Pertanika J. Sci. & Technol. 32 (S2): 135 - 149 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Effect of Cutting Speed and Feed per Tooth on the Trimmed Surface Roughness and Tool Wear During Milling of CFRP: Aerostructural Part

Syahrul Azwan Sundi[1]*, Izzat Afandi Abdul Hakim[1], Mohd Farid Mahadi[1], Noramin Nazar Shah[1], Raja Izamshah[1], Intan Sharhida Othman[1], Mohd Shahir Kasim[2] and Mohd Nor Hafizi Noordin[3]

[1]*Faculty of Industrial and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*
[2]*Faculty of Design of Innovative and Technology, Universiti Sultan Zainal Abidin (UNISZA), Kampung Gong Badak, 21300, Terengganu, Malaysia*
[3]*Defense Research Institute (DRI), Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi 57000 Kuala Lumpur, Malaysia*

ABSTRACT

The machining quality plays a pivotal role in determining the service life of components. In this context, the primary focus of the experimental investigation is centered on the impact of cutting conditions during edge trimming of carbon fiber reinforced plastics (CFRP) material. The ultimate objective of this experiment is to pinpoint the most effective machining parameters, specifically the cutting speed, V_c and the feed per tooth, f_z, to minimize damages during the edge trimming process using actual aerostructural sample components composed of CFRP material. Furthermore, the study took into account the issue of tool wear on cutting tools. The Design of Experiment (DoE) technique, specifically the Taguchi L_9 orthogonal arrays method, was used to conduct this research. It was shown that the feed per tooth, f_z, and the cutting speed, V_c, had the biggest effects on the trimmed surface quality as the longitudinal surface roughness increased. It was demonstrated that the fracture of the pyramidal tooltips in router-type tools happened more frequently at higher cutting speeds, V_c. The optimal machining parameters for minimizing damages during CFRP edge trimming were

ARTICLE INFO

Article history:
Received: 16 August 2023
Accepted: 09 May 2024
Published: 14 June 2024

DOI: https://doi.org/10.47836/pjst.32.S2.09

E-mail addresses:
syahrul.azwan@utem.edu.my (Syahrul Azwan Sundi)
m052220004@student.utem.edu.my (Izzat Afandi Abdul Hakim)
m052220002@student.utem.edu.my (Mohd Farid Mahadi)
m052220034@student.utem.edu.my (Noramin Nazar Shah)
izamshah@utem.edu.my (Raja Izamshah)
intan_sharhida@utem.edu.my (Intan Sharhida Othman)
shahirkasim@unisza.edu.my (Mohd Shahir Kasim)
mohdhafizi@upnm.edu.my (Mohd Nor Hafizi Noordin)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

the combination of the feed per tooth, f_z at 0.05 mm and cutting speed, V_c at 50 m/min. The most significant element influencing the tool's wear was the cutting speed, V_c.

Keywords: Carbon fiber reinforced plastics (CFRP), machining conditions, milling, surface quality, tool wear

INTRODUCTION

Due to a few benefits, like being lightweight and having high modulus, specific strength, and corrosion resistance, carbon fiber reinforced plastics (CFRP) are becoming a more significant and vital material in the aerospace sector. The usage of CFRP materials has been on an upward trend over the past year. For instance, the weight of the composite structure in the Boeing 777, which entered service in 1995, was only 10 %, whereas the aircraft A350 XWB began using over 50 % of the composite structure in 2010 (Hashish, 2013). This outcome unmistakably demonstrates the interest and demand for the use of CFRP by the aerospace sector.

Comprehending the complicated phenomenon of composite behavior, including its inhomogeneity and interaction with the cutting tool during machining, is crucial. The quality of the machined composite part, such as delamination, cracking, fiber pull-out, and burned matrices, may be caused by the machining process. The abrasive character of the reinforcement fibers and the necessity of neatly shearing them impose additional demands and limitations on the choice of optimal tool materials and shape (Sheikh Ahmed, 2009). Surface roughness is one of the measurable factors that significantly affect dimensional accuracy, the functioning of the machined composite's mechanical properties, and the overall cost of manufacture. Understanding the kinetics of machining operations and the mechanics of material removal is essential to achieving the appropriate surface roughness of the machined surface.

Literature Review

Numerous difficulties arise while attempting to determine the proper machining parameters for cutting the edges of CFRP material. When milling CFRP, problems with integrity and surface finish are common (Sheikh-Ahmed & Shahid, 2013). Surface finish and damage are the two characteristics that define the surface quality produced by finish machining CFRP. When two panels are assembled in the aerospace industry, a higher degree of surface roughness will impact the CFRP's quality since it cannot bond the two together. On the other side, while milling CFRP material, the rapid tool wear brought on by the abrasive nature of composite materials provides another challenge—the imperfect machining at a faster transverse causes rapid tool wear. The rise in feed rate during machining is widely thought to be the primary driver of this issue. The overall tool wear rate is also influenced by the depth of the cut (Halim et al., 2017).

Bi et al. (2022) investigated the wear characteristics of uncoated multiple flutes for milling operations. Their research encompassed a range of feeds per tooth, spanning from 0.01 to 0.15 mm/tooth while keeping spindle speed constant at 3000 rpm. Through a combination of theoretical analysis and practical experimentation, the authors proved the influence of tool wear on machining performance. They uncovered that the top ply exhibited less burr damage, primarily due to the dominance of SLHCE in the top ply cutting process, which resulted in less pronounced tool wear, thanks to clearance. In contrast, the bottom ply experienced greater cutting dominance by SRHCE, leading to increased damage.

