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A Review on Effect of Cooling Method and Cutting Tool Geometries on Surface Defect of Carbon Fibre Reinforced Polymer Workpiece by End Milling Process

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Abstract: In this modern industrial revolution era, the usage of advance material is very common. Carbon Fibre Reinforced Polymer (CFRP) is one of the common composite that has been used in the industries due to desired properties, such as high tensile strength to weight ratios, tensile modulus to weight ratios, low coefficient of thermal expansion, high fatigue strengths and thermal conductivity. However, the machining of CFRP is always a challenging task. A lot of studies have been conducted to improve the machinability of CFRP. In this study, we will be focusing on the effect of cooling condition and tools' geometry on the surface defect of CFRP during milling. A review study on previous researches were done to gather information for our study. From the study, we found out that cryogenic cooling method is the best for the milling of CFRP due to the lower temperature causing more resistance against delamination of CFRP. High value of rake angle, helix angle, and clearance angle will provide a better surface finish. However, the effect of clearance angle is not as significant as the effect of rake angle and helix angle on surface roughness.

Keywords: Carbon Fibre Reinforced Polymer (CFRP), Cooling Method, Tool Geometries, Surface Defects

1. Introduction

In the process of material removal, metal cutting can be considered as one of the most important manufacturing process. Metal cutting is the removal of metal chips from a work item in order to obtain a final product with the specified size, shape, and surface roughness [1]. Milling process is the process where material is removed from a dedicated work piece through rotary cutting. It is the most common form of machining that are able to create a variety of features on a part by removing unwanted material. It allows modelling in complex forms and can produce shaping as well as details in a work piece, such as shapes, slots, holes, notches, grooves, pockets and others. The milling process is carried out using milling machines and cutting tools, performed on a work piece which is secured to the fixture, that are attached to a platform in the milling machine. The working process normally consists of a first roughing cycle, where it is a fast process to remove the material in a rapid process while leaving a sufficient layer

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of material for the finishing stage. The finishing stage is where the removal of a small amount of material with respect to the initial project regarding the tolerances of the dimensions and the degree of roughness of the surfaces.The introduction should describe general information on the subject matter area of study. It is usually arranged in such a manner to gradually bring to focus the specific motivations of the current study, the research questions, the problem statements, the hypotheses, the objectives, as well as the expected outcome.

There are a few types of cooling condition for milling process, which are conventional flood cooling, minimum quantity lubrication (MQL), cryogenic cooling, and combined cryogenic and minimum quantity lubrication (CryoMQL). Cutting fluid have been used for atleast the last 120 years for increasing machining productivity and maintaining or improve surface integrity after the process. However, the drawback is the loss of cutting fluid, where 30 percent of fluid is lost through leaks in circuits or in the cleaning process [2]. The other cooling methods are alternatives to the flood cooling method to avoid the use of large amount of cutting fluids. S. Sartori, A. Ghiotti, and S. Bruschi introduced three hybrid cooling techniques, which are hybrid LN2rake + MQLflank, LN2flank + MQLrake, and CO2rake + MQLflank. It is found that combined CryoMQL can eliminate tool crater wear and achieved better surface topography [3].

Carbon fibre reinforced polymer composites (CFRP) are lightweight, strong materials that are used to make a variety of products, with carbon fibre serving as the principal structural component and the “P” in CFRP standing for plastic or polymer [4]. CFRP materials possess good rigidity, high strength, vibration resistance, high ultimate strain, low density, corrosion resistance, high fatigue resistance, and low thermal conductivity, but they are bad conductors of electricity and non-magnetic [5].

Milling requires the use of a sharp cutter, which is attached to the milling machine and spun by the spindle. The cutter is a cylindrical tool with sharp teeth distributed around the outside, with flutes between the teeth allowing material chips to travel away from the work piece. They are designed with cutting teeth on the face and edge of the body, which can be used to cut in several direction. This is because they do not have cutting teeth over the entire end, but do have a ‘dead' area in the centre, end mills can only be cut utilising the side of the cutter and the outer periphery of the terminating end [6].

Heat is created in every machining process, and it is largely focused in the cutting zone. The chip tool, work piece, and shear-plane interfaces all emerged in this zone. As a result, cutting temperature has a significant impact on the surface finish of the workpiece and the precision of the machine tools. As cutting speeds have increased in machining operations, the thermal elements of cutting have grown increasingly relevant. This is due to the fact that temperature affects not only the rate of tool wear, but also the thermal expansion and final surface polish of the work piece [7].

Surface integrity refers to the state of a work piece's surface after it has gone through a manufacturing process such as milling. The material characteristics of a work piece are affected by its surface integrity, and the ramifications of these changes are a mechanical engineering design problem. Surface integrity has two aspects which are surface topography and surface metallurgy. Surface topography describes the roughness, waviness, lay, or texture of the outermost layer of the work piece, while surface metallurgy describes the nature of the altered layers below the surface such as plastic deformation, residual stresses, and hardness.

1.1 Objectives

The objective of this study is to study the effect of cooling condition and tool geometries on surface roughness and delamination factor of CFRP work piece. We will also determine the significance of each tools’ geometry on the effect of surface roughness of CFRP.

2. Materials and Methods

In order to establish a comprehensive review, the selection of research papers that related to the machining performance of CFRP, especially the cooling method and tool geometries were systematically analyzed. For us to be able to select a suitable article to review, we need to first understand the scope of our study and identify the criteria required for our study. Table 2.1 summarize the criteria needed for this study on effect of cooling condition on surface roughness. Table 2.2 summarize the criteria needed for this study on effect of tools' geometries on surface roughness.

