity deviation decreased with increasing water pressure and slower traverse speed, resulting in improved jet stability. The large hole diameter of 12 mm in the AWJ cutting led to enhanced roundness stability across cutting speeds (Figures 8(f) and 9), because the jet maintained more linear motion along the curved path and was less affected by the cutting head vibration [22]. The AWJ cutting of three-layer WPCs at 350 MPa showed more fluctuating roundness with respect to the cutting speed compared to single-layer WPCs because of the layered material structure.

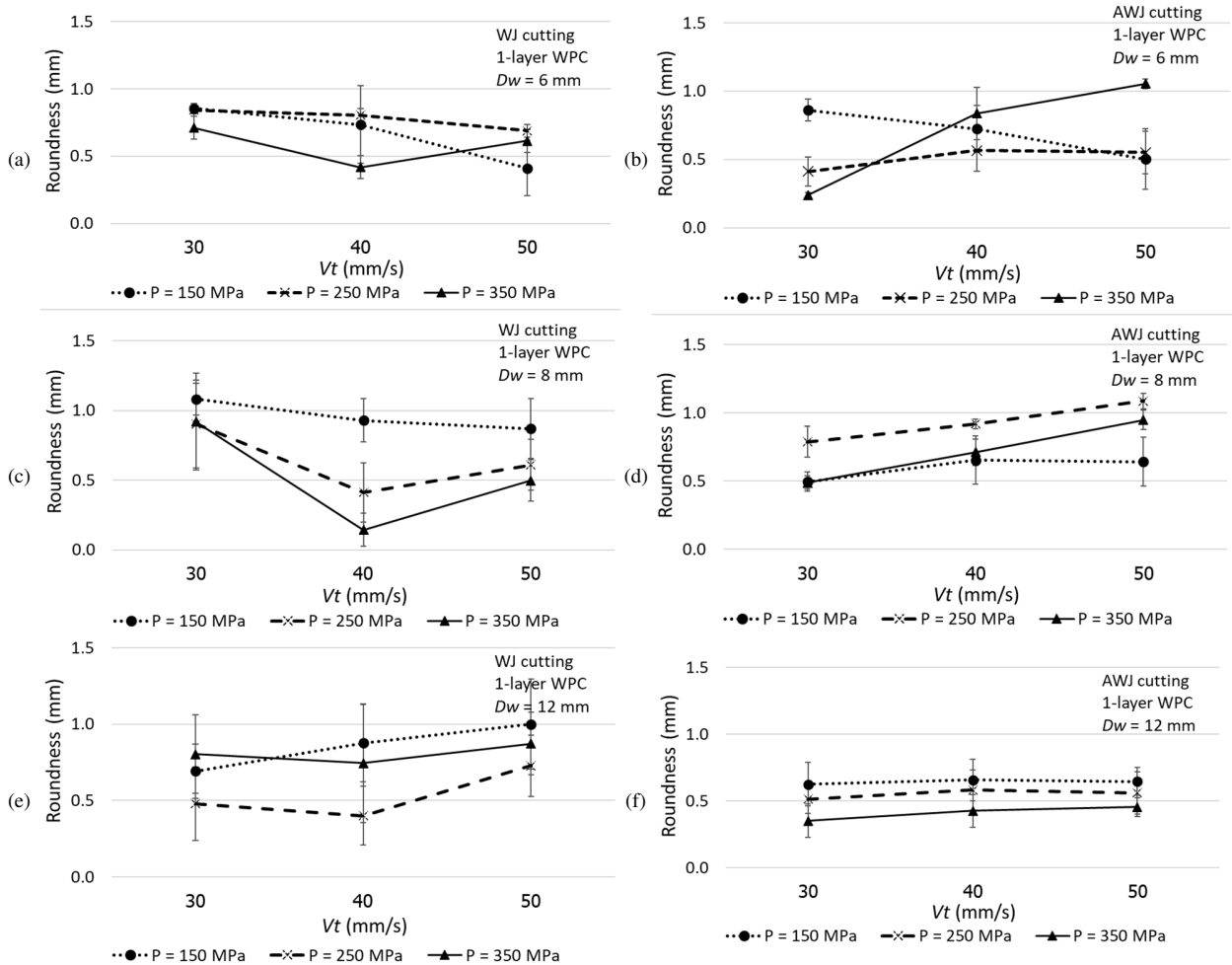


Fig. 9. Effects of cutting parameters on the roundness of single-layer WPCs.