Duboust et al. (2016, 2017) substantiated that surface quality was most significantly affected by the feed rate and the type of tool used. Fiber orientation emerged as a crucial factor in the chip removal mechanism and surface damage. Can (2017) indicated that inclined machining positions consistently yielded superior along and cross-directional surface trimmed quality compared to vertical machining across all cutting conditions. Furthermore, in a study by Khairusshima et al. (2017), an optimization study on CFRP material milling employing the Response Surface Method (RSM) revealed that the most substantial impact on trimmed surface roughness and delamination of the CFRP material was the feed rate when deployed helical helix end mill tool. The quality of the trimmed surface finish along the machining direction is correlated with a higher feed rate and lower spindle speed, which is caused by the increase in the effectiveness of chip thickness (Sheikh-Ahmed & Shahid, 2013).

Wang et al. *(*2016) established that cutting speed played a pivotal role in influencing the cutting temperature during CFRP composite material milling. Following cutting speed, feed rate and radial depth of cut were identified as secondary factors. In two separate studies, Sundi et al. (2019) highlighted that the geometric features of tools, particularly the number of teeth or flutes in router-type tools, had a notable impact on the resulting surface quality when performing edge trimming on specific CFRP materials.

More recently, Cunningham et al. (2018) conducted a comparative analysis of Multi-tooth (MT) or burr tools and Up-Down or Compression Routers (UD) under cryogenic conditions. They found that cryogenic machining improved both tool geometries' average surface roughness and delamination length. In a separate study by Kuo et al. (2021), various cutting scenarios were modeled during the trimming of composite materials, mainly the CFRP. This simulation investigated the impact of cutting circumstances on delayed tool wear, vibrations, and the consequent surface integrity while accounting for the deflections caused in the cutting tools by bending moments. The study's conclusions provided an overview of the underlying cutting mechanisms in charge of cutting forces and tool flank wear, as well as information on how they affect the texture, roughness, and topography of machined surfaces.

In contrast to previous research efforts, the current study analyzes a specific type of CFRP material that exhibits distinct characteristics. Notably, this material adheres to aerospace standards. Moreover, the study introduces a unique range of cutting parameters distinct from existing literature. The primary objective is to investigate the impact of the cutting speed, V_c and the feed per tooth, f_z, on the quality of trimmed surfaces when using a burr tool for edge trimming this particular CFRP material. The trimmed surfaces underwent thorough examination using a surf-tester apparatus to quantify the average surface roughness, denoted as Ra. Additionally, microscopy tools were employed to analyze the machined surfaces in detail to better understand the underlying processes. The study also monitored tool wear rates using appropriate equipment to establish a correlation between surface damage and tool wear.

MATERIALS AND METHODS

Methodology Overview

The cutting speed, V_c, and the feed per tooth, f_z, were the primary cutting conditions chosen for the current work-study. On a real sample of an aerostructural composite panel with the specifications stated in the next paragraph, experimental work was done using a router tool type. At the conclusion of the research milestone, longitudinal surface roughness and tool wear observation were the principal analyses performed. The overall structure of the current research work is summarized in Figure 1.

