

EVALUATION OF MILLING/TRIMMING PERFORMANCES FOR CFRP MATERIAL UTILIZING VARIOUS BURR/ROUTER TOOL GEOMETRICAL FEATURES



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2021

DECLARATION

I declare that this Choose an item. entitled "Evaluation Of Milling/Trimming Performances For CFRP Material Utilizing Various Burr/Router Tool Geometrical Features" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

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DEDICATION

Alhamdulillah praise to Allah for the strength, guidance and knowledge that was given by Allah for me to complete this study. A special appreciation, I dedicate this thesis to my beloved parents, Mohd Hasni Bin Bakar and Ruhaizah Binti Ramli. Finally, for my supervisor Mr Syahrul Azwan Bin Sundi@Suandi, a lot of thanks to him for guidance and advices in completing this thesis



ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) has found significant application in a variety of industrial sectors, particularly in the aerospace and automotive industries, due to its superior mechanical properties such as high strength, light weight, and corrosion resistance. The objective of the experiment was to study the optimum router tool geometry for the specific CFRP materials. The second objective of this research is to investigate the effect of the surface quality and the tool wear when various tool geometry of router type is used during edge trimming of CFRP material. Finally, to propose the most optimal burr/router tool geometry for trimming a specific CFRP material. The selected study material was a CFRP panel with a thickness of 3.25 mm and a total of 28 plies. Three different types of tool geometries manufactured of tungsten carbide material with the same diameter, 6.35 mm, while varying in the number of flutes and helix angle were successfully studied. The Model Pro II MDX-540 was used to trim the CFRP edges. The surface roughness of panel material is measured with the Mitutoyo Surftest SJ-410. A Kistler Dynamometer type 9257B was used to measure the cutting force. A Nikon MM-800 measuring microscope was used to evaluate tool wear. Following the conclusion of three cutting tool processes, all data gathered was evaluated. To prevent CFRP damage during edge trimming, an ideal set of machining parameters is used. A spindle speed of 5938 RPM, a cutting speed of 118.47 m/min, and a feed rate of 297mm/min are the optimal machining setup. For each tool, the machine mode is down and up cutting. Cutting tool 1 (T1) provided the least amount of surface roughness when compared to the overall mean value in both machining directions, according to the data. The cutting tool 2 (T2), on the other hand, has the highest surface roughness value. In the meantime, cutting tool type 3 (T3) is halfway between the other two tool types. In comparison to T1, when the tip of the pyramid cutting edge tool is really obviously smooth, tool wear observations show evident fractures at T2 and T3.

ABSTRAK

Polimer Bertetulang Gentian Karbon (CFRP) telah menemui aplikasi penting dalam pelbagai sektor perindustrian, terutamanya dalam industri aeroangkasa dan automotif, kerana sifat mekanikalnya yang unggul seperti kekuatan tinggi, ringan dan rintangan kakisan. Objektif eksperimen adalah untuk mengkaji geometri alat penghala yang optimum untuk bahan CFRP tertentu. Objektif kedua penyelidikan ini adalah untuk menyiasat kesan kualiti permukaan dan haus alatan apabila pelbagai geometri alat jenis penghala digunakan semasa pemangkasan tepi bahan CFRP. Akhir sekali, untuk mencadangkan geometri alat burr/penghala yang paling optimum untuk memangkas bahan CFRP tertentu. Bahan kajian yang dipilih ialah panel CFRP dengan ketebalan 3.25 mm dan sejumlah 28 lapis. Tiga jenis geometri alat yang berbeza yang dihasilkan daripada bahan tungsten karbida dengan diameter yang sama, 6.35 mm, manakala variasi dalam bilangan seruling dan sudut heliks berjaya dikaji. Model Pro II MDX-540 digunakan untuk memangkas tepi CFRP. Kekasaran permukaan bahan panel diukur dengan Mitutoyo Surftest SJ-410. Kistler Dynamometer jenis 9257B digunakan untuk mengukur daya pemotongan. Mikroskop pengukur Nikon MM-800 digunakan untuk menilai kehausan alatan. Berikutan kesimpulan daripada tiga proses alat pemotong, semua data yang dikumpul telah dinilai. Untuk mengelakkan kerosakan CFRP semasa pemangkasan tepi, satu set parameter pemesinan yang ideal digunakan. Kelajuan gelendong 5938 RPM, kelajuan pemotongan 118.47 m/min, dan kadar suapan 297mm/min adalah persediaan pemesinan yang optimum. Untuk setiap alat, mod mesin adalah ke bawah dan ke atas memotong. Alat pemotong 1 (T1) memberikan jumlah kekasaran permukaan paling sedikit jika dibandingkan dengan nilai min keseluruhan dalam kedua-dua arah pemesinan, mengikut data. Alat pemotong 2 (T2) pula mempunyai nilai kekasaran permukaan yang paling tinggi. Sementara itu, alat pemotong jenis 3 (T3) berada di tengahtengah antara dua jenis alat yang lain. Berbanding dengan T1, apabila hujung alat canggih piramid benar-benar licin, pemerhatian haus alat menunjukkan keretakan yang jelas pada T2 dan T3.

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A million thank to my lovely family for giving me support. I cannot find the appropriate words that could properly describe my appreciation for their support and faith in our ability to success. Lastly, I would thanks to all who are involved directly or non-directly in my project. I surely cannot forget your kindness and only Allah can repay you all. Thank you.

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LIST OF SYMBOLS

D,d	-	Diameter
\mathbf{V}_{f}	-	Feed Rate
Fz	-	Feed Rate per Tooth
Ν	-	Spnidle Speed
Т	-	Tool Type
W	-	Centre thickness
a _e	-	Cutting Width
Vc	-	Cutting Speed
(⁰)	- 14	Angle
	Kultz	SEL DKA



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LIST OF ABBREVIATIONS

Aramid Fibre Reinforced Polymer AFRP _ AWJM Abrasive Water Jet Machining CNC **Computer Numerical Control** _ CFRP Carbon Fibre Reinforced Polymer _ Fibre Reinforced Polymer FRP _ GFRP **Glass Fibre Reinforced Polymer** _ HAZ Heat Affected Zone _ HSM High-Speed Machining Rotary Ultrasonic Machines RUM



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CHAPTER 1

INTRODUCTION

1.1 Background

Over the last decade, the usage of Carbon Fibre Reinforced Plastic (CFRP) composites in aerospace applications such as primary and secondary aircraft components has risen sharply. These lightweight composites have excellent physical and mechanical qualities, such as better corrosion resistance, high specific strength or stiffness, and good dimensional stability, as well as the ability to form complicated forms. (El-Hofy *et al.*, 2017). Polymer composites are displacing standard aluminium as the most often used material in aircraft to implement the change. Besides, Carbon Fibre Reinforced Plastic (CFRP) fuselage structures or aircraft's main body structure were first used in civil aviation with the debut of the BOEING 787 Dreamliner in October 2011 and the AIRBUS A350-XWB in January 2015. (Kupski and Teixeira de Freitas, 2021). As a matter of fact, the usage of CFRP materials in the aerospace sector is becoming more widely adopted.

Furthermore, machining operations such as trimming or milling to the final shape, as well as drilling, are commonly required to facilitate component assembly due to the workpiece's surface roughness. Surface roughness and dimensional accuracy are directly related. Therefore, identifying a fine surface finish to ensure an acceptable tolerance in the finishing process is usually required. Tolerance and strength requirements place a restriction on the maximum allowable roughness in many practical design applications. (Sundi *et al.*, 2019).

Next, the tool materials for machining composites should be strong to sustain the abrasiveness of the fibres and debris produced during the machining process. The tool geometry should have a sharp edge capable of shearing the fibres cleanly. The router or burr tool's tool geometry would seem to reduce defects on the trimmed surface. The main factors identified affecting the mass of harmful particles were the tool geometry and the cutting parameters that effected the formation of the chip thickness (Sundi *et al.*, 2020).