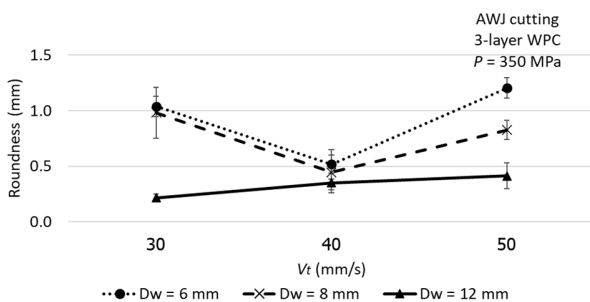


Fig. 10. Effects of cutting parameters on the roundness of three-layer WPC.

A comparison of the hole roundness using AWJ cutting (at 350 MPa water pressure and 30 mm/s traverse speed) and conventional drilling is presented in Table IV, with average values and standard deviations provided in parentheses.

As observed, convectional drilling produced superior roundness for both single-layer and three-layer WPCs, with averaged roundness within 0.08 mm, compared to average roundness within 1.00 mm for AWJ cutting (Figures 6 and 7). The imperfect roundness caused by AWJ cutting reflects the difference in the material removal mechanism. The drill bit effectively shreds the predominantly plastic WPCs, resulting in relatively uniform cutting force throughout the depth of cut

[23]. In contrast, the AWJ removes material through erosion, with machinability being influenced by the depth of cut and the layered structure of the composite [6]. This mechanism can induce burr formation, thereby degrading roundness. Despite operational limitations, such as noise, dust, and scalability for high-volume production, AWJ remains an environmentally friendly cutting technology [6]. AWJ provides advantages in machining variable hole sizes and enables continuous production by reducing processing time and eliminating tool-change interruptions. According to ISO 286-2: 2010 [24], holes produced by drilling are preferred for close running fits, while AWJ cutting is suitable for loose running fits with appropriate hole size compensation (d_f).

TABLE IV. COMPARISON OF HOLE ROUNDNESS BETWEEN AWJ CUTTING AND DRILL BIT

WPC	Diameter (mm)	Roundness (mm)		Roughness (mm)	
		AWJ	Drill bit	AWJ	Drill bit
1-layer	6	0.239 (0.125)	0.041 (0.012)	0.162 (0.075)	0.032 (0.009)
	8	0.488 (0.087)	0.025 (0.011)	0.151 (0.122)	0.027 (0.008)
	12	0.351 (0.115)	0.035 (0.008)	0.452 (0.103)	0.026 (0.010)
3-layers	6	0.940 (0.104)	0.052 (0.014)	0.251 (0.057)	0.028 (0.010)
	8	0.882 (0.085)	0.075 (0.009)	0.282 (0.069)	0.031 (0.009)
	12	0.248 (0.046)	0.050 (0.012)	0.305 (0.118)	0.024 (0.007)

C. Hole Surface Roughness

The mean surface roughness and the standard deviations for WJ and AWJ cutting at 350 MPa water pressure for both single-layer and three-layer WPCs are shown in Table V. Figures 11 and 12 illustrate the machined hole surface and the influence of cutting parameters on the roughness of WPCs.

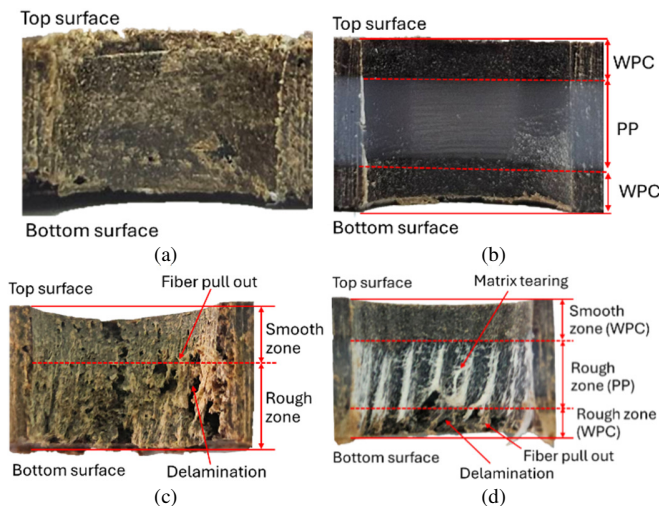


Fig. 11. Surface roughness: (a) drilling of single-layer WPCs, (b) drilling of three-layer, (c) AWJ cutting of single-layer WPCs, and (d) AWJ cutting of three-layer.