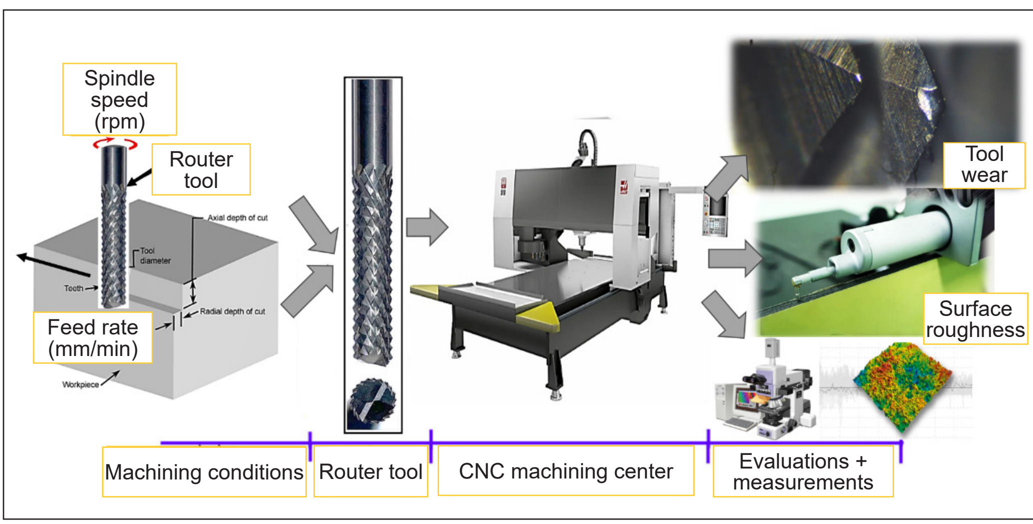


Figure 1. Illustration of the research methodology overview

Materials

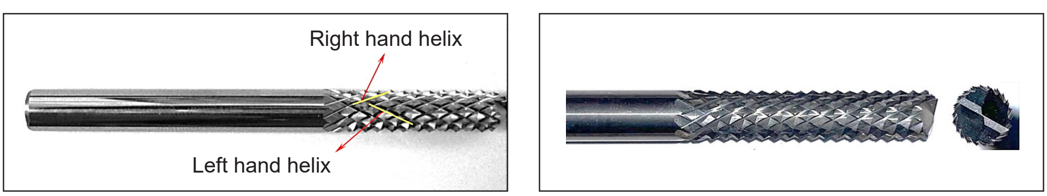
The thickness of the CFRP specimen used in this work was 3.25 mm, made of unidirectional (UD) fabric. It contained 26 plies, including two thin layers of woven glass/epoxy textiles. The Hexcel Composite Company's carbon/epoxy prepreg created the 26 unidirectional plies. The composite was stacked in the following order: [45/135/90_2/0/90/0/90/0/135/4 5_2/135]s. The areal density of the carbon plywood was 203 g/ m^2, compared to 107 g/m^2 for the glass. While the glass ply was woven, the carbon ply had a single-directional (UD) fiber arrangement. The CFRP was compacted using a vacuum pump under controlled atmospheric conditions during curing. The laminate was prepared in a mold and then placed inside an autoclave. The curing cycle involved heating the temperature to 180°C at 3°C/min and maintaining it for 120 minutes. Subsequently, the temperature gradually lowered to room temperature at the same rate. The cycle occurred under a pressure of 700 kPa within the autoclave while being vacuum-bagged and evacuated to 70 kPa. The glass had a cured ply thickness (CPT) of 0.08, while the carbon had a CPT of 0.125. Employing this curing recipe yields a nominal fiber volume fraction of 60%.

Cutting Tool

Table 1 describes the cutting tool utilized in this project, which has a 6.35 mm diameter. It is an uncoated tungsten carbide router or burr tool. The specific tool geometries used during the current work's experimental phases are detailed in Figure 2. There were nine tools in total were used, one for each run.

Table 1
Cutting tool geometries/details

	Diameter (mm)	Number of teeth	Number of helix		Angle of the helix (°)		Length (mm)
			Right	Left	Right	Left	
Burr/Router	6.35	10	10	10	30	30	75



(a) (b)

Figure 2. Geometry information for the burr or router tool; (a) geometric specifics; and (b) physical representation of the tool

Design of Experiment

One of the statistical methods, the Taguchi method (Orthogonal Array L_9), was used to arrange the entire experiment. This investigation focused on two machining parameters: the cutting speed, V_c and the feed per tooth, f_z. The cutting speed, V_c settings were 50 m/min (low), 100 m/min (medium), and 150 m/min (high), with feed per tooth, f_z set to 0.05 mm (low), 0.1 mm (medium), and 0.15 mm (high). In the following formulas, the correlations between cutting speed (V_c), spindle speed (N), feed per tooth (f_z), and feed rate (Vf) are illustrated. On the other hand, Table 2 provides the edge-trimming parameters that were used in this research.

$$\mathrm{Vc} = \frac{\pi \times \mathrm{D} \times \mathrm{N}}{1000} \qquad (1)$$

$$\mathrm{fz} = \frac{\mathrm{Vf}}{\mathrm{N}} \quad \mathrm{fz} = \frac{\mathrm{Vf}}{\mathrm{N}} \qquad (2)$$

where V_c = cutting speed, D = diameter of cutting tool, N = spindle speed, f_z = feed per tooth, V_f = feed rate.

Table 2
Machining settings

Run (R)	**Cutting Speed, V_c (m/min)**	**RPM**	**Feed per Tooth, F_z (mm)**	V_f (mm/min)
1	50	**2526**	0.05	**125**
2	100	**5053**	0.15	**752**
3	50	**2526**	0.1	**251**
4	100	**5053**	0.05	**251**
5	100	**5053**	0.1	**501**
6	150	**7579**	0.1	**752**
7	150	**7579**	0.05	**376**
8	50	**2526**	0.15	**376**
9	150	**7579**	0.15	**1128**

Taguchi Method

The Taguchi method represents a structured approach essential in experimental design and data analysis, particularly concerning Taguchi L_9 orthogonal arrays. It is carefully crafted to conduct controlled experiments to gain valuable insights into process behavior. Through the utilization of this method, researchers concentrate on fine-tuning process parameters to achieve optimal output characteristics across diverse materials. At the heart of this approach lies the optimization of crucial output attributes such as material surface quality, tool wear, and surface roughness (Ra). These attributes play a pivotal role in determining the quality and performance of machined components.

Signal-to-Noise (SN) ratios—a crucial component in assessing performance and variability—are integrated into the Taguchi approach. SN ratios are useful for evaluating the desired output's quality in terms of noise components and provide a thorough understanding of process behavior. When applied with L_9 orthogonal arrays, this methodical technique promotes a comprehensive understanding of the process under study. It gives researchers the ability to maximize parameters and provide better-than-average results. In the end, this approach greatly advances the field overall, improves efficiency, and refines operations (Pang et al., 2014; Ramnath et al., 2017).

Surface Roughness Measurement and Tool Wear Observation

The workpiece's surface finish was measured using a Mitutoyo Surftest SJ-410 surface roughness tester. In this study, the assessment of surface roughness was referred to as Ra (Arithmetical mean deviation). Longitudinal surface roughness was assessed with each measurement's stylus traveling a distance set to 4 mm. Each machined surface was assessed at five measurement sites, and the ultimate average Ra value was computed to quantify the level of surface smoothness for each specimen. Figure 3 displays the measurement apparatus for determining the quality of the surface roughness.