1.2 Problem Statement

Several problems have been analyzed based on a method for choosing the optimum machining parameters for CFRP materials edges. This problem occurs because many issues need to be resolved.

Typically machinery issues are related to the surface of quality, especially in CFRP materials (Jawahir *et al.*, 2011). CFRP materials are known for being hard to cut, which may lead to a range of micro- and macro-geometric material failures such as delamination, uncut fibres, burning matrices, fibre pull-outs, cracking, and micro-cracking. (Geier, 2020). In industries such as aerospace or aircaft, it places great emphasis on accuracy and dimensionality in the process. Moreover, it is to produce a quality product. The challenge is to get better Surface Roughness, Ra which is to get the lowest value of surface roughness during the final test. Therefore, the highest value will have a detrimental effect on the surface quality.

In addition, the problem that will arise during the machining of this CFRP material is the wear of tools. The impact of workpiece processing and integrity does not differ from standard alloys in general. In this respect, the effect such as increased speeds of cutting and wear results in increased cutting temperatures and a high chance of damage of the matrix. (Jawahir *et al.*, 2011). The facts are that increasing the cutting speed and decreasing the

feedrate will cause in tool wear. In order to overcome faults identified during machining of CFRP composites, cutting tool design and material selection are important (Ozkan *et al.*, 2019).

Therefore, whether obvious or not, the tests carried out in the research investigations will undoubtedly face some challenges and difficulties. The characteristics and tools utilised to avoid or eliminate difficulties are the focus of this research. Furthermore, research might give an overview and subsequently a suggestion for change.

1.3 Research Objectives

The main goals of this study is to find the best tool geomtery during edge trimming of CFRP material. There are guidelines that have been given in finishing this project in order to properly achieve the objectives:

- i. To study the optimum router tool geometry for the specific CFRP materials.
- ii. To investigate the effect of the surface quality and the tool wear when various tool geometry of router type is used during edge trimming of CFRP material.
- iii. To propose the most optimum burr/router tool geometry for trimming a specific UNIVERSITI TEKNIKAL MALAYSIA MELAKA CFRP material.

1.4 Scope of Research

The scope of the project is defined by the research target objectives established at the start of the project, which are focused on the chosen geometry and the type of router used to cut the CFRP material. This research also looked at cutting force, tool wear, and surface roughness. This study employs three different types of router devices, each with its own set of geometries, namely the number of flutes and helical angles. The cutting condition is used continuously for all three tools in accordance with the machine speed. The use or operation of trimming on CFRP materials has resulted in a variety of results on the material's surface. As a result, it is possible to determine which cutting tools are the best and most efficient for machining operations.

1.5 Research Significant

Machining fibre reinforced composites is a crucial activity for maximising the use of these modern materials in engineering disciplines. Extreme cutting impacts must be avoided during machining to avoid waste product in the last stages of the manufacturing cycle. Mechanical and thermal qualities are critical for machining FRP. The fibre employed in composites has a significant impact on the cutting tool selection during cutting edge material, shape, and machining parameters. It is critical to verify that the tool chosen is appropriate for the material. (Sorrentino and Turchetta, 2014).

This study has a significant influence on industry, academia, and the community. As machining in industry, needs a tight balance between productivity, item quality, and tool selection, it is critical to have the correct feed and speed. If machines and cutting tools are pushed too aggressively, the time it takes to change tools will eat up any productivity increases, and machinists will burn their tools out too rapidly. Machines, on the other side,

may cut appliance costs at the price of productivity, and time is money in the parts-making sector. That is why it is so important to discover the perfect spot for maximum tool life.

Impact in academia, as well as the able to discuss new environmental and social problems, is a distinct benefit for students. This may be used to justify study and to contribute to current knowledge. As a result, students' capacity to openly approach these new concerns, handle the challenges of new fields of research, and produce literature for the subject area is highly regarded, and therefore it is a significant addition to knowledge. Developed by the Malaysian Ministry of Education as a result of the Malaysia Education Blueprint (MEB) 2013 to 2025, it governs all national education issues, from preschool to higher education. The ministry, led by the Minister of Education, aims to provide all Malaysians with equal access to quality education, educate highly skilled, knowledgeable and united Malaysians and indirectly create employment opportunities. Therefore, entrepreneurship education in Malaysia creates entrepreneurial students as part of the National Action Plan for Higher Education as an initiative to drive economic innovation and change to create new wealth and job creation (Kamaruddin *et al.*, 2017).

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1.6 Thesis Outline

The reports are divided into the following chapters as below:

Chapter 1: Introduction

The introduction to this project's research is more direct in this chapter. Background, problem statement, study purpose, and research scope are explanations of elements.

Chapter 2: Literature Review

Chapter 4:Results and Discussion

ALAYS !!

Based on the project title, this chapter focuses more on the research and applicable theory.

Chapter 3: Methodology This section discusses the methods for determining the subject of study and research depending on the objectives.

This section covers the project's output, from the results collected to the hardware being created.

Chapter 5: Conclusion

This section will cover the project's overall overview and conclude based on the project's outcome and improvements that can be done to make the project better for future use.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter highlights the current state of knowledge and theory in carbon fibre reinforced polymer machining research (CFRP). The information acquired will provide an extra source for the project in researching and growing it to be more effective, since it will be used in creating assessments and analyses based on past research. A few literature studies were conducted in order to gain a general understanding of the project's research.

2.2 Composite Materials

Composite materials are made up of mixing two or more materials that do not dissolve or merge into one other with relatively diverse properties. The various composite materials work together to produce the composite unique characteristics. The combination of this matrix and separated phases provides composites with a large difference in characteristics from either component (Jacoby, 2004). These composite mixtures come in a variety of shapes and sizes, and they're used in a variety of sectors. The design and mix are determined by the material's demand and application. However, in this research, a specific CFRP material shall be the focus material to be studied.

2.2.1 Aramid Fibre Reinforced Polymer (AFRP)

Aramid fibre reinforcing polymer (AFRP) is a fibrous composite material made of synthetic fibres. This material's features include high tensile strength, low thermal expansion coefficient, and light weight. It is been widely employed in aerospace, national defence, and military applications (Yang, Song and Zhang, 2015). Next, aramid fibre is a composite material that is not heat resistant and robust. ARFP is a hard, coarse material with a long

life expectancy in materials design (Modak *et al.*, 2020). In addition to its characteristics and even pasting Aramid sheages on the surfaces, aramid fibre has demonstrated benefits in improving the material's tensile strength (Dhanesh *et al.*, 2020). Figure 2.1 shows the application of aramid fibre.



Figure 2.1 Kevlar Helmet of Aramid Fibre Application (Kulkarni et al., 2013)

2.2.2 Glass Fibre Reinforced Polymer (GFRP)

A Glass Fibre Reinforced Plastic (GFRP) is a composite material made up of a matrix that are typically polyester and fibreglass. The fiber to resin ratio varies depending on the application as illustrates in Figure 2.2 (Farinha, de Brito and Veiga, 2019). Because of its low weight, high environmental strength, and even electrical conductivity capabilities, Glass Fiber Reinforced Polymer (GFRP) composite materials have been employed in numerous buildings. GFRP is widely used in the aircraft industry, and its utilization in buildings and civil engineering infrastructure, such as pedestrian bridges, cooling towers, low-rise buildings, automobile Fiber Reinforced Polymer (FRP) bridge decks and telecommunication towers, as well as secondary structures in industrial facilities, has lately expanded (Vieira *et al.*, 2018).