TABLE V. SURFACE ROUGHNESS RESULTS FOR SINGLE-LAYER AND THREE-LAYER WPCS

WPC	P (MPa)	Vt (mm/s)	WJ-roughness (mm)			AWJ-roughness (mm)		
			6	8	12	6	8	12
1-layer	350	30	0.544 (0.034)	0.592 (0.146)	0.613 (0.259)	0.160 (0.046)	0.155 (0.132)	0.471 (0.112)
		40	0.513 (0.116)	0.591 (0.101)	0.394 (0.079)	0.347 (0.122)	0.479 (0.162)	0.295 (0.014)
		50	0.588 (0.121)	0.484 (0.162)	0.524 (0.323)	0.588 (0.109)	0.544 (0.112)	0.564 (0.195)
3-layer	350	30	0.528 (0.103)	0.663 (0.148)	0.303 (0.247)	0.246 (0.037)	0.257 (0.055)	0.303 (0.120)
		40	0.687 (0.137)	-	-	0.579 (0.157)	0.377 (0.057)	0.319 (0.081)
		50	-	-	-	0.359 (0.203)	0.408 (0.102)	0.198 (0.023)

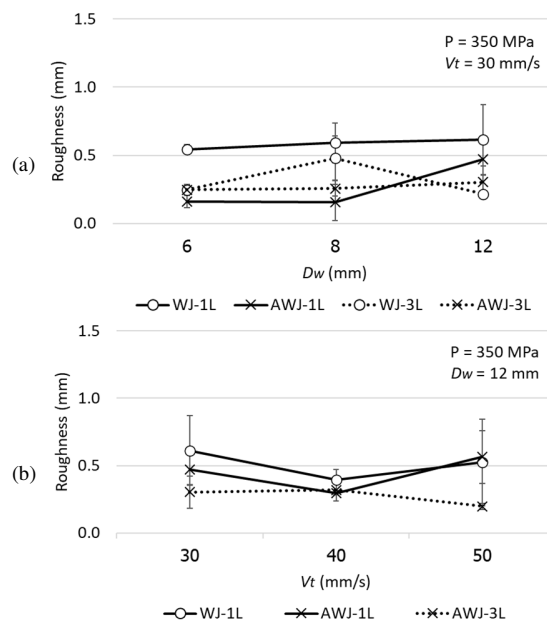


Fig. 12. Effects of cutting parameters on the surface roughness of WPCs: (a) hole diameter effect and (b) cutting speed effect.

Smooth surfaces were observed in the upper zone, whereas the deeper zone exhibited a rough surface, delamination, and fiber pull-out for both WPC structures (Figures 11 (c) and (d)). In three-layer WPCs, matrix tearing in the middle PP layer resulted in vertical stripes and grooves. These characteristics arise from the anisotropic response of fibers and matrix to cutting forces, with roughness primarily caused by fiber pull-out, tearing, and delamination [12]. Surface roughness increased with cutting depth due to reduced jet energy and unstable jet-workpiece interaction, consistent with [25].

There was no discernible pattern of roughness variation regarding process parameters for WPCs. Also, there was little difference in surface roughness between traversal speed and hole diameter cutting at 350 MPa water pressure (Figure 12). According to Figure 12(a), AWJ cutting produced smoother surfaces than WJ cutting at a traverse speed of 30 mm/s and a pressure of 350 MPa. The AWJ cutting parameters must be carefully controlled to obtain high surface quality levels, where smoother surfaces are produced by high abrasive flow and low

traversal speed [26]. A comparison of drilling (Figures 10(a) and (b)) and AWJ cutting (Figures 10(c) and (d)) shows that drilling yields smoother hole surface when appropriate conditions are applied. Good hole quality can be obtained by reducing trust force and torque with increased spindle speeds and decreased feed rates relative to the drill bit diameter [27]. In AWJ cutting, the distinct layered structure of composites results in varying machinability across depths, influencing different material removal behaviors and surface roughness [28]. A comparison of the surface roughness with conventional drilling (Table IV) reveals that drilling yields considerably less roughness than AWJ cutting, thus ignoring the need for finishing. Conversely, the surface roughness created by AWJ cutting reaches approximately 0.500 mm, suggesting that a further polishing operation is required to reduce friction in assembled component.