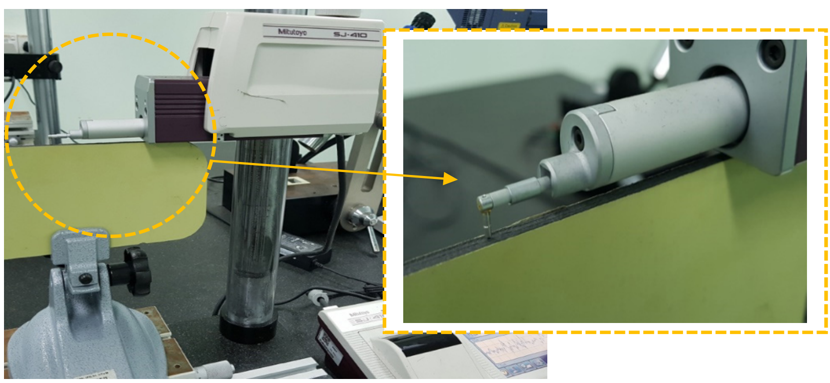


Figure 3. Mitutoyo SJ-410 surf tester equipment for surface quality evaluation

An optical microscope, Nikon MM-800, was also used to check each cutting tool's tool wear and learn how each machined surface was finished. With a magnification range of 1× to 100×, this microscope made it easier to spot tool wear or damage and provided a sharper picture of what was happening on the trimmed surfaces. E-max software attached to a personal computer eased the image capturing and data processing when the specimen was under the microscope. Both surface damage observations and tool wear assessments were made with the Nikon MM-800 microscope, as shown in Figures 4 and 5. The burr tooltip, which is the primary area of engagement during the machining process, was the focus of the evaluation of the tool wear following the CFRP trimming.

RESULTS AND DISCUSSION

When specifying the surface quality of machined CFRP material in production, surface roughness plays a significant impact. The surface layer can be quickly altered during manufacturing, which alters the composite's mechanical characteristics.

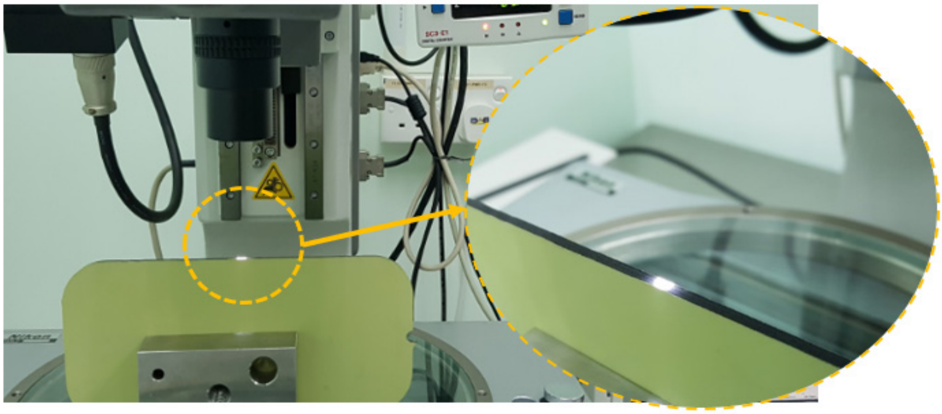


Figure 4. Examination of surface damage on trimmed surfaces using the Nikon MM-800

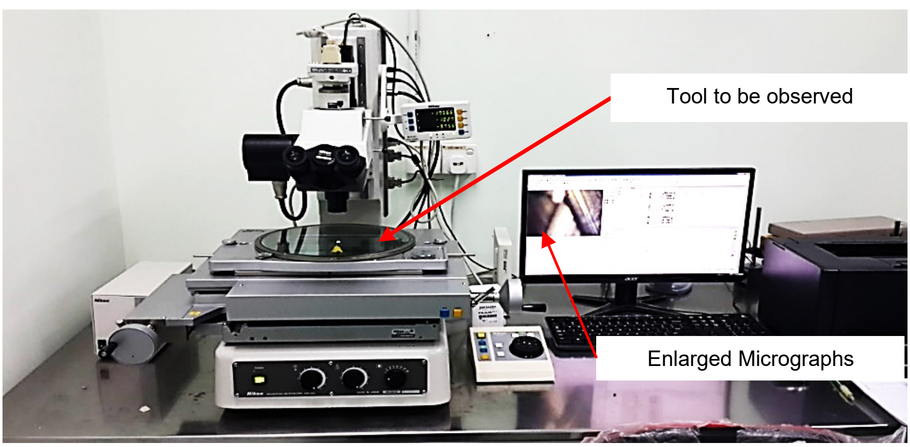


Figure 5. Observation of tool wear using the Nikon MM-800 optical microscope

In general, Figure 6 demonstrates that an increase in the feed per tooth, f_z, will cause an increase in the Ra value of surface roughness for all three cutting speeds, V_c applied. Surface roughness rises proportionately as the feed per tooth, f_z, rises. The lowest average Ra value of surface roughness was seen in run 8, which has a cutting speed, V_c at 50 m/min and the feed per tooth, f_z, at 0.15 mm. The surface roughness measurement, Ra, generated the maximum value for the highest cutting speed, V_c at 150 m/min and the highest feed per tooth, f_z, at 0.15 mm, represented by run 9.