Figure 2.2 Glass Fibre Reinforced Polymers (GFRP) Elements (Farinha, de Brito and

Veiga, 2019)

2.2.3 Carbon Fibre Reinforced Polymer (CFRP)

Carbon Fibre Reinforced Polymers (CFRP) are composite materials that rely on carbon fibres for strength and toughness. Besides, polymers acting as a cohesive matrix to protect and keep the fibres together, as well as providing some toughness. Carbon fibres have directional qualities that are extremely different from metals, and they may be designed to produce mass reductions that metals cannot. Because of their artificially organised material, the qualities and performance of these materials may be customised to applications by selecting polymer matrices through a choice of application strength, length, direction and quantity of reinforcing fibre. (Fekete and Hall, 2017). Furthermore, the variety of applications for (CFRP) composite materials is expanding in high-tech industries such as automotive, marine, and aerospace, according to CFRP's superior particular mechanical characteristics. CFRP composites also offer excellent damage tolerance, damping ability, dimensional stability, and corrosion resistance. On other hands, carbon fibre has a high production cost, and the lamination and fine machining processes for take a long time and contribute to the operational costs (Geier and Pereszlai, 2020). In Figure 2.3 shows the structure of CFRP with mention the different of polymer resin and carbon fibres.



Figure 2.3 Structure of CFRP (Liu, Zwingmann and Schlaich, 2015)

2.2.4 The Importance of CFRP in Today Industries

Carbon Fibre Reinforced Polymers (CFRP) were some of the most potential material for achieving lightweight application requirements. In comparison to other materials such as high-strength steel or light metals, the market for carbon fibre reinforced materials is expected to increase at a rate of approximately 10% per year, as it has in latest years. CFRP's relevance in the lightweight material mix. The primary export markets in this industry are aerospace and automotive. Despite the fact that material prices make for a major amount of the expense of CFRP parts, effective production systems remain in demand (Schneider and Petring, 2018).

The importance of carbon fiber can be seen in the aerospace and automotive industries. In the aerospace industries, Carbon fiber's high modulus allows it to structurally replace metals like aluminium and titanium. Carbon fibre is widely employed in the aircraft sector because of the weight reductions it provides. Because every pound saved in weight may make a significant difference in fuel usage, the Boeing 787 Dreamliner becoming the best-selling commercial aeroplane in industry. Carbon fibre reinforced composite makes up the majority of the aircraft's structure. Next in automotive industry, Carbon Fiber's unique weave becomes a symbol of high-tech and high-performance. In addition, it is typical to find an aftermarket automobile component that has a single layer of carbon fibre but has numerous layers of fibreglass below to cut the price. This is a situation of where the appearance of the carbon fibre is the key factor. Although these are some of the most usual applications for carbon fibre, new designs develop on a regular basis. Carbon Fibre is rapidly expanding, and in only 5 years, this list will be considerably longer (Johnson, Todd, 2020). As shown in Figures 2.4 and 2.5, it displays the use of materials on the Boeing 787 and





Figure 2.4 Material Consumption in the Boeing 787 Dreamliner (Kuruc et al., 2017)



Figure 2.5 CFRP B-Pillar inner reinforcement of BMW (Lin et al., 2020)

2.3 Carbon Fiber Reinforced Plastic (CFRP) Ply Stacking

Hybrid composites are composite materials that consist of more than one type of fibre. There are several techniques for combining these fibres, including stacking layers of fibres, compounding fibres, mixing two different types of fibres in the same layer to create an interaction hybrid, selective fibre placement where it is needed for better force, and positioning each fibre according to precise orientation. (Rajak *et al.*, 2019). Positive angles are counterclockwise, whereas negative angles are clockwise, since the x- axis represents 0°. The laminate code is a basic and easy way to describe the ply orientations and stacking sequence of the laminate. The most basic method for defining a laminate made up of fibres oriented at various angles such as 0°, 45° , 90°, and 135° was using brackets to represent the proportion of different ply orientations in the laminate as illustrated in Figure 2.6. (El-Hofy, 2014).



Figure 2.6 Configurations of lamina fibres (El-Hofy, 2014)

Because of the through-thickness normal and shear loads at the hole border, the stacking sequences of laminates have an impact on joint strength. The application of a 90° layer to the surface is thought to improve bearing strength by generating normal compressive through-thickness stress, which can prevent delamination. Because of the occurrence of significant inter-laminar shear stresses in such laminates, less uniform stacking sequences have lower bearing strengths (Pramanik *et al.*, 2017). An example of the researcher stacking sequence is presented in Table 2.1.

	Ply or Part Number	Orientation (°)	
MAL	Y8/4 P1	90	
S	P2	45	
E .	P3	0	
EX.	P4	45	V. I
5	P5	90	
5	P6	45	
43 Alex	P7	0	
-sun	P8	45	
shl.	P9	90	. And
	P10	.45	اويون
	P11	0 **	
UNIVER	SITI TP12NKAL	MALA45SIA ME	ELAKA
	P13	90	
	P14	45	
	P15	0	

Table 2.1 Example of CFRP Stacking Sequence (Prakash et al., 2016)

2.4 Machining of CFRP

The machining of CFRP has very coarse fibers and presents a challenge to the machine due to its anisotropic and inhomogeneous state (Monoranu *et al.*, 2020). Machining composites certainly different from machining metals. The reaction of composites with cutting tools during machining is a complicated factors to understand (Sundi *et al.*, 2019). Besides, CFRP machining that is both budget and reproducible has become a main issue for the tooling and machining industries. Milling, drilling, and waterjet cutting are the most used

methods for machining CFRPs.Next, tool sharpness, tool life, and cutting requirements have all been established as determining variables in milling and drilling operations. In the machining of CFRPs, the most usual category tool wear has been a increase in cutting edge radius, which causes an increase in machining forces and makes defined cutting of the fibres more complicated (Uhlmann *et al.*, 2014). Therefore, non-conventional machining processes have been applied in the cutting of FRP, although each method has its own set of benefits and drawbacks. CFRP has been cut using laser beams, water jets, and abrasive water jets, for example (El-Hofy, 2014).

2.4.1 CNC Milling Machine

CNC (computer numerical control) technology is a type of technology that uses digital data to control and manipulate machining processes. A CNC milling machine is a complicated piece of mechatronic machinery that consists of several interfaces and numerous mechanical components. (Luo *et al.*, 2019). Furthermore, the created deposition tool allowed the CNC milling machine to extrude the material to construct 3D geometry with great strength. CNC milling machines use a subtractive manufacturing method to create items by removing material from the workpiece (Jyothish Kumar, Pandey and Wimpenny, 2018). Subsequently, changing the feed rate, width of cut, or depth of cut on a three-axis CNC milling machine may then change the material removal rate. Increased feed rates have been observed to reduce tool life and necessitate more power for the spindle motor and axis drives (Ma *et al.*, 2017). Table 2.2 illustrates the example of primary CNC programming.

Main CNC Code (P510)
G21 ;
M98 P9007 T19 ;
M6 ;
G58 G90 X10.0 Y-8.0 ;
G43 H19 Z10.0 F1000 ;
S5308 M03 ;
G0 Z-5.0 ;
G1 Y3.0 F2548 ;
M98 P511 L13 ;
G0 Z 200.0 ;
Y50.0;
M30 ;

Table 2.2 Example of CNC programming (El-Hofy, 2014)

2.4.2 Abrasive Water Jet Machining (AWJM)

Abrasive Water Jet Machining (AWJM) is utilised in the aerospace industry for rough routing of excess material for the finished state and dimensions. As a result, fine abrasive grains can be used in the finishing process. AWJM is environmentally friendly, but it has limitations in that it can produce heat damage on the exit side, and also some damage from high-pressure water wedging and abrasive contamination of the work material. (El-Hofy, 2014). On the other hand, it can overcome tool wear and associated surface quality degradation, AWJM is becoming more widely used in CFRP cutting (Monoranu *et al.*, 2020). Furthermore, because AWJM has low tool wear and increases laminate durability limits by up to 10%, it demonstrates greater surface integrity in most composite materials, while it may introduce new flaws like kerf taper or lag (Ruiz-Garcia *et al.*, 2019). Illustration of cutting sheet metal using abrasive water jet machining as in Figure 2.7.