D. Regression Analysis of Hole Roundness in AWJ Cutting

AWJ can produce holes in both single-layer and three-layer WPCs; however, complete penetration in three-layer WPCs was not consistent across all cutting conditions. Regression analysis was employed to predict the hole roundness corresponding to the AWJ cutting parameters for the single-layer WPCs at a 95% confidence level. A normality test performed prior to the regression analysis provided a p-value of 0.228 (> 0.05), indicating that the roundness data had a normal distribution. The interactions of $P*V_t$ and $P*V_t * D_w$ have p-values less than 0.05, indicating a significant effect on roundness. As shown in Table VI, the initial model indicates a low adjusted R^2 of 38.86%, meaning insufficient prediction. Thus, insignificant variables (p-value > 0.05) were eliminated by a stepwise regression method to improve model accuracy. The updated regression model, as demonstrated in (2), provides an adjusted R^2 of 77.43%, which is considered satisfactory for predicting the hole roundness of single-layer WPCs.

TABLE VI. REGRESSION ANALYSIS OF HOLE ROUNDNESS OF AWJ CUTTING FOR SINGLE-LAYER WPCs

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	9	0.68855	0.07651	2.84	0.031*
P	1	0.11215	0.11215	4.16	0.057
V_t	1	0.01891	0.01891	0.70	0.414
D_w	1	0.06463	0.06463	2.40	0.140
$P*P$	1	0.00752	0.00752	0.28	0.604
V_t*V_t	1	0.01606	0.01606	0.60	0.451
$P*V_t$	1	0.21829	0.21829	8.09	0.011*
$P*D_w$	1	0.08853	0.08853	3.28	0.088
V_t*D_w	1	0.08425	0.08425	3.12	0.095
$P*V_t*D_w$	1	0.12635	0.12635	4.68	0.045*
Error	17	0.45852	0.02697		
Total	26	1.14706			
R-sq (adj)		38.86%			

Note: * Parameters have a significant effect on the p-value of less than 0.05.

$$R_h = -2.275 + 0.012P + 0.040V_t + 0.179 D_w - 1.500 \times 10^{-5} P^2 - 4.400 \times 10^{-4} P V_t - 0.003 V_t D_w \quad (2)$$

A regression model was developed to predict roundness, and the validation revealed a small difference of 3.19% between the predicted and actual values. Response optimization determined the optimal AWJ parameters as an abrasive mass flow rate of 6.67 g/s, a water pressure of 350 MPa, and a traverse speed of 30 mm/s, resulting in a

desirability index of 0.848 and a roundness of 0.351 mm. The model enables the prediction of hole roundness based on the AWJ cutting parameters and assists in optimal process selection, thereby reducing the number of trial experiments during the process setup.

IV. CONCLUSIONS

This research investigated hole machining for different Wood-Plastic Composite (WPC) structures utilizing Abrasive Waterjet (AWJ) cutting, and compared its performance with traditional drilling. A full factorial experimental design was conducted to examine the effects of cutting parameters, including water pressure, traverse speed, abrasive flow rate, and hole size on the hole characteristics, roundness, and surface roughness. The results show that complete hole penetration was achieved for all Waterjet (WJ) and AWJ cutting in single-layer WPCs; however, particular conditions were inadequate for through cutting in three-layer WPCs because of their higher strength. AWJ achieved better hole quality than WJ, with roundness and surface roughness being significantly affected by water pressure and traverse speed. Hole defects were more pronounced in three-layer WPCs than in single-layer WPCs due to higher strength and layered structure. A regression model was developed to predict roundness, and its validation showed that the average difference between the expected and actual values was about 3.19%. The model enables the prediction of hole roundness based on the AWJ cutting parameters and assists in optimal process selection, thereby reducing trial-and-error during process setup. Response optimization identified the optimal AWJ cutting parameters as an abrasive flow rate of 6.67 g/s, a water pressure of 350 MPa, and a traverse speed of 30 mm/s. This led to a roundness of 0.351 mm and a desirability index of 0.848. In comparison to conventional drilling, this method produces better roundness within 0.08 mm, while AWJ enables a roundness of up to 1.00 mm. Nevertheless, the AWJ provides an acceptable alternative for hole machining in WPCs. Drilling is proposed for close running fits due to its superior roundness, whereas AWJ is suitable for loose running fits with proper hole size compensation. Considering surface roughness, the drilling results in significantly lower roughness compared to AWJ cutting and requires no finishing process, while AWJ cutting generates a surface roughness reach to 0.500 mm, necessitating additional polishing to minimize friction in assembled component. AWJ provides advantages in processing time by eliminating tool change disruption and offering flexibility in hole dimensions. These findings provide practical guidance for selecting AWJ conditions from an industrial perspective to improve machined hole quality and productivity in WPC machining applications.

DATA AVAILABILITY

The data presented in this study are available from the corresponding author upon reasonable request.

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