A rougher finish on the trimmed surface resulted from increased cutting speed, V_c and the feed per tooth, f_z. This finding is consistent with a prior study by Karataş and Gökkaya (2018), who found that greater feed rates, V_f, were associated with increased trimmed or milled surface quality. In contrast, higher cutting speeds, V_c, were associated with a

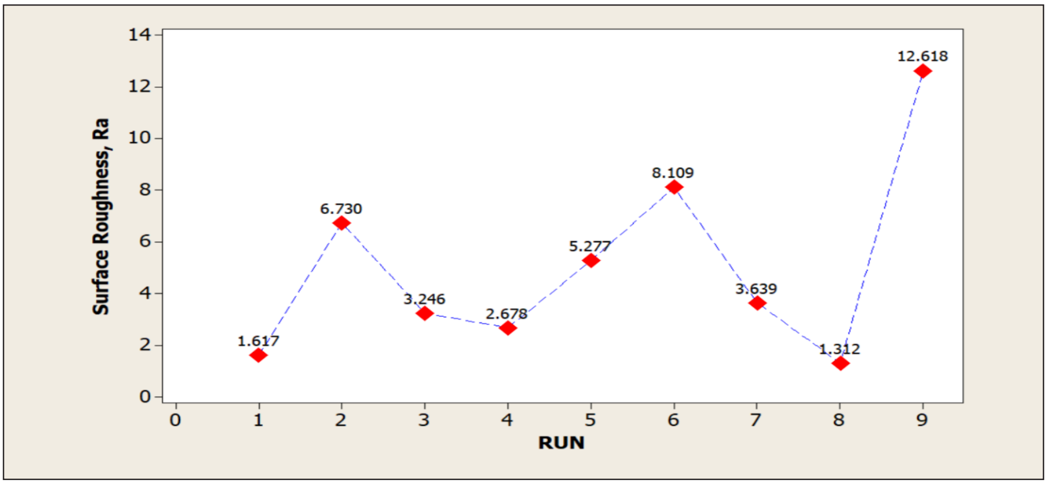


Figure 6. Average surface roughness, Ra value vs. number of Runs (refer to Table 2)

similar decrease. In contrast, Bi et al. (2022) findings showed that lower feed rates, V_f (0.01 mm/tooth) or lower feed per tooth, f_z (0.01 mm/tooth), led to more severe tool wear and lower-quality machining.

Taguchi—Signal to Noise (SN) Ratio Analysis

The means of the SN ratio for the smaller, better qualities of surface roughness, as determined by Minitab software, are shown in Figure 7. The graphs' slope unequivocally demonstrates that feed per tooth, f_z, is the second most important element influencing the trimmed surface quality after cutting speed, V_c. Of all the cutting settings examined, the best combination for achieving the best surface roughness was 50 m/min of cutting speed, V_c and 0.05 mm of feed per tooth, f_z. Both settings were the first or the smallest settings overalls.

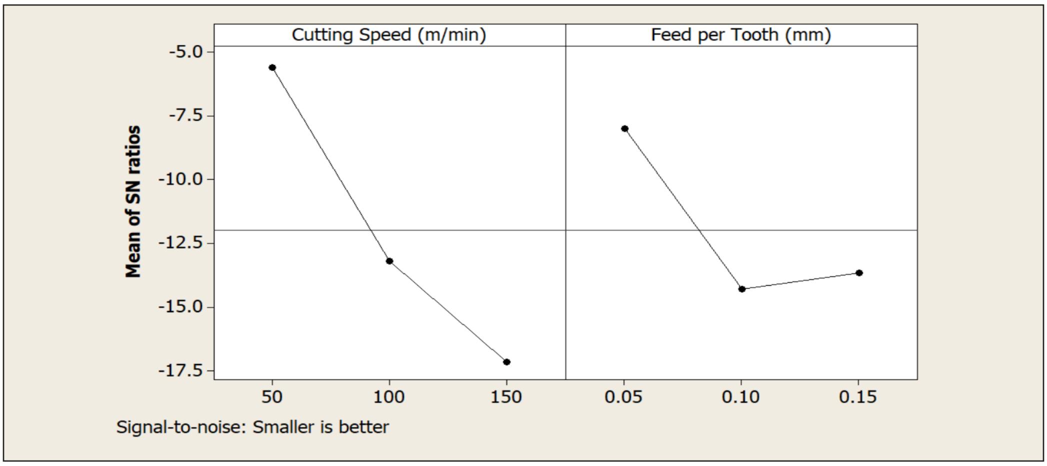


Figure 7. Main effects plot for signal-to-noise (SN) ratio (data means)

Microscopy Evaluation

From looking at the microscopic photos of the machined surface in run 3 operated at a cutting speed, V_c of 50 m/min and a feed per tooth, f_z of 0.10 mm, some areas had experienced fiber pull-out (Figure 8a). A clear illustration of a well-machined surface with no obvious flaws is shown in Figure 8(d). However, Figure 8(b) reveals some areas exhibiting matrix smearing and visible signs of matrix burnout. Notably, the extent of damage increased with higher spindle speeds and feed rates.