Figure 2.7 Abrasive Water Jet Machining cut pieces of metal

(https://www.thefabricator.com/thefabricator/article/waterjetcutting/the-pressure-behind-

abrasive-waterjet-cutting)

2.4.3 Rotary Ultrasonic Machining

The CFRP drilling was performed out on Rotary Ultrasonic Machines (RUM). RUM is a hybrid technique which combines the mechanism of diamond grinding with ultrasonic machining. The turning tool axially vibrates at the ultrasonic frequency during drilling and goes towards the workpiece in the axial direction as illustrated in Figure 2.8 (Cong *et al.*, 2012). Therefore, there are parts and processes that are suitable for using this RUM Machine. In addition, throughout the hole-making of brittle and difficult-to-cut materials, Rotary Ultrasonic Machining (RUM) may efficiently reduce both cutting force and surface roughness. In the hole making of ceramic matrix composites, RUM might also increase machining effectiveness and decreasing delamination. (Wang *et al.*, 2020).



Figure 2.8 Illustration of drilling process of CFRP material using Rotary Ultrasonic

Machining (Cong et al., 2012)

2.4.4 Laser Cutting Machining

Fast cutting speeds and limited cutting forces are important for composite laser machining. However, the Heat Affected Zone (HAZ) is a serious problem due to inhomogeneous characteristics of CFRP laminate, low polymer vaporisation point, and complicated thermal gradients. (Li, Li and Yang, 2020) CFRP laser cutting is a non-contact and non-abrasive machining technology which shows different benefits like removing tool wear, vibration and force cutting. Also, laser cutting is ideal because of it is can use in large-scale of manufacturing production with high efficiency of process.Nevertheless, some problems in CFRP laser cutting caused by heat effects are highly visible. Recession of the matrix, extrusion of fibres, craters, and smelting are examples of flaws that might decrease the mechanical qualities of the components produced. (Li *et al.*, 2018). Figure 2.9 shows the cutting of sheet metas using laser cutting machine.



Figure 2.9 Metal sheets are cut using a Laser Cutting Machine (https://machineryfuture.weebly.com/knowledge/laser-cutting-machine-02)

2.5 Milling/Trimming of CFRP

Milling/trimming is one of the required machining operations that has been used as a finishing process to get the effective dimensional precision. The milling process includes the removal of material from workpieces by using a rotary cutting tool with one or more active milling cutters. As a fact, in FRP material, there are two types of milling process materials. This kind is similar to peripheral milling, also known as side trimming, and another type is end milling operation. Besides from the phrase itself, there are differences in how it is utilised by researchers and industry in other places, such as edge or slot trimming and edge or slot router operation. This end milling process, however, is dependent on the process machine applied on the end or face part of the cutting tool. (Sundi *et al.*, 2021).

2.5.1 Process Requirement

To eliminate vibration and deflection coming from high trimming forces, high strength machine tools are required for cutting CFRP. CFRP milling demands the adjustment of the abrasive and conductive tiny fiber and the matrix particles. Besides, an extraction system is required because to dangerous and abrasive dust released by the chips, and also any gases created during processing. Next, High-Speed Machining (HSM) has the potential to minimise machining duration and burr formation while also increasing productivity, accuracy, and product quality. Because of that, (HSM) also help to decreases the cutting forces, tool deflection, and temperature, but it required better operating abilities and more tool balance and runout control. In end milling, runout generates a torchoidal motion of the cutter teeth, which compromises machining stability and increases surface roughness (El-Hofy, 2014). Moreover, high technology and precision equipment are required to produce the high-quality tools. The greatest results are achieved using routers with "diamond cut" tool geometries or burrs for glass and carbon fibres, and inverse helical designs for aramid fibres. Therefore, one of the most difficult aspects of FRP machining is avoiding material degradation, such as burning and cleaning issues, during edge trimming operations. (Sundi *et al.*, 2021). The milling procedure for cutting CFRP material is shown in Figure 2.10.



Figure 2.10 Schematic sketch for Peripheral milling Process (Uhlmann and Protz, 2019)

2.5.2 Cutting Speed and Workpiece Feed

CFRP cutting of material done using the machine depends on the cutting speed and feed rate. Operation that are always used are such as end or face milling, slot and trimming. In addition, there is a lot of investigation done by researchers to find the right cutting tool and speed in getting the best surface roughness. The suggested cutting speeds and feed rates
for milling CFRP composites with routers range from 6 to 12 mm in diameter varied from different manufacturers, as well as depending on the application and the appropriate tool shape and tool materials. (El-Hofy, 2014). As an example of the parameter tool used by the SANDVIK company, the Face or surface milling process is recommended at cutting speed in the range of 300-500 m/min and for feed is in the range of 0.40-0.60 mm/rev. There are several parameters of cutting speed and feed rate from researchers, as listed in Table 2.3.

Tool Type	Cutting speed (m/min)	Feed Rate (mm/tooth)	Experimented by
Router or Burss	50, 100, 150	0.05, 0.15, 0.1	(Sundi, Izamshah and Kasim, 2020)
Burr Tools	120	0.012	(Monoranu et al., 2020)
Flue End Mills Tools	50, 100, 150	0.05, 0.15, 0.1	(Can, 2017)
Solid carbide Routers with (PCD)	200	0.03, 0.06	(El-Hofy et al., 2017)
Solid uncoated carbide end mills	160, 165, 179, 194, 200	0.125, 0.14, 0.175, 0.225, 0.25	(Khairusshima and Sharifah, 2017)
Staggered & Straight teeth PCD cutters	<u>ل</u> الم مليس	ي ٽ <u>و</u> ڪ	(Chen <i>et al.</i> , 2017)
Rhombic & RS Staggered helical milling cutter	ITI TEKNIKA 100	L MALAYSI	A MELAKA (Chen <i>et al.</i> , 2018)

Table 2.3 Table of Speed Cut and Feed Rate used in previous experiment.

Table 2.4 Optimizations parameter used in previous experiment

Tool Type	Cutting speed (m/min)	Feed Rate (mm/tooth)	Experimented by
Router or Burss Tool	2506	376	(Sundi, Izamshah and Kasim, 2020)
Router or Burss Tool	3000	1500	(Sundi et al., 2019)
Burr Tool	2300	500	(W.N.F. Mohamad, S.B. Mohamed, M. Minhat, 2017)
Burr Tools End Mill	2313.870 to 2336.042	500 - 530	(Mohamad <i>et al.</i> , 2016)

2.5.3 End Mill Geometry

For milling the FRP, there have been a choice of cutter shapes or design. Fluted tools, burr routers and diamond routers are now the most often utilised geometries. The selection of router geometry might be material-oriented to propose certain equipment for the handling of certain working materials (El-Hofy, 2014). For example, the routers with the burrs tool, also known as diamond cut tool geometry, produced the greatest end result for glass and carbon fibre contrasted helical design for aramid fibres. (Sundi, Izamshah and Kasim, 2020).

2.5.3.1 Burr Routers Tools

This burr or router tool has different types and sizes in terms of diameter and length. Also, the cutting tool has a different count or type of flute and angle of helix depending on the use of the process performed. In modern cutting tools for CFRP machining, router and burr tools have unique and complicated geometries on the edges or cutting surfaces. Thus, traditional techniques are no longer suited for cutting CFRP materials and cannot be applied (Prakash et al., 2016). Next, in CFRP cutting operation, the surface roughness results are lower by using a router or burr tool with low speed as well as at high milling speed. TEKNIKAL MALAYSIA MEL Meanwhile, when using high efficient chip thickness, fibre pullout might have been detected. Through router or burr tools, greater smoothness surfaces have been achieved than with abrasive tools (El-Hofy, 2014). Other from that, the burr tool tends to reduce flaws on the trimmed surface. However, as the feed is increased, these faults tend to increase. Even, because of the less damage produced from machine specimens with fine and coarse teeth, router and burr tools are the most suitable tool use for Slotting CFRP material (Sundi, Izamshah and Kasim, 2020). Figure 2.11 illustrates the sort of router produced by the fraisa company.