Table 2.1: Summarize of criteria needed for the study on effect of cooling condition on surface roughness

Parameters	Condition
Machining method	Milling
Machine	Mazak Nexus 410-II CNC milling machine
Cutting parameters (feed rate, spindle speed, cutting speed)	Constant
Work piece	Carbon Fibre Reinforced Polymer
Depth of cut	Constant
Tools' geometries	Constant
Cooling method	Manipulated

Table 2.2: Summarize of criteria needed for the study on effect of tools' geometries on surface roughness

Parameters	Condition
Machining method	Milling
Machine	Mazak Nexus 410A-II CNC milling machine
Cutting parameters (feed rate, spindle speed, cutting speed)	Constant
Work piece	Carbon Fibre Reinforced Polymer
Depth of cut	Constant
Cooling method	Constant
Tools' geometries	Manipulated

For the machining method, only article that studies on milling will be considered. Articles that discuss about other machining method will not be selected for review as it will affect the result of our study. For example, for drilling of CFRP, the surface defect is not the same throughout the drilled hole. The entrance, centre, and exit of the hole experienced different surface defect and have different surface roughness. However, for end milling, the surface defect throughout the milled surface will be almost similar. Thus, there will be a difference in result for drilling and milling method.

Mazak Nexus 410A-II CNC milling machine will be set as the default machine for our study. However, it is not an important criterion that must be followed. This is because the results obtained from other CNC milling machine will still be the same and can be referred or reviewed. As long as the experiments conducted by the authors perform milling operations and under the allowable specification for Mazak Nexus 410A-II CNC milling machine as stated in Figure 3.25, such as the spindle speed does not exceed 12000rpm.

The cutting parameters must be kept constant, as the cutting parameters are able to give changes to the result on surface roughness and delamination factors. The depth of cut throughout the experiment also must be kept constant to avoid any influence on the results. The work piece used for the study of the article must be carbon fibre reinforced polymer, and any other material will not be accepted. This is because different materials have different machinability, which the results obtained may be different. Thus, in order to avoid any error, we will only be reviewing the articles that performed studies on CFRP only.

The cooling method and tools' geometries will be the main point of our study, where the reviewed article must study the effect or cooling condition or tools' geometries on the surface defect of CFRP.

2.1 Selection of article

In order to select the suitable article to be reviewed, first we will go through the article's aims and scope of study. If the article meets our criteria that stated in sub-chapter 3.14.1, then it can be selected to be reviewed. The article also must be a recent study, preferably in the previous 5 years. This is to make sure that the informations and results in the article are not outdated and are still valid. The results and conclusions from each article must be compared to other article to make sure that the trend of the results and findings of the research are similar. This also serves as a validation to prove that the results obtained are correct and can be used for our review.

2.2 Review of article

First, the author and the topic of the article will be introduced to provide an insight of the article. Then, the method used for the study of the article will be briefly explained to provide a general information on the method used for the study. After that, a critical discussion will be made on the results obtained from the article, including the experiments that have been done, the data that were collected from the study, and the analyzed results. Other articles will serve as a proof or support for the results obtained from the article.

3. Results and Discussion

3.1 Effect of cooling condition on the surface roughness and delamination of CFRP

A study by N. Arjun on analysis of surface integrity in machining of CFRP under different cooling conditions to find out the best cooling condition for the machining of CFRP. Figure 3.1 shows the average surface roughness of CFRP for each cooling condition with different feed rate, where CF represent the highest feed rate and VF2 represent the lowest feed rate.

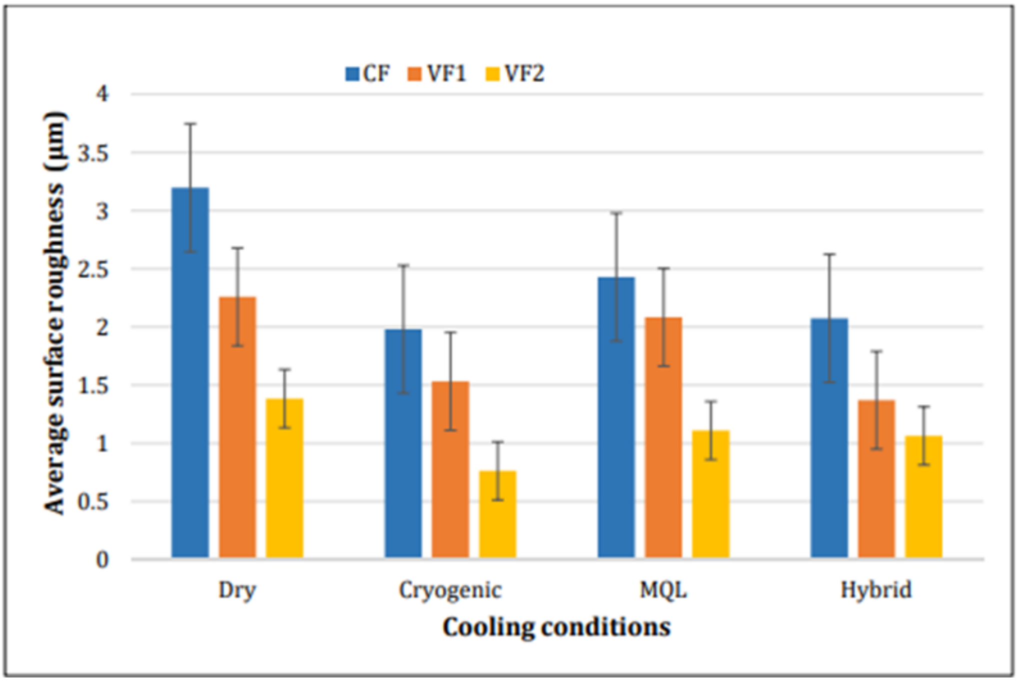

Figure 3.1: Average surface roughness of CFRP for each cooling condition with different feed rate [8]