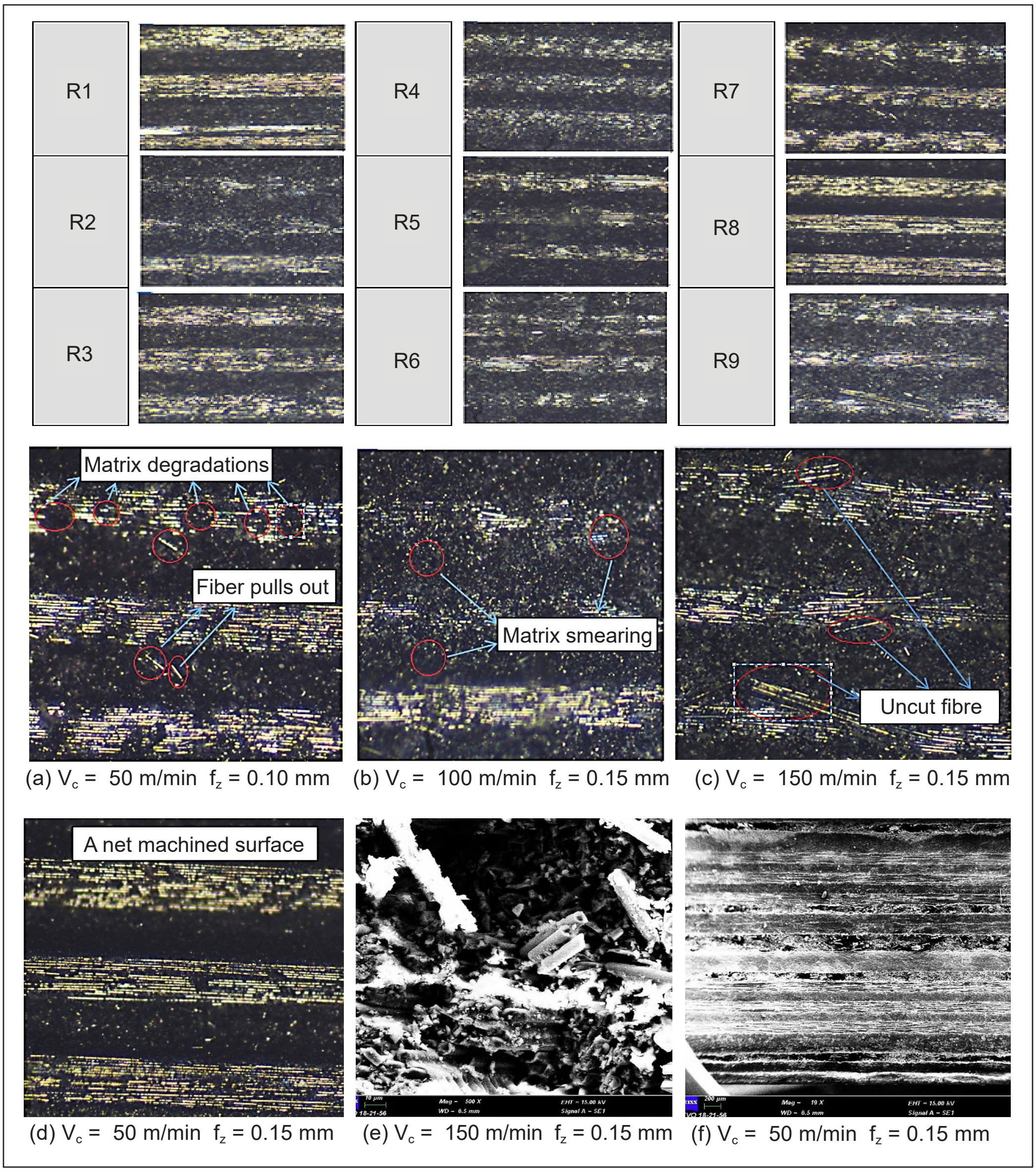


Figure 8. Overall microscopic images and SEM images of the trimmed surface

Conversely, the combination of trimming parameters featuring a cutting speed, V_c of 150 m/min and a feed per tooth, f_z of 0.15 mm in run 9 resulted in the most severe surface damage, as evident from the microscopic and SEM images in Figure 8(e). These images depict most fibers remaining uncut and illustrate the poorest surface integrity among all the tested conditions.

Tool Wear Observation

The examination of the burrs tool after the CFRP trimming process revealed fractures in the tooltip, and the corresponding data is presented in Table 3. It is evident that the cutting tool was subjected to a lower cutting speed, and V_c exhibited minimal damage compared to the others. Runs 2, 4, and 5, where moderate cutting speed, V_c, at 100 mm/min, was utilized, showed moderate damage to the tools. However, the most significant tool fractures were observed in runs 6, 7, and 9, where the damage to the tooltip was notably pronounced. This underscored the relationship between higher cutting speed, V_c and increased tool tip fractures. Additionally, it became apparent that the tool's wear condition influenced surface roughness values, with higher tool wear correlating with elevated surface roughness readings. Figure 9 depicts the photomicrograph of run 9, which appeared to align with the observed surface finish.

Furthermore, the variation in applied feed rates also generally impacted tool wear. These findings aligned with those of Cunningham et al. (2018), who reported that surface