Figure 2.11 Router or Burr Tool from Fraisa Company (Geier, Szalay and Biró, 2018)

2.5.4 Surface Quality

Surface quality plays an important role in determining the accuracy of the machine in making evaluations by researchers. Selection of machine parameters and appropriate geometric will effect the results of the surface. Furthermore, the high cutting speed and feed rate provide excellent surface quality. (Sur and Erkan, 2020). Besides, the quality of the machined surface will effects the durability, hardness, and lifetime of CFRP workpieces. (Liu, Chen, *et al.*, 2017). The use of laser machining process will produce Heat Affected Zone (HAZ) (Li, Li and Yang, 2020). Therefore, the temperature will increase during the machine depending on the cutting temperature (Kumar and Gururaja, 2020). The method to analyze this surface roughness is by measuring on the workpiece surface. Normally, it will measure using a point (stylus) on the same surface repeatedly such as 4 or 5 points. Then, the result of average Surface Roughness, RA will give the value applied to the surface of the workpieces. Figure 2.12 shows an illustration of the surface roughness measurement.



Figure 2.12 Illustration of Surface Roughness measurements (https://www.elcometer.com/en/coating-inspection/industrial-coating-inspection-physicaltest-equipment/surface-cleanliness-surface-profile/elcometer-7062-marsurf-ps10-surface-

roughness-tester.html)

2.5.5 Cutting Forces

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Chip thickness is a critical element in determining cutting forces in milling and it is affected by peripheral immersion and cutting width, a_c . Also, the burr router removes very fine chips that is similar to what is removed in the grinding process. Following that, force decreases with cutting speed and subsequently increases due to tool wear and the cutting force also increases with the cutting length as a factor of continuous tool use (El-Hofy, 2014). Besides, another issue that arises in milling is that high milling force results in poor machining quality, hence an optimised tool structure is required. (Liu, Qian, *et al.*, 2017). Cutting forces in the x and z axis, torque, and surface roughness all have an impact on machining variables including depth of cut, feed rate, and tool rotating speed. Researchers discovered that lower speed rates resulted in lower cutting forces and tool wear. On the work piece machining orientations shows that using 90° working part machining orientations reduced cutting forces caused lower surface roughness whereas utilising 0° workpiece machining orientations (Wang *et al.*, 2020). Figure 2.13 show the milling process from the top view.



Figure 2.13 Milling process from the top view (Huang et al., 2016)

2.5.6 Tool Wear

Cutting process has been found as a critical element with tool sharpness, tool wear, and cutting parameters during the milling and drilling process. In the machining of CFRPs, the most typical category tool wear is a gain in cutting edge radius, which causes a rise in milling forces and makes defined cutting of the fibres more hard. Meanwhile, using these cutting-edge tools, a process window for CFRP slot milling could be developed with high cutting rates ranging from 400 to 600 m/min which can be achieved while minimizing tool wear and produced as part workpiece quality (Uhlmann *et al.*, 2014).

The tool's life, based on deteriorating workpiece quality and data may only be analyzed qualitatively if the cutting sharpness reduces or the cutting edge rounds increases. During the edge trimming, tool life are depends on the depth of the cut and the tool material used. Usually, the length is in the range of 100 until 200 m. In addition, because of the hard cutting process, slotting operations are normally exposed to a limited lifespan of approximately ~30m. Besides, tool wear may take a variety of shapes, depending on the design, material, and cutting parameters of the tool. (El-Hofy, 2014). Figure 2.14 shows the cutting edge of the workpiece.



Figure 2.14 Cutting Edge cut the workpiece

(https://www.canadianmetalworking.com/canadianmetalworking/article/cuttingtools/identi

fying-tool-wear)

2.6 Machining Parameters

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The basic structure when a project is initiated was machine parameters. The target is to achieve the objective of selecting the set speed router or burr cutting tool. Therefore the major output of this machine parameter is surface integrity, machining damages, temperature-cutting and force-cutting. In addition, the most of damages caused by CFRP composite material are typically investigated to minimise such damages as delamination, surface roughness, fibre removal, smearing and fibre breaking.

There are a number of parameter information selected in making the investigation depending on the researchers. The information is such as feed rate, (f) cutting speed, (V), flute number (T), and spindle speed (N). Tables 2.4 and 2.5, it shows examples of experiments performed by researchers in determining machine parameters.

Cutting Speed (m/min)	Slot Depth (mm)	Feed Rate (mm/tooth)	Tool Type	Cutting Environment	Workpiece Lay-up configuration			
Phase 1: Eff	ect of tool h	elix angle – full	immersio	n slotting (new t	ools) followed			
by 3⁄4	engagemer	nt life trials to fla	ink wear c	riterion VB of 0.	.1 mm.			
200	5	0.03	Tool A Tool B Tool C	Twin-nozzle CA	Type-1			
Phase 2: I	Effect of wo	orkpiece lav-up c	onfigurati	on – full immers	ion slotting			
	(partially worn tools) 200							
200	5	0.03	Tool A Tool B Tool C	Twin-nozzle CA	MD (Type-1 Type-2 & Type-3)			

Table 2.5 Machine Parameter used by (El-Hofy et al., 2017)

Table 2.6 Machine Parameter used by (Ma et al., 2017)

Cutting Width (mm)	Spindle Speed (r/min)	Cutting Speed (m/min)	Chip Load (mm/tooth)	MRR (mm ³ /min)
2	955	30	0.05	192.0
3	955	30	0.05	288.0
4	955	30	0.05	384.0
5	1270	40	0.05	716.3
6	1270	40	0.05	859.5
7 .	1270	40	0.05	1002.8
8	1430	45 5	0.05	1524.0
9	1430	45	0.05	1714.5
9.5	ERS 1430 EKN	KAL M.45_AYSIA	0.05 KA	1809.8

2.7 Summary

The researches have investigated a wide variety of machining parameters from high speed to low speed and also the types of cutting tools that have been utilised. In order to determine the ideal machining parameters, it is also to prevent damage to the CFRP materials and achieve a smooth surface. Most researches observed at three critical responses in the edge trimming of CFRP that were surface roughness, cutting force, and tool wear. Feed rate and spindle speed also are key factors to determining CFRP damage according to several study articles. Researchers have also discovered that machining with a low spindle speed and feed rate give a results in the greatest surface roughness and tool wear. Conclude the final sentence stated that the proposed work research is found to be aligned with the current and previous works performed by number of reseachers around the world to search the most optimum geometry during edge trimming of CFRP material.



CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the flow of research initiatives. The aim of establishing the appropriate range of CFRP edge cutting tools for a burr or router is attainable. This research study includes four stages of experiments that are carried out in a systematic manner to attain the goals we set for ourselves. The initial stage of study involves selecting a router or burr cutting tool and creating jig fittings to hold the composite material. The second step includes three distinct types of cutting tools as well as the cutting tool method employed for the cutting process towards the CFRP material. Tool wear, surface finish, and cutting force results may be obtained in the third step by collecting data on each procedure. Finally, the results from phase 3 were examined. The material is machined using the characteristics necessary to achieve the project's objectives.

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3.2 Flow Chart



3.3 Material Details

This study results material is a true CFRP composite material from the aerospace industry. As shown in Table 3.1, the panel is 28 layers strong, with 26 layers of unidirectional carbon or epoxy prepreg for total carbon and the remaining two thin layers of glass or epoxy woven fabric adhering to the top and bottom of the CFRP laminate. As a result, the panels' total thickness is 3.25mm. Because the fabric has a multi-directional composite structure, the stacking alignment from this material is [45/135/902/0/90/0/90/0/135/452/135]s. The orientation of each ply is shown in Table 3.2.