According to the results in Figure 3.1, when conducting the experiment in high feed rate, the surface roughness produced is the highest for dry machining, while cryogenic cooling conditions produced the lowest surface roughness. For medium feed rate, dry machining produced the highest surface roughness, while hybrid cooling method produced the lowest surface roughness. For low feed rate, dry machining produced the highest surface roughness, while cryogenic cooling produced the lowest surface roughness. Overall, regardless the feed rate, dry machining has the highest surface roughness, while machining under cryogenic cooling conditions will produced the lowest surface roughness.

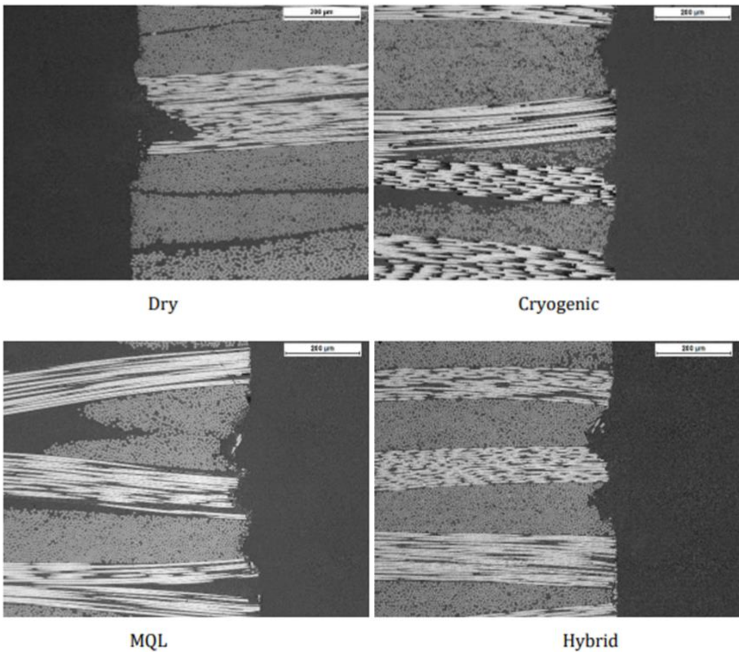

Figure 3.2: Micrographs under all cooling conditions at constant feed [8]

Based on the results in Figure 3.2, dry machining produced the deepest sub-surface damage, which extend up to 176 µm. Machining under cryogenic cooling condition produced the best surface finish, where the damage was confined to a maximum depth of 61 μm from the surface. This validates the results in Figure 3.1, where dry machining produced the highest average surface roughness, while machining under cryogenic cooling condition produced the lowest average surface roughness.

The results can be explained by the high cutting temperature produced during dry machining, which lead to thermal softening of the matrix that results in weakening the support for fibres. Finally, this will lead to fibre pull-out which creates cavities that will increase the surface roughness of the machined surface. On the other hand, the lower temperatures that involved in cryogenic machining are able to increase the bonding strength between the fibre and matrix, resulting in fewer fibre pull-out and defects, thus able to produce a smoother surface finish.

Another study was done by M. Sezer, et al., on cryogenic machining of carbon fiber reinforced plastic (CFRP) composites and the effects of cryogenic treatment on tensile properties. Figure 3.3 shows the delamination factor of CFRP under dry machining and machining under cryogenic cooling condition with different feed rate.

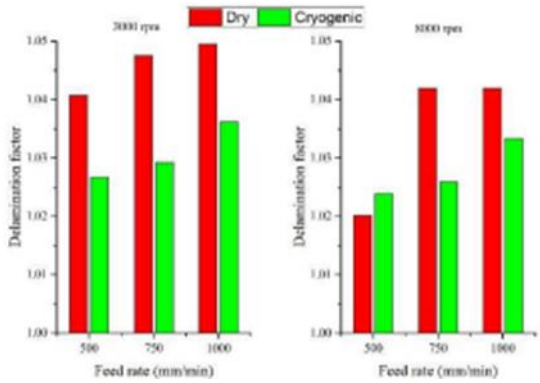

Figure 3.3: Delamination factor of CFRP under dry machining and machining under cryogenic cooling condition with different feed rate [9]

Based on the results obtained in Figure 3.3, on average, the delamination factor of CFRP under dry machining is higher than machining under cryogenic cooling condition. This is also supported by Khairusshima, et al., that stated smaller delamination occurred in the milling of CFRP under cryogenic condition, where chilled air at -10˚C was used as a coolant compared to dry machining. According to S. Barnes, et al., at low temperatures, the tensile strength and stiffness, shear modulus and transverse strength of CFRP increase. Thus, CFRP laminates show more resistance against delamination when undergo machining under cryogenic condition than that of the dry machining.