Table 3
Images of tooth fracture

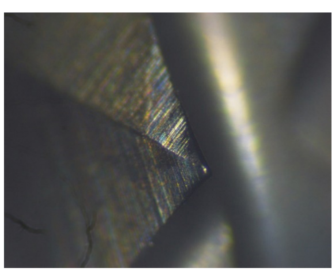
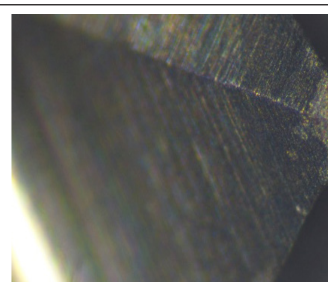
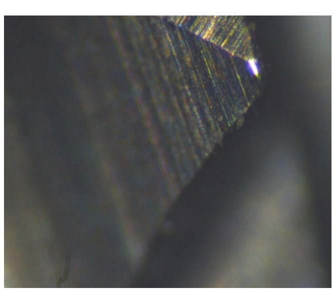
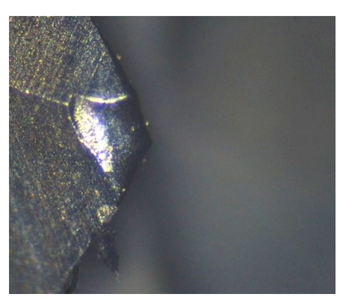
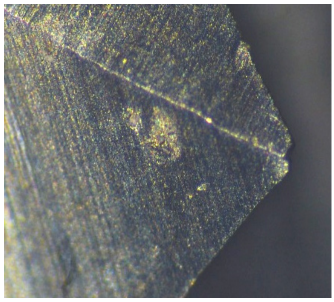
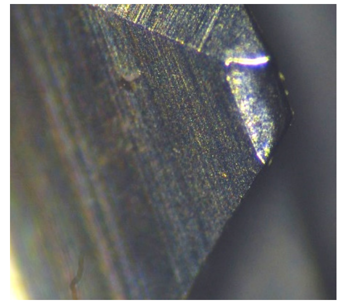
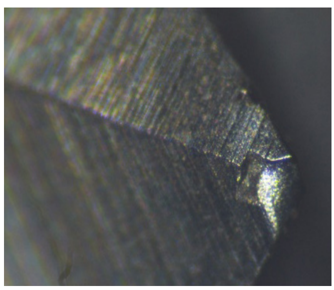
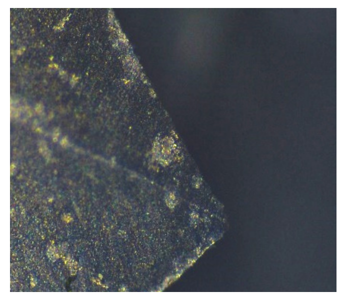
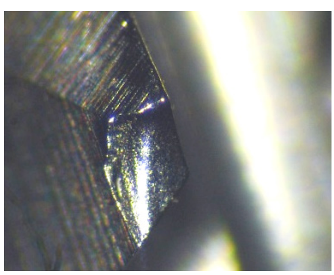
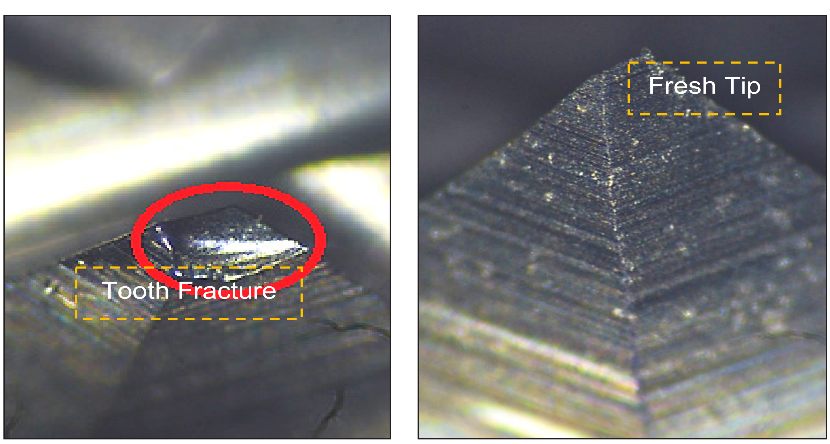
RUN No.	Tooth Fracture	RUN No.	Tooth Fracture
(1)		(2)	
(3)		(4)	

Table 3 *(continue)*

RUN No.	Tooth Fracture	RUN No.	Tooth Fracture
(5)		**(6)**	
(7)		**(8)**	
(9)			



(a) (b)

Figure 9. (a) Fractured tooth; and (b) tooltip of pyramid tooth still obviously seen

roughness worsened with increasing tool wear, primarily affecting the CFRP panel. In a separate study by Devan et al. (2022) and Urresti et al. (2022), it was noted that tool wear was primarily influenced by abrasive wear and the rounding of the cutting edge, attributed to the hard abrasion of carbide grains. The study also concluded that tool life is inversely proportional to cutting speed, V_c feed speed, V_f and depth of cut.

CONCLUSION

This study clarifies the effect of the cutting speed, V_c and the feed per tooth, f_z, on the edge-trimming of CFRP material during the machining process.

1. The cutting speed, $V_{c,}$ as the longitudinal surface roughness rose with greater feed per tooth, f_z, was shown to have the greatest influence on the trimmed surface quality.
2. It was shown that at greater cutting speed, V_c, the fracturing of the pyramidal tooltips in router-type tools occurred more frequently.
3. Based on the SN ratio study, it was determined that the combination of the cutting speed, V_c and the feed per tooth, f_z at level 1 (50 m/min and 0.05 mm) resulted in the best machining parameters for reducing damages during CFRP edge trimming.
4. The cutting speed, V_c, has been shown to have the greatest influence on the effect of the tool damage during CFRP edge trimming.

ACKNOWLEDGEMENTS

The authors appreciate the financial support from the Ministry of Education (MOE), Malaysia, and Universiti Teknikal Malaysia Melaka (UTeM). Short-term Grant, PJP/2022/FTKMP/S01896 and Industrial Matching Grant, INDUSTRI(URMG)/EISSB/FTKMP/2023/I00078 were utilized to fund the project.