No of Ply	Areal Density	Fabric Type	CPT/Ply
ALA MA	(g/m^3)		(mm)
26	203	Unidirectional	0.125
2 💈	107	Woven	0.08
28	310		3.25
	No of Ply 26 2 28	No of Ply Areal Density (g/m ³) 26 203 2 107 28 310	No of PlyAreal Density (g/m³)Fabric Type26203Unidirectional2107Woven28310

Table 3.2 Number of plies and orientation

اويتور سيتي (°) Orientation کل مليسيا ملاك												
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
45	135	90	90	0	90	0	90	0	135	45	45	135
P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27
45	135	90	90	0	90	0	90	0	135	45	45	135

3.4 Cutting Tool Specification

The burr type cutting tool used to cut CFRP material has three distinct geometric parameters, although they all have the same size diameter of 6.35mm, or 1/4 ". The first tool is a GET company carbide burr tool with a length of 76 mm. The second tool is a 76.5mm cutting tool from the Evertools firm. Finally, the chosen cutting tool is made of carbide material and has a length of 76 mm. Table 3.3 displays the tool's cutting properties, while Figures 3.1,3.2, and 3.3 depict the kind of cutting tool.

Tool	Diameter	Number of	Number of helix		Angle of l	Length	
	(mm)	teeth				(mm)	
			Right	Left	Right	Left	
T1	6.35	12	12	12	32	32	76
T2	6.35	10	10	10	28	28	76.5
T3	6.35	8	8	8	24	24	76

Table 3.3 Router or burr tool Properties



Figure 3.1 Cutting Tool of T1



UNIVERSITI Figure 3.3 Cutting Tool of T3A MELAKA

3.5 Jig Fixture

The fabrication of jigs and fixtures is one of the most crucial processes that must be completed before CFRP composite machining can begin. Jigs and fixtures are created to handle very thin CFRP composite plates that are constructed so that the material does not move throughout the production process. Jigs and fixtures are also essential in creating good CFRP machining. The plate will move and impair the surface roughness if the jig does not correctly secure the CFRP plate during milling.



Figure 3.4 Jig Fixture use in this experiments

3.6 Machine Specification

Trimming the composite CFRP material was accomplished using a Pro II MDX-540 Model 3D Milling Machine. This machine makes use of the X-axis, Y-axis, and Z-axis. Machining transfer coding is utilised to regulate the movement of the cutting tool. Table 3.4 lists the parameters of this machine.

UNIVParameters EKNIKAI	MALA Specification AKA
Axis Travel:	500 x 400 x 155mm
Max. Machinable:	500 x 400 x 125mm
Maximum Feed Rate:	125mm/sec (7500mm/min)
Maximum Acceleration:	0.2G
Motors (X,Y,Z):	AC Servo
Spindle Motor:	400W
Spindle Speed Range:	400-12,000rpm
Weight (with case):	170kg
Axis Travel:	500 x 400 x 155mm

Table 3.4 The parameters of this machine



Figure 3.5 Machining use for trimming material

3.7 Machine Parameter

These are the machining parameters used to optimise cutting conditions during CFRP material routing. The two machining factors studied in this study are spindle speed and feed rate. The up and down cutting machining mode has a spindle speed of 5938 rpm, a cutting speed of 118.47 m/min, and a feed rate of 297 mm/min. The following equations depict the connection between cutting speed, spindle speed, and feed rate. Table 3.5 lists the machining settings utilised in this project.

Tools	Run	Machining	Cutting Speed,	Spindle	Feed Rate,	Feed/Rev,
		Mode	$V_{C}(m/min)$	Speed, N	V_{f}	Fz
				(rpm)	(mm/min)	
	R1	Down				
		Up				
T 1	R2	Down	118.47	5938	297	0.05
11		Up				
	R3	Down				
		Up				
	R1	Down				
		Up				
тэ	R2	Down	118.47	5938	297	0.05
12		Up				
	R3	Down]			
		Up				

Tools	Run	Machining	Cutting Speed,	Spindle	Feed Rate,	Feed/Rev,
		Mode	V _C (m/min)	Speed, N	V_{f}	F_z
				(rpm)	(mm/min)	
	R1	Down				
		Up				
т2	R2	Down	118.47	5938	297	0.05
15		Up				
	R3	Down				
		Up				

3.8 Surface Roughness Measurement

Surface roughness is studied using the Mitutuyo SJ-410 machine on the material's trimmed component. Because it can measure up to 0.0001 m, this equipment is extensively used for measurement in the industry. Ra is used to assess surface roughness for quality purposes by using Arithmetic Mean Roughness. The stylus travel distance was set at 5 mm for each measurement. This work is assessed in the longitudinal measuring direction, with 9 measurement points on each machined surface. As a result, the final average Ra for each specimen indicates a variable surface polish outcome depending on the cutting tool employed.



Figure 3.6 Measuring surface roughness using SJ-410

3.9 Cutting Force

The cutting force during the edge trimming machining of CFRP composite was measured using a tri-axis piezoelectric dynamometer of type 9257B from Kistler with a top plate 100x170mm. The equipment is seen in Figure 3.4. Experimentation with impact testing is used to efficiently determine the output signal between measured cutting forces and applied forces. The dynamometer was placed on the jig fixture's bottom, while the CFRP material was installed on the jig. To avoid material movement during milling, the composite CFRP is always correctly fastened with the jig. If the material shakes during edge trimming, the cutting force value will change, rendering it incorrect. The optimal dynamometer amplifying load measurement range in the three axes, as well as its sensitivity value, are shown in Table 3.6.

Table 3.6 Dynamometer technical data

Axis	Measuring Range (kN)	Sensitivity (pC/N)	Pretensioning Direction	Operating Temperature Range
Fx	-5 5	-7.5		+ 1
Fy	ملىيىىكملاك	-7.5	Vertical	, ∽ °C 70 °C
Fz	-5 10	-3.7	. Q. I	1 dad

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Figure 3.7 Multi-Component Dynamometer Type 9257B

3.10 Observation on Tool Wear

For this wide visualization, tool wear was assessed using a Nikon MM-800 measuring microscope. This microscope has a magnification power ranging from 1x to 100x. It may alter the magnification of the figure to zoom in or out and make the tool's impact more visible. In addition, the router tool was held horizontally to observe tool wear. This system was linked to the E-Max Data programme and was used to show images obtained using a microscope. As a consequence, as shown in Figure 3.8, this E-Max programme includes a comprehensive picture data analysis for analysing the structure and size of visual information.



Figure 3.8 Nikon MM-800 use for observe tool wear

CHAPTER 4

RESULTS

4.1 Introduction

The results and analysis in this chapter are based on surface roughness, cutting force, and tool wear. This chapter goes through the outcomes that were acquired. With reference to the surface roughness, cutting force, and tool wear results, the shape of the cutting tool was successfully proposed at the end of the data analysis using the optimized machining parameters.

4.2 Machine Configuration

A milling machine was used in the experiment. The spindle speed was 5938 RPM, the cutting speed was 118.47 m/min, and the feed variation per tooth was 297 mm/min. The rationale for selecting this machining parameter optimization is to obtain the proper speed router tool in cutting carbon fibre material, which may achieve a smoother surface and identify the tool point geometry used over the whole experimental matrix. Surface roughness, cutting force, and tool wear were measured and evaluated to examine the influence of machining parameters on edge trimming of CFRP materials. In this experiment, the cutter rotation to the direction of feed cutting tool applied is Conventional Milling (Up) and Climb Milling (Down). Accordingly, the data analysis results were utilised to determine the type of router tool geometry used for the low residual outcomes of the experimental design matrix.

4.3 Surface Roughness

Surface roughness is a key factor in defining the surface finish of CFRP materials machined router tools. The manufacturing process has the potential to rapidly alter the surface layer, resulting in changes in the mechanical properties of these composites. Surface finish is affected by elements such as cutting speed, cutting force, and tool shape. The roughness parameters contribute in achieving a smooth surface finish by adjusting the process parameters. The workpiece was set in the SJ-410 Surftest at the end of each cutting tool run to collect an average reading of surface roughness. Surface roughness was measured along the feed direction or the longitudinal direction. Also, the surface roughness obtained differs depending on the material cutting process (up cut or down cut).