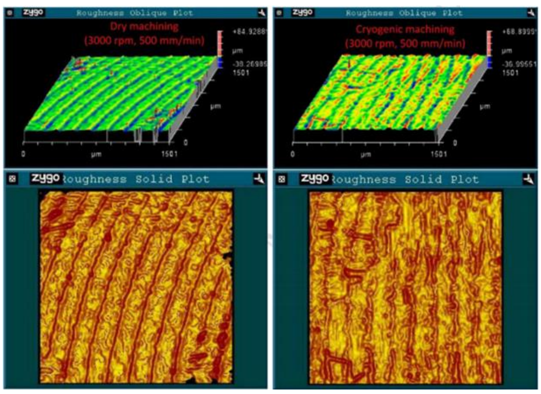

Figure 3.4: Surface roughness of CFRP under dry machining and cryogenic machining [9]

Based on the results obtained in Figure 3.4, the surface roughness of CFRP under dry machining is higher than the surface roughness of CFRP under cryogenic machining, which are 84.9μm for dry machining and 68.9µm for cryogenic machining. According to T. Xia, et al., and G. Basmaci, et al., cryogenic cooling of workpiece will change the material structure of CFRP work piece from ductile to brittle because of the rapid decrease in the temperature of the material. The changes in material properties of CFRP will improve chip breakability. Moreover, cryogenic cooling can reduce the formation of thermal damage at the machined surfaces and also reduces cutting temperature, which helps keep the sharpness of the cutting edge.

Figure 3.5 shows the SEM images of the surface of CFRP for dry and cryogenic machining. Based on the Figure, it can be seen that the machined surface obtained during cryogenic machining is smoother than that of the dry machining. For dry machining, irregular fibre breakages, fibre and matrix debris, and fibre pull out can be seen clearly and more frequent. This is because during cryogenic machining, due to cryogenic coolant, the bonding forces between fibre and matrix increases, which prevents the formation of defects that occurs during dry machining.

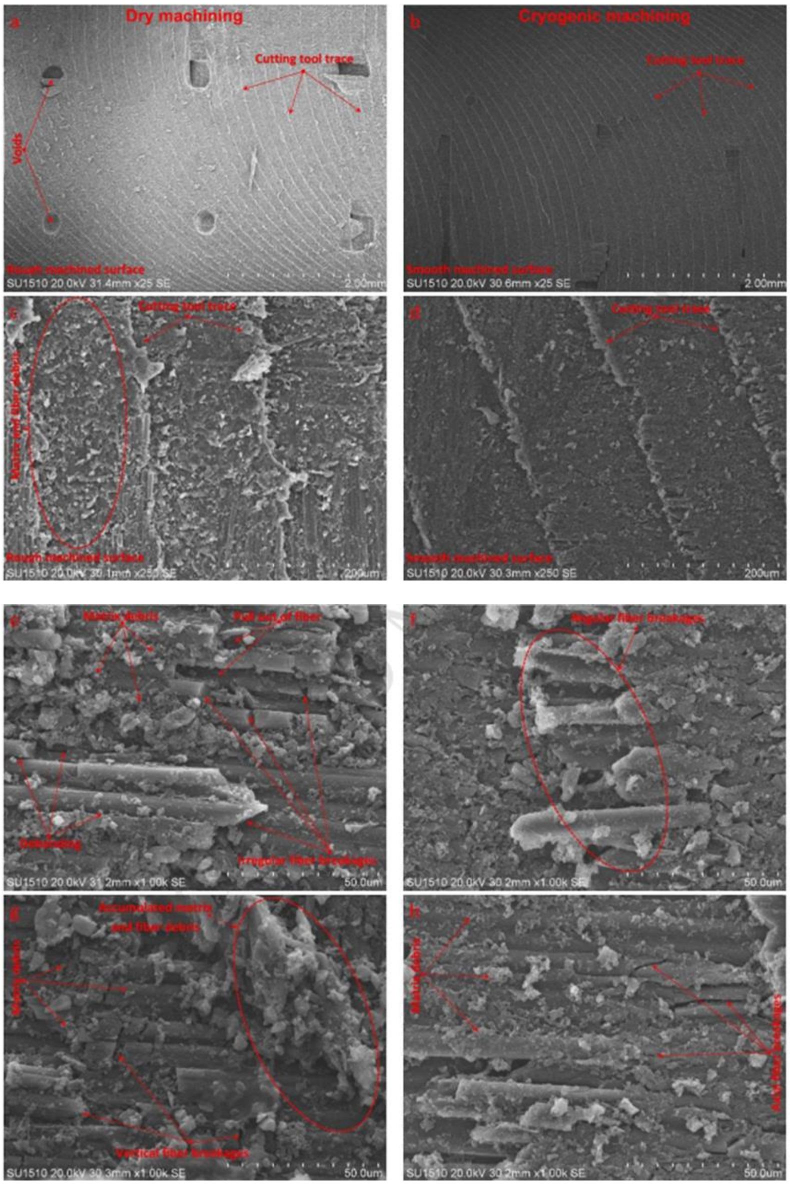

Figure 3.5: SEM observations of CFRP after dry machining and cryogenic machining [9]

3.2 Effect of number of flutes on the surface roughness and delamination of CFRP

A study by M C H Ling et al., was conducted to analyse the effect of end mill flutes on delamination in milling of synthetic FRP composite. For the experiment, there are 3 levels with different number of flutes. The feed rate, spindle speed, and depth of cut were kept constant throughout the whole study.

No	Tool geometry	Average,Fd Glass FRP composite	Average,Fd Carbon FRP composite
1.	2 flutes	1.23	1.07
2	3 flutes	1.21	1.06
3	4 flutes	1.19	1.04

Figure 3.6: Delamination factors of glass FRP and carbon FRP samples [10]

We will be taking account only the results for carbon FRP composite samples as glass FRP composite is out of our study scope. According to the result in Figure 3.6, the delamination factors of CFRP is the highest when using tool with 2 flutes and it is the lowest when using tool with 4 flutes. In conclusion, the study shows that using tool with lower number of flutes will increase the delamination factors, thus increasing the delamination that occur on CFRP during end milling.