REFERENCES

Bi, G., Wang, F., Fu, R., & Chen, P. (2022). Wear characteristics of multi-tooth milling cutter in milling CFRP and its impact on machining performance. *Journal of Manufacturing Processes, 81*, 580-593. https://doi.org/10.1016/j.jmapro.2022.07.008

Can, A. (2017). Effect of edge trimming parameters on surface quality of C arbon fiber reinforced polymer composites. *Journal of Science Engineering, 17*(1), 302–311. https://doi.org/10.5578/fmbd.54017.

Karataş, M. A., & Gökkaya, H. (2018). A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials.-*Defence Technology*, *14*(4), 318–326. https://doi.org/10.1016/j.dt.2018.02.001

Kuo, C., Liu, J., Chang, T., & Ko, S. (2021). The effects of cutting conditions and tool geometry on mechanics, tool wear and machined surface integrity when routing CFRP composites. *Journal of Manufacturing Processes, 64*, 113-129. https://doi.org/10.1016/j.jmapro.2021.01.011

Cunningham, C. R., Shokrani, A. and Dhokia, V. (2018). Edge trimming of carbon fiber reinforced plastic. *Procedia CIRP, 77,* 199-202. https://doi.org/10.1016/j.procir.2018.08.285

Devan, D. J., Almaskari, F., Sheikh-Ahmad, J., & Hafeez, F. (2022). A study on tool wear of tungsten carbide cutters in edge trimming of CFRP. *Journal of Mechanical Science and Technology, 36*(5), 2499-2510. https://doi.org/10.1007/s12206-022-0432-z

Duboust, N., Melis, D., Pinna, C., Ghadbeigi, H., Collis, A., Ayvar-Soberanis, S., & Kerrigan, K. (2016). Machining of carbon fiber : Optical surface damage characterisation and tool wear study. *Procedia CIRP, 45,* 71–74. https://doi.org/10.1016/j.procir.2016.02.170

Duboust, N., Ghadbeigi, H., Pinna, C., Ayvar-Soberanis, S., Collis, A., Scaife, R., & Kerrigan, K. (2017). An optical method for measuring surface roughness of machined carbon fiber-reinforced plastic composites. *Journal of Composite Materials, 51*(3), 289–302. https://doi.org/10.1177/0021998316644849.

Halim, N. F. H. A., Ascroft, H. & Barnes, S. (2017). Analysis of tool wear, cutting force, surface roughness and machining temperature during finishing operation of ultrasonic assisted milling (UAM) of carbon fiber reinforced plastic (CFRP). *Procedia Engineering, 184,* 185–191. https://doi.org/10.1016/j.proeng.2017.04.084.

Hashish, M. (2013, September 9-11). *Trimming of CFRP aircraft components*. [Paper presentation]. WJTA-IMCA Conference and Expo, Texas, USA.

Khairusshima, M. K. N., Aqella, A. K. N., & Sharifah, I. S. S. (2017). Optimization of milling carbon fiber reinforced plastic using RSM. *Procedia Engineering, 184,* 518–528. https://doi.org/10.1016/j.proeng.2017.04.122.

Pang, J. S., Ansari, M. N. M., Zaroog, O. S., Ali, M. H., & Sapuan, S. M. (2014). Taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite. *HBRC Journal, 10*(2), 138-144. https://doi.org/10.1016/j.hbrcj.2013.09.007

Ramnath, B. V., Sharavanan, S., & Jeykrishnan, J. (2017). Optimization of process parameters in drilling of fibre hybrid composite using Taguchi and grey relational analysis. *IOP Conference Series: Materials Science and Engineering 183*(1), Article 012003. https://doi.org/10.1088/1757-899X/183/1/012003

Sheikh-Ahmad, J., & Shahid, A. H. (2013). Effect of edge trimming on failure stress of carbon fiber polymer composites. *International Journal of Machining and Machinability of Materials, 13*(2-3), 331-347. https://doi.org/10.1504/IJMMM.2013.053231

Sundi, S. A., Izamshah, R., Kasim, M. S., & Abdullah, M. K. A. (2019). Effect of machining parameters on surface quality during edge trimming of multi-directional CFRP material: Taguchi method. *IOP Conference Series, Materials Science and Engineering, 469*(1), Article 012095. https://doi.org/10.1088/1757-899X/469/1/012095.

Sundi, S. A., Izamshah, R., Kasim, M. S., Amin, A. M., & Kumaran, T. (2019). Influence of router tool geometry on surface finish in edge trimming of multi-directional CFRP material. *IOP Conference Series: Materials Science and Engineering, 469*(1), Article 012026. https://doi.org/10.1088/1757-899X/469/1/012026.

Urresti, I., Llanos, I., de Lacalle, L. L., & Zelaieta, O. (2022) Study of the surface integrity during CFRP trimming: Tool material and geometry, fiber orientation and tool wear effect analysis. *Procedia CIRP, 108*, 660-664. https://doi.org/10.1016/j.procir.2022.03.102

Wang, H., Sun, J., Li, J., Lu, L., & Li, N. (2016). Evaluation of cutting force and cutting temperature in milling carbon fiber-reinforced polymer composites. *International Journal of Advanced Manufacturing Technology, 82*(9–12), 1517–1525. https://doi.org/10.1007/s00170-015-7479-2.