	2			
Tools		2	3	Average (µm)
T1-R1-D	0.572	0.614	0.596	0.594
T1-R2-D	0.759	0.449	0.730	0.646
T1-R3-D	0.626	0.440	0.56	0.542
T2-R1-D	0.885	0.774	0.889	0.849
T2-R2-D	0.853	0.121	0.940	1.001
T2-R3-D	1.331	1.023	2.350	1.568
T3-R1-D	ERS 0.485 EKM	0.490	YSIA0.54FLAP	0.505
T3-R2-D	0.718	0.982	0.639	0.780
T3-R3-D	2.348	0.198	0.611	1.644

 Table 4.1 Overall Surface Roughness Data (Down Cutting)

T= Tool, R= Run, D= Down Cut



Longitudinal Surface Roughness (Down Cutting) vs Geomtery

Figure 4.1 Longitudinal Surface Roughness (Down Cutting), Ra Result

Tool 1 (T1) had the lowest average surface roughness value, Ra, which ranged between 0.5941 μ m and 0.6461 μ m. Tool 3 (T3) is located in the middle of the rests of two different types of tools, with Ra values ranging from 0.505 μ m to 1.644 μ m. The highest Ra values were found in Tool 2 (T2), ranging from 0.8492 μ m to 1.5681 μ m. In general, the run numbers (R1-D), (R2-D), and (R3-D) demonstrate low surface roughness, indicating that the machining parameters used were spindle speed of 5938 RPM and feed rate of 297 mm/min. Even thought, the lowest of the surface roughness is in tool 3 at run number (R1-D), but other runs on the tool show high values that make the result be high. As a result, tool 3 (T3) has the maximum surface roughness, as shown by the run number (R3-D). The large disparity in Ra values obtained from the lowest (T3-R1-D) and highest (T3-R3-D) which is about 1.644 μ m minus 0.505 μ m and equivalent to 1.139 μ m or nearly three times different provides proof that the difference in tool geometrical design impacted the trimmed surface quality. The geometrical design features on the tools varied. T1 has a greater number of flutes than T2 and T3. Then, T1 has the same helix angle for both the right and left flutes, whereas T2 and T3 have a distinct helix angle for both flutes. The results of cutting down are clearly shown in Figure and Table 4.1, which follow the graph's trend.

Tools	1	2	3	Average (µm)
T1-R1-U	0.956	0.997	1.042	0.998
T1-R2-U	0.745	0.944	0.620	0.770
T1-R3-U	0.830	0.940	0.736	0.835
T2-R1-U	0.691	0.865	0.818	0.791
T2-R2-U	1.009	1.108	0.920	1.012
T2-R3-U	1.224	1.209	1.227	1.220
T3-R1-U	0.542	0.721	0.901	0.721
T3-R2-U	0.790	0.611	0.783	0.728
T3-R3-U	0.850	0.743	1.091	0.895

 Table 4.2 Overall Surface Roughness Data (Up Cutting)

T= Tool, R= Run, U= Up Cut





Figure 4.2 Longitudinal Surface Roughness (Up Cutting), Ra Result

The lowest average surface value Ra cutting tool is Tool 3 (T3), which ranged between 0.7213 μ m and 0.8947 μ m, followed by Tool 1 (T1), which ranged between 0.8352 μ m and 0.9983 μ m. Meanwhile, tool 2 (T2) has the greatest Ra values, with a range of 0.7914

μm to 1.220 μm. In general, T3 resulted in the lower surface roughness displayed by Run no. 1 (R1-U), whose machining parameters were the same as the other runners, specifically spindle speed, N at 5938 RPM and feed rate, 297 mm/min. T2, on the other hand, has the maximum surface roughness, as indicated by the Ra value in Run no. 3. (R3-U). The huge disparity in Ra values obtained by the R1-U of T3 and R3-U of T2 nearly (1.22 μm – 0.7213 μm = 0.4987 μm or 2 times different) gives proof that the tool geometrical feature impacted the trimmed surface quality. As a result, assuming the feed rate is the same, the surface quality trimmed by tool T1 should be better than the T2 and T3 tools. However, there is not that much of difference in surface roughness between these three cutting tools, and they are all still excellent below 2 μm. Tool T3 has the smallest amount of helix angles when compared to T1 and T2 and has the lowest overall surface roughness Ra values. The upcutting results between the three tools are then shown in figure and table 4.2.

4.4 Cutting Force

The cutting force generated by the router cutting tool during the CFRP machining process. Throughout the procedure, the cutting force component measures and generates data. The data acquired included three forces: normal force along the X-axis, feed force along the Y-axis, and axial force along the Z-axis. The resulting force, Fr, was calculated using all of the data using the formula in (4.1).

$$Fr = \sqrt{Fx^2 + Fy^2 + Fz^2}$$
 (4.1)

Fx= The force is applied along the X-axis

Fy= The force is applied along the Y-axis

Fz= The force is applied along the Z-axis







Figure 4.4 Resultant Force Vs No of Run (Up Cut)

The graph above indicates that when the number of helixes and helix angle change, the cutting force reduces, despite the fact that cutting up and down gives similar results. The same spindle speed of 5938 RPM and 297 mm/min can be observed throughout the whole run. When compared to the other tools, tool 1 has the highest helix angle while tool 3 has the least. As the number of helixes reduces, so do the shear forces of these three runs. This result is similar to the study of a previous research by (Waqar et al., 2017), in which this researcher said that the tool with the highest geometric parameters of helix angle is the ideal cutting tool in terms of cutting force. According to the graphs in Figures 4.3 and 4.4, the resultant force drops with each tool utilized.

Furthermore, it is generally believed that the smallest resultant force presented by tool 3 was 3.500N on average for both the machining directions of up and down cutting. That averaging is which had the fewest number of tooth and helix angles due to thermal effect, particularly the polymeric matrix's low glass transition temperature, Tg. Fracture and deterioration may occur if the cutting temperature exceeds the glass-transition temperature (187°C) of the CFRP matrix (Yashiro, Ogawa and Sasahara, 2013).

4.5 Tool Wear VERSITI TEKNIKAL MALAYSIA MELAKA

The cutting tool gradually fails as a result of material machine operation. The more or for a longer period of time the tool is used, the more tool wear is created. Tip tools and tool bits are among the tools that are affected. Following CFRP trimming, the ends of the cutting tool teeth were detected in the burr tool. Under a Nikon MM-800 measuring microscope, tool wear was seen. The information is shown in table 4.3 and 4.4.



Table 4.3 Microscopy images



Table 4.4 Image of Tooth Fracture

The major importance is put on T1 and T3, which produced the lowest and greatest surface roughness values, respectively. The table above clearly shows that the tooth of cutting tool 1 which underwent the spindle speed (5938 RPM) with feed rate 297 mm/min has the least amount of damage when compared to the others. The tool fractures are most

obvious at tools 2 and 3, where the damages at the tip of the tooth are extreme. As a result, the smaller the helix angle, the greater the fracture of the tip. Table 4.4 displays the overall and enlarged micrographs for all selected router tool geometries with the specified cutting condition applied.

Surface roughness is also affected by tool wear. The higher the surface roughness measurement, the greater the tool wear. The photomicrograph of the tool in figure 4.5 (b) appears to correlate to the surface finish outcome. Furthermore, variations in the number of teeth on the cutting tool influenced tool wear in general. This shows that tool wear is caused by high abrasion on the tool edges rather than by high cutting force. (López De Lacalle et al., 2009). The results are similar to the results obtained by (Voss et al., 2017), who indicated that raising the clearance angle a lower the contact area between tool and material. As a result, forces and tool wear are minimized, and milling quality is improved.