Another study was done by K. Erol, et al., which investigate an experimental study of end milling of CFRP composite. The experiment was conducted by using a constant spindle speed and depth of cut. For the tool's geometries, the diameter and helix angle of the tool were kept constant, where the only variable was the number of flutes. Based on the results obtained in Figure 3.7, for every feed rate and cutting speed, the delamination factor for end milling process by 4 flute end mill will always be lower than 3 flute end mill. Thus, we can conclude that the delamination factor decrease when the number of flute increase, regardless of the cutting speed and feed rate.

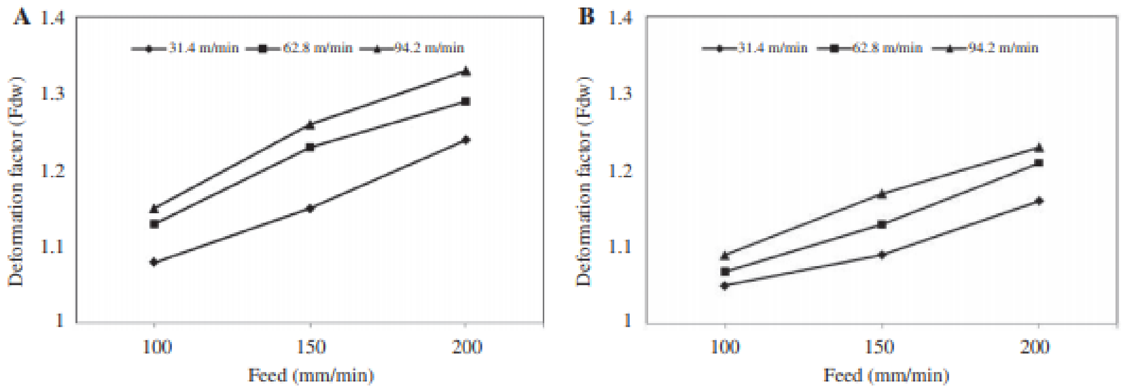

Figure 3.7: The delamination factor for (A) three flutes and (B) four flutes [11]

3.3 Effect of helix angle on the surface roughness and delamination of CFRP

A study was done by R. Izamshah, et al., to investigate the effects of cutter geometrical features on surface roughness. The experiment was carried out by using 12 tools with different tool geometries. Figure 3.8 shows the results of the experiment conducted, where different surface roughness was obtained when using different tools.

Tool	Rake angle	Clearance angle	Helix angle	Surface roughness (μm)			
				Run 1	Run 2	Run 3	Average
1	5	10	30	0.69	0.66	0.67	0.67
2	10	10	30	0.34	0.35	0.37	0.35
3	15	10	30	0.28	0.26	0.25	0.26
4	14	6	30	0.92	0.89	0.9	0.90
5	14	8	30	0.83	0.84	0.86	0.84
6	14	12	30	0.72	0.7	0.69	0.70
7	14	14	30	0.8	0.78	0.77	0.78
8	8	6	20	1.1	1.11	1.13	1.11
9	8	6	25	1.23	1.2	1.21	1.21
10	8	6	30	0.85	0.85	0.84	0.85
11	8	6	35	0.83	0.81	0.8	0.81
12	8	6	40	0.32	0.34	0.31	0.32

Figure 3.8: Experimental measured values of surface roughness [12]

According to Figure 3.8, we will be focusing on tool 8, 9, 10, 11, and 12. This is because the rake angle and clearance angle were kept constant, and the only variable is the helix angle. Thus, we can observe the effect of helix angle on surface roughness. On average, as the helix angle increase, the surface roughness decrease. This is because a high helix angle can reduce the stuck-chip description by effectively extracting the chip away from the cutting zone, thus improving the surface roughness.

Another research was done by R.S. Jiang, et al., on the influence of helix angle on the composite machining process. The experiment was done by using constant cutting speed and depth of cut, where the manipulated variable was helix angle. Figure 3.9 shows the result obtained from the experiment, where the surface roughness varies with different helix angle.

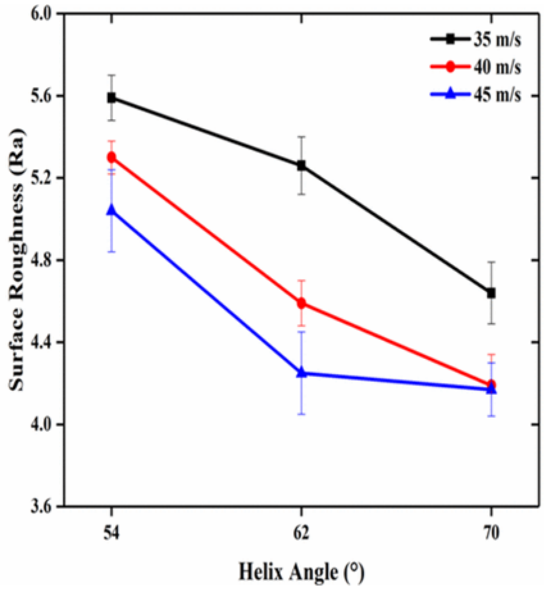

Figure 3.9: Effect of helix angle on surface roughness [13]

According to the results obtained in Figure 3.9, the surface roughness of the material gradually decreases with the increase of helix angle for all cutting speed. Thus, we can conclude that at different cutting speed, higher helix angle will still produce a better quality of surface finish with lower value of surface roughness. However, higher cutting speed will still result in a better quality of surface finish. Thus, using a combination of high cutting speed and high helix angle is recommended for a better surface finish.

The same author also studied the effect of helix angle on resultant forces. The results is shown in Figure 3.10, where the resultant forces varies with different helix angle.

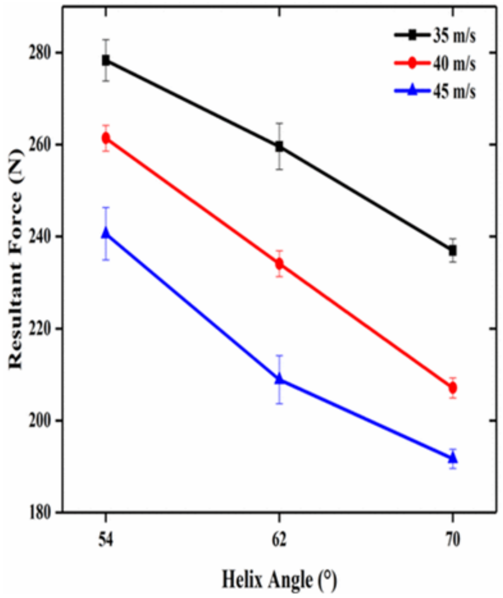

Figure 3.10: Effect of helix angle on resultant forces [13]

It can be seen from Figure 3.10 that with the increase of helix angle, the cutting force for every cutting speed also decrease. It can be observed that the highest cutting force is shown when helix angle is equal to 54˚ and at the cutting speed of 35m/s. Thus, this also shows that the lower the cutting speed, the higher the cutting force. This is because, when the cutting speed decreased, the feed per tooth increased, which increase the cutting force. From Figure 3.10, it can be seen that, at higher cutting speeds, the increase of helix angle has more significant effect on the reduction of cutting force.

Overall, both authors' studies found that the surface roughness will decrease with the increasing value of helix angle. This is also supported by a theory that a high helix angle is able to reduce the stuck-chip disruption because it can effectively extract the chip away from the cutting zone.

3.4 Effect of rake angle on the surface roughness and delamination of CFRP

The same author, R. Izamshah, et al., also study on the effect of rake angle on surface roughness. Based on the result in Figure 3.8, we will be focusing on tool 1, 2, and 3, because the helix angle and clearance angle were kept constant, and only rake angle will vary. It can be seen clearly that as the rake angle increase, the average surface roughness value decreases. The author emphasis that burr formation characteristic at the machined edge surfaces changes with different rake angle.

Another study was done by M. Helmy, et al., on rake angle effects on ultrasonic-assisted edge trimming of multidirectional CFRP laminates. The edge trimming experiments were conducted by using a Mazak FJV-250 UHS 5-axis CNC milling machine on a CFRP work piece. The surface roughness was measured in terms of arithmetical mean height (Ra) in the transverse direction using 3D laser microscope KEYENCE model VK-X100. Figure 3.11 shows the effect of spindle speed, feed rate, rake angle, and amplitude on the surface roughness. However, only the effect of rake angle will be discussed as other parameters are out of our study's scope.

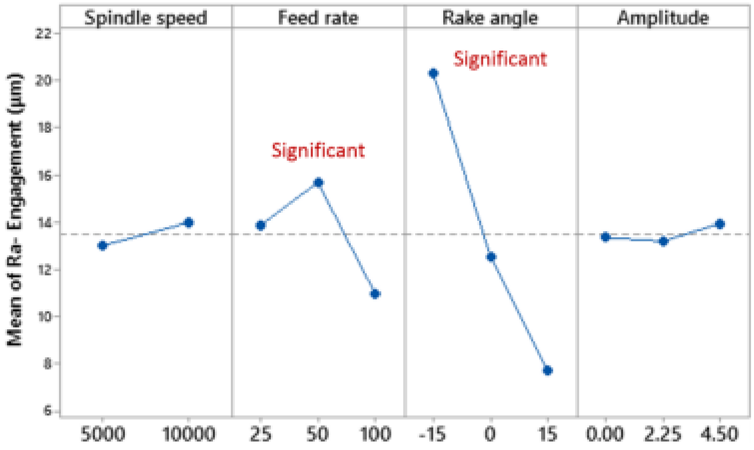

Figure 3.11: Effect of spindle speed, feed rate, rake angle, and amplitude on surface roughness [14]

The author explained that rake angle is important in deciding the chip formation mechanism. Based on the results in Figure 3.11, a positive rake angle produces cleaner cuts and was able to reduce the surface roughness dramatically compared to rake angle of 0˚ and -15˚. This is due to the application of tension and shear load on the fracturing of carbon fibre when positive rake angle was used. On the other hand, when zero or negative rake angle were used, it applied compression and bending or buckling of the fibre. This can be seen from the observation at Figure 3.12. Based on Figure 3.12 (a), when rake angle of 0˚ was used, the subsurface damage can be seen clearly, where there was matrix degradation, fibre lost, and fibre pull out. However, based on the observation on Figure 3.12 (b), when rake angle of 15˚ was used, better subsurface with minor loss of fibre can be seen. There were only some smeared matrix and voids on the subsurface of CFRP. This proves that higher rake angle will produce a better surface finish with lesser subsurface damage and lower surface roughness.