Figure 4.5 (a) The tooth tool's tip may still be seen plainly (b) Fractured tooth

4.6 Surface Integrity

The highest and lowest values on each cutting tool utilised for the examination of the material surface image were chosen based on the values obtained on the surface roughness. Figures 4.7 and 4.8 illustrate microscopic pictures of the machine surface acquired after

trimming at a spindle speed of 5938 RPM and a feed rate of 297 mm/min. It demonstrates that certain places have seen fibre pullout. Picture 4.8 shows the machine with the lowest surface roughness, whereas figure 4.9 shows the clean machine (c). Figure 4.9 (b) shows matrix smears and sections of the matrix that have been burnt. When the number of teeth and helix angles are reduced, the damage region becomes obvious. This means that the surface roughness data shows that as the average surface roughness value increases, the tool wear increases. However, cutting tool 2 has the most maximum damage figure at 4.9 (a), where the majority of fibres rip out, and it has the poorest surface integrity among the other tools.



Figure 4.6 Microscope image of surface roughness



Figure 4.7 Surface Roughness is determined by microscopic photographs of a machined



Figure 4.8 Surface Roughness is determined by microscopic photographs of a machined

Contract of

surface with a lower roughness.



(a)

(b)



Figure 4.9 Microscopic images of machine surfaces for various cutting tools

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CHAPTER 5

CONCLUSION

5.1 Introduction

The results and potential future work improvements from the examination of the influence of cutting tools on trimming the edges of CFRP materials are discussed in this chapter. This chapter analyzes the achievement of the study's objectives and stresses overall performance. Make comments and recommendations for future work in terms of how to improve and will assist the aerospace sector in improving efficiency.

5.2 Conclusion

This research to evaluated into the best router tool geometry as well as the impact of surface quality and tool wear on certain CFRP materials utilised during the edge trimming process. To measure the Cutting Force involved, three carbide burr tools with varied shape were used in trials using a Kistler dynamometer of type 9257B. To highlight degradation, damage to tools and workpieces under the surface was inspected using a microscope type of Nikon MM-800. The following conclusions may be derived from the findings:

i) In terms of tool geometry, the cutting tool (T1) has the most teeth compared to T2 and T3, or even the same helix angle for both the right and left flutes. Through the machining mode of up and down cutting, tool 1 achieves lower surface roughness than tools 2 and 3. As a result, the cutting force at T1 is the highest, which is ideal for the properties of Carbon Fiber material. It is less effective if the resultant value is low attributable to tool wear and material surface effects. This result describes the tool geometrical feature of T1 better

of the chip formation due to the number of teeth gap and makes it smooth so that it would not harm the material's surface.

- ii) Tool 1 generates a high resultant force value, whereas tools 2 and 3 obtain decreased resultant force values. For all of the machining parameters used, the resultant force shows a clear trend on the cutting forces. The thermal effect, particularly the low temperature of glass transition, Tg, of the polymer matrix, was thought to be the primary factor influencing the resulting force. As a result, significant mechanical energy is required to create more shear and, consequently, thermal efficiency.
- iii) The above conclusion is supported by optical microscopy observations of the trimmed surface, which clearly show signs of matrix degradation, uncut fibre, and fibre pull-out on the trimmed surface of the high lower surface result of cutting tool T2 and T3, but not so much on the trimmed surface of T1.

iv) Wear happens depending on the cutting parameters. Ends of tipped pyramids or diamond-shaped cutting teeth that have been damaged off. Fractures of pointed pyramid ends are more obvious on cutting tools 2 and 3, which have less teeth and helical angles.

5.3 Recommendation

In the studies obtained, improvements can be made in the future. Therefore, there are several recommendations that have been identified throughout this study. During the machining process, the cutting force condition will produce cutting temperature and chip formation. In analyzing to determine the better glass transition temperature as well as the chip temperature, can use infrared thermograph camera IRISYS 4010 in getting clearer

results. Following that, the wear characteristics of the burr tool are only evaluated by inspecting it under an optical microscope. The behavior can only be studied using a scanning electron microscope for better understanding and wear monitoring (SEM). After that, the CFRP material utilised may be adjusted with different plate thickness differences and multiple ply orientations to determine surface roughness by optimising cutting tools and machine parameters. Finally, destructive tests such as tensile, impact, and compression testing may be used to investigate the effect of process factors on the mechanical characteristics of CFRP composite materials.



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APPENDICES

APPENDIX A Gantt Chart for BDP1

Project	Expected / Actual	(BDP 1) 2020/2021															
Activity		1	2	3	4	5	6	7	8		9	10	11	12	13	14	15
Title Registration	Expected	BREIFING															
	Actual																
Searching Joural	Expected																
	Actual																
Searching Information of geometry tool	Expected																
	Actual		40														
Chapter 1: Introduction	Expected		X	16.						EAK							
	Actual			7						1 BR			V				
Chapter 2: Literature Review	Expected									TERN	_		M				
	Actual	DP 1				-	1			MID			<u></u>				
Chapter 3:	Expected	B			-			-		-							
Research	Actual	m	۵ ر	ڪر		2			2	ى ب		w V	<u>ي</u> ون-	او			
Report Draft Submission	Expected			121		. A. 1				ve				2.0			
	Actual			n.i	sur.	5			1	AT O	LPA.	IVIE	LA	n.m			
Presentation	Expected																
	Actual																
Report Submission (PSM1)	Expected																
	Actual																

Project	Expected / Actual	(BDP 2) 2020/2021															
Activity		1	2	3	4	5	6	7	8		9	10	11	12	13	14	15
Briefing	Expected																
	Actual																
Pre- Experimental	Expected																
	Actual																
Experiment: Edge Trimming	Expected																
	Actual																
Experiment: Cutting Force	Expected																
	Actual	1A															
Experiment: Surface Roughness	Expected		302							¥							
	Actual			NAA						BRE/							
Experiment: Tool Wear	Expected									RM			V				
	Actual									ID TE		7	U/				
Analysing Data	Expected									Σ							
	Actual			14	~	-	• 4	-	_	3 1		. 41		1			
eLogbook Submission	Expected	-	(5						r Ç	2	V	7.	2			
	Actual	TI	TE	K	NI P	ĊĂ	LI	N A	L	AYS	IA	ME	LA	KA			
Report Draft Submission	Expected																
	Actual																
Submission of Final Report	Expected																
	Actual																
BDP	Expected																
Presentation	Actual																

APPENDIX B Gantt Chart for BDP 2

Technical Data	Туре	9257B				
Measuring range						
F _x , F _y	kN	-5 5				
Fz	kN	-5 10				
Calibrated measuring range						
F _x , F _y	kN	0 5				
	kN	0 0,5				
Fz	kN	0 10				
	kN	0 1				
Sensitivity						
Fx, Fy	pC/N	≈–7,5				
Fz	pC/N	≈–3,7				
Natural frequency						
fn(x), fn(y)	kHz	≈2,3				
fn(z)	kHz	≈3,5				
Pretensioning direction		vertical				
Operating temperature range	°C	070				
LxWxH	mm	170x100x60				
Weight						
Degree of protection IEC/EN 60529 (w. c	IP67					
Connection	Fischer flange 9 pol. neg.					

APPENDIX CDynamometers Type 9257 from Kristler



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Dekan Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan Universiti Teknikal Malaysia Melaka

Tuan

PENGKELASAN TESIS SEBAGAI TERHAD BAGI TESIS PROJEK SARJANA MUDA

Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh **LIMA** tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

Nama pelajar: MOHAMAD AFIQ ASNA BIN MOHD HASNI (B091810370) Tajuk Tesis: Evaluation of Milling/Trimming Performances for CFRP Material utilizing Various Burr/Router Tool Geometrical Features

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA" "KOMPETENSI TERAS KEGEMILANGAN"

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: EVALUATION OF MILLING/TRIMMING PERFORMANCES FOR CFRP MATERIAL UTILIZING VARIOUS BURR/ROUTER TOOL GEOMETRICAL FEATURES

SESI PENGAJIAN: 2020/21 Semester 1

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