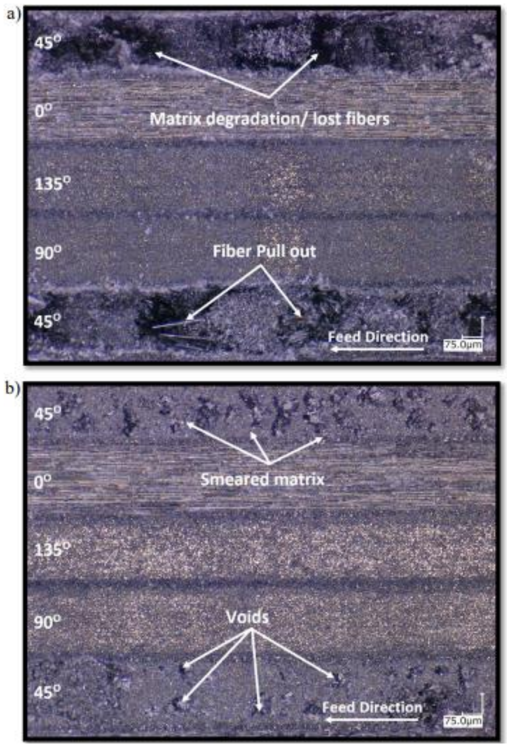

Figure 3.12: Effect of rake angle (a) 0˚ and (b) 15˚ on the surface quality of CFRP [14]

Another study was done by S. Jamal, et al., which focus on the evolution of cutting forces during slot milling of unidirectional carbon fiber reinforced polymer (UD-CFRP) composites. Slot milling experiments were conducted by the author on CFRP work piece under dry machining condition. Three different rake angles were used in the experiment, which were -15˚, 0˚, and 15˚. All other tools' geometries and cutting parameters were kept constant. The milling operation was performed on a 3mm thick CFRP laminates. The cutting forces was measured using Kistler (Type 9257B) piezoelectric dynamometer and the cutting force signals were conditioned and filtered by a 1kHz low pass filter using Kistler (Type 5070) charge amplifier.

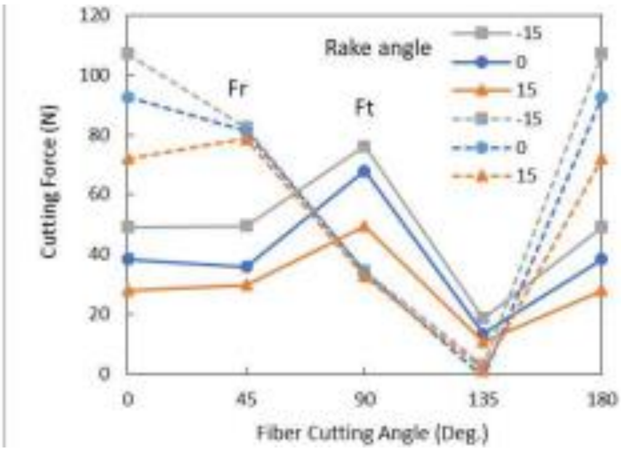

Figure 3.13: Effect of rake angle and fibre cutting angle on cutting force [15]

Based on the results shown in Figure 3.13, as the rake angle increased from -15˚ to 15˚, the cutting force decreased. The increasing of cutting force will directly influence the surface roughness of work piece, due to the effect on shearing force. For rake angle of 15˚, the shearing force is the smallest, which indicates a very efficient cutting of the fibre. According to T. Kaneeda, higher rake angle will produce continuous chip formation and reduce deformation to the fibre, which supports the results obtained by S. Jamal, et al. Overall, all the studies above obtained a similar result, where the surface roughness and delamination of CFRP can be reduced by implying a high rake angle.

3.5 Effect of clearance angle on the surface roughness and delamination of CFRP

A study was done by R. Izamshah, et al., which investigate the effect of clearance angle on the surface roughness. Based on the results in Figure 3.8, only experimental results from tool 4, 5, 6, and 7 will be taken for our study. This is because for the 4 selected experiments, all other parameters were kept constant, where only the clearance angle was varied. According to the results, clearance angle had slight effect on the surface roughness, where the increase of clearance angle will reduce the surface roughness. However, for the observation under the microscope, for different clearance angle, there was no significant change in the characteristic of the milled surface. Even though the effect of clearance angle is not significant on the burr formation and surface roughness, it is still an important parameter to be considered during milling, as the proper selection of clearance angle is necessary in term of high stability and reduction of machining vibration as proposed by L.T. Tune and E. Budak.

Another study was done by M. Henerichs, et al., to study the influence of tool geometry and fiber orientation on the machining forces and workpiece's surface. The purpose of the study is to increase the understanding of machinability of CFRP and thus prolong the tool life and increase workpiece's quality by adjusting the tool's geometries.

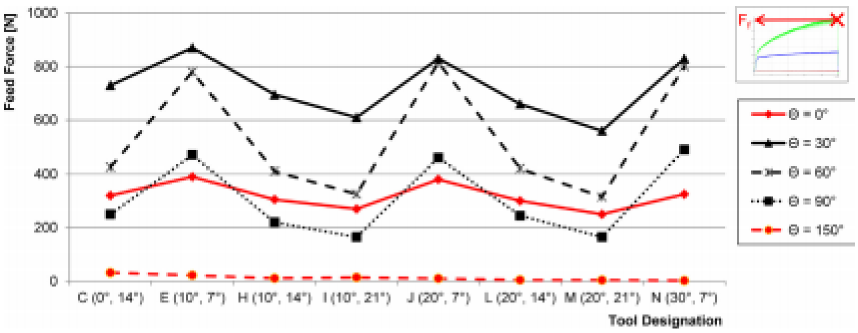

Figure 3.14: Effect of tools' geometries on feed force [16]

Based on Figure 3.14, we will be focusing on the red continuous line from the second point to the fourth point. It, can be seen that the feed force decrease with the increasing of clearance angle from 7˚ to 21˚. The effect of clearance angle on surface defect of workpiece was further analysed by observing the machined surface using scanning electron microscope (SEM). The result is shown in Figure 3.15.

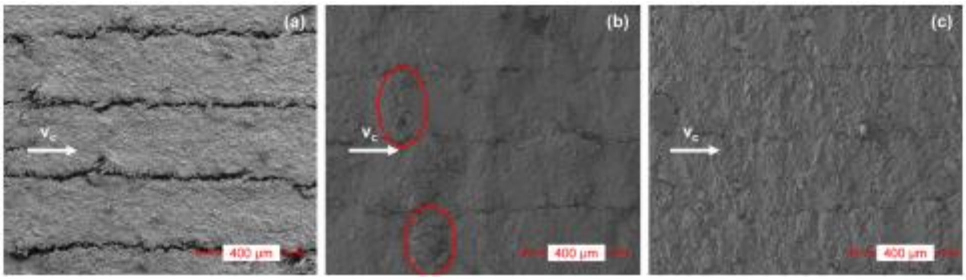

Figure 3.15: Machined workpiece's surface analysed using SEM. Surface machined with tool E (a), tool C (b), and tool I (c) [16]

Based on Figure 3.15, surface machined by tool E and tool I will be analysed to find out the effect of clearance angle on surface defects of CFRP. It can be clearly seen that the surface machined by using tool E, which has the lowest clearance angle showed an intensive removal of matrix material. This is due to the small clearance angle which pressed down the fibre material in a wide area, resulting in a squeeze out of matrix material. For the surface that was machined by using tool I, the surface looked less uneven and less combed compared to the other two surface. This proved that the increasing of clearance angle can produce a better surface quality with lesser surface defects.

According to the studies conducted by previous researchers mentioned above, them researches all came into a simple conclusion, where the increasing of clearance angle will reduce the surface defect of CFRP and produce a better surface finish. High clearance angle makes the cutting tool sharper and causes the material to be removed smoothly, which resulting in lower cutting force used [17]. This justify the results obtained from Figure 3.14. However, it will reduce the tool's strength, therefore degrades the tool's life. However, the experimental studies by the authors above did not mention about 0 value or negative value of clearance angle. This is because clearance angle of any cutting tool must have a finite positive value. If the clearance angle is set to zero or negative, then the finished surface of the workpiece will be in direct contact with the flank surface of the tool [17]. This causes the generation of excessive heat in the contact zone, which will lead to burned surface and lower quality of surface finish. Thus, normally the clearance angle is always kept positive.

3.6 Significance of tool geometric parameters on the effect of surface roughness and delamination of CFRP

A study was done by S. Waqar, et al. to elucidate cutting tool geometric parameters significantly affecting the cutting force and surface roughness. For this study, analysis of variance (ANOVA) was used to analyse the experimental data collected. Figure 3.16 shows the ANOVA results for surface roughness.

Source	DF	SS	MS	F Value	% Contribution
Rake Angle	2	3.4642	1.7321	23.19*	38.89 %
Helix Angle	2	5.1841	2.5920	34.71*	58.20 %
Clearance Angle	2	0.1088	0.0543	0.73	1.22 %
Error	2	0.1494	0.0746		
Total	8	8.9065			

*Significant at 95% confidence level Surface Roughness
DF = Degree of freedom, SS = Sum of Squares, MS = Mean Sum of Squares

Figure 3.16: ANOVA for surface roughness [18]

Based on Figure 3.16, it can be observed that the percentage contribution for rake angle, helix angle, and clearance angle to the surface roughness were 38.89%, 58.20%, and 1.22% respectively. This showed that factors that are significantly influencing the surface roughness are rake angle and helix angle, where helix angle being the most influential parameter. Whereby, clearance angle had only little influence on the results of surface roughness.

This trend can also be seen by the results of previous studies on subchapters above, where the changes in rake angle and helix angle will greatly influence the surface roughness, while the changes in clearance angle only had minor effect on the surface roughness.

4. Conclusion

In conclusion, the objectives for this review study have been achieved as we had determined the effect of coo cooling condition and tools' geometries on the surface defect of CFRP during milling. It is shown that cryogenic cooling condition is the best for milling of CFRP, due to its low temperature and low heat generation. CFRP laminates show more resistance against delamination when undergo machining under cryogenic condition than that of the dry machining, due to the increase of tensile strength and stiffness, shear modulus and transverse strength because of the low temperature.

By increasing the number of flutes, the delamination factor will be decreased, hence decreasing the surface roughness and obtain a better surface finish for CFRP work piece. For helix angle, the surface roughness will decrease with the increasing value of helix angle. This is also supported by a theory that a high helix angle is able to reduce the stuck-chip disruption because it can effectively extract the chip away from the cutting zone.

When the rake angle increased, the cutting force also increased. The increasing of cutting force will directly influence the surface roughness of work piece, due to the effect on shearing force. Higher rake angle will produce continuous chip formation and reduce deformation to the fibre. Thus, the surface roughness and delamination of CFRP can be reduced by implying a high rake angle. For clearance angle, the increasing of clearance angle will reduce the surface defect of CFRP and produce a better surface finish. High clearance angle makes the cutting tool sharper and causes the material to be removed smoothly, which resulting in lower cutting force used.

For the analysis of variance (ANOVA), factors that are significantly influencing the surface roughness are rake angle and helix angle, where helix angle being the most influential parameter. Whereby, clearance angle had only little influence on the results of surface roughness. Thus, if there are a limitation on the number of tools, and we are unable to obtain an optimum tool geometry, we can prioritize on the helix angle first, which means choosing the best helix angle, following by rake angle. The factor of clearance angle can be ignored, since it only has minor contribution to the effect of surface roughness.

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