IOP Conference Series: Materials Science and Engineering

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The Effect of Cutting Speeds on Tool Wear and Surface Roughness when Milling Carbon Fiber Reinforced Polymer

The Effect of Cutting Speeds on Tool Wear and Surface Roughness when Milling Carbon Fiber Reinforced Polymer

Aisyah Madihah Mustafa[1], Najlah Sakinah Shahruddin[1], Nor Farah Huda Abdul Halim[1*], Alya Naili Rozhan[1] and Maziati Akmal Hattiar[2]
[1]Department of Manufacturing and Materials Engineering,Kulliyyah of Engineering, International Islamic University Malaysia,53100 Gombak
[2]Department of Science in Engineering,Kulliyyah of Engineering, International Islamic University Malaysia,53100 Gombak

Email: farahudahalim@iium.edu.my

Abstract. Carbon fibre reinforced polymeric material (CFRP) is increasingly being used to replace metallic materials, particularly in the automobile and aerospace industries. The mechanical properties of the CFRP such as excellent weight to strength ratio give beneficial outcome in improving the performance of the part made from CFRP. However, machining of CFRP such as milling is difficult and challenging due to the abrasiveness of the CFRP. Therefore, the influence of cutting speeds on tool wear and surface roughness when milling CFRP in a dry condition is the aim of this paper. The milling test was carried out using 6 mm WC-Co end mill tool having 30° helix angle. Milling of CFRP was performed with three different cutting speeds, V_c (94, 113 and 132 m/min) while feed rate, f (1800 mm/min) and radial depth of cut,a_e (2 mm) were remained constant. Milling CFRP with V_c=132 m/min resulted in increasing of tool wear by 15 % and increasing of surface roughness by 10% when compared with V_c= 94 m/min. CFRP surface damages such as matrix smearing, delamination and fibre pull out was observed when milling with higher cutting speed.

1. Introduction

Attractive properties of Carbon Fiber Reinforced Polymer or CFRP such as excellent damage tolerance, fatigue resistance and high wear resistance made them extensively employed in high end industry especially in automotive and aerospace industry. More recently, CFRP has been used as a main material for aircraft main components such as door, wings and fuselage. This is attributed to its superior strength-to-weight ratio when compared to other materials such as metal, which improves fuel efficiency and load bearing reinforcement, both of which are determined by the aircraft's weight[1]. Also, CFRP can be manufactured nearest to its final product shape where post machining processes are still necessary to meet final dimension of the product. However, machining CFRP is challenging due to the anisotropy and non-homogenous characteristics of the CFRP. Edge trimming and drilling are still necessary for final part accuracy and hole making purposes. Selections of cutting parameters during machining of CFRP are crucial. Application of high cutting speed for example may lead to increasing of cutting temperature as well as increasing the tool wear rate. This can be explained by the abrasive nature of the carbon that may lead to the aggressive rubbing of the tool cutting edge on the machined surface[2-4]. Unlike machining metallic material where plastic deformation occurs during the removal process, CFRP undergoes brittle fracture where dust-like residual is formed, hence, minimizing the amount of heat removed [5,6]. Besides, machining beyond the glass transition temperature (Tg) will resulted in softening of the matrix resin, thus induced internal damage and degraded the quality of the CFRP [6,7]. Also, selection of cutting parameters during milling of CFRP such as cutting speed, feed rate, and depth of cut significantly affect the tool wear as well as surface damage. Rashid et al. [8] found that milling CFRP can be machined up to 13 m with low cutting speed (670 RPM) whereas at high cutting speed (6300 RPM) can only machined up to 8.4 m before the tool failed. This indicates that the increasing of contact time between the cutting tool and CFRP as the cutting speed increased. Moreover, studies found that increasing of cutting speed significantly increased the tool wear and shorten the tool life [7]. Sundi et al. [9] found that at lower cutting speed (2506 RPM), fibre pull out was not observed as compared with machining at high cutting speed (5012 RPM). They concluded that the fiber pull out occurred was due to the thermo-mechanical loads resulted from the increasing of cutting speed and cutting temperature along the milling process. Nguyen-Dinh et al. [10] observed that the effect of cutting parameters on surface roughness is more prominent when compared with cutting speed and machining distances during milling CFRP. They found that the measured surface roughness (Ra) increased up to 5.5 µm when V_c is increasing to 250 m/min, compared to machining at lower V_c= 150 m/min (Ra=1.7 µm). Therefore, in this research, an experimental investigation was performed to identify the effect of the cutting speed on the tool wear and surface roughness of the CFRP.

2. Experimental set-up and procedures

Mazak Nexus 410A-II Vertical Machining Centre was employed to conduct an experimental investigation during milling of CFRP. Three flutes of uncoated tungsten carbide (WC-Co) solid milling tool having 6 mm diameter was used as a main cutting tool. Two dimensions of CFRP which are 200x200x5 mm and 200x50x5 mm were applied to observe the tool wear and surface roughness development, respectively. Special fixture was used to clamp the CFRP panel and strip on the machine table as shown in Figure 1. Cutting parameters employed in this experimental investigation was tabulated in Table 1. All machining tests were performed dry.

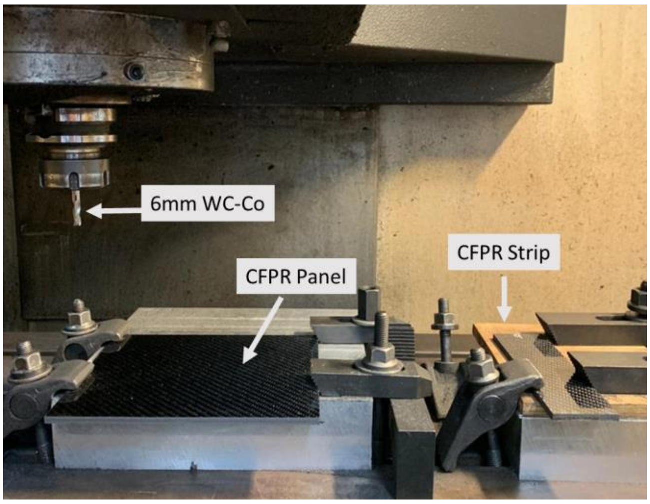

Figure 1. The experimental set up.

Figure 2. 6 mm diameter of K3EPEN 060C end mill

Table 1. Cutting parameters during milling CFRP

Cutting Parameters	Value
V_c (m/min)	94, 113, 132
f (mm/min)	1800
a_e (mm)	2

The tool wear and surface roughness was measured for every 400 mm distance travelled. The image of tool wear at each flutes was captured using Dino-Lite Premier and processed by using the digital imaging and measurement software. The average surface roughness (Ra) of the CFRP was measured using stylus type surface profiler, Mahr Federal Model 6910431 MarSurf M300 C set with 4 mm traverse length and 0.8 mm cut-off length. To confirm the carbon chip does not adhere on the CFRP surface and influence the measurement value, they were cleaned using an alcohol before Ra measurement. The CFRP machined surface was also observed and analysed using Alicona SL 3D profiler to further inspect the surface topography and condition after machining. The machining was conducted until 3200 mm machining length before the test was stop.

3. Results and discussion

3.1. Tool wear

The effect of different cutting speed during milling of CFRP over 3200mm machining length is shown in Figure 3. The tool wear value for all cutting speed increased as the machining length increased. Milling of CFRP with V_c=132 m/min resulted in highest tool wear with maximum 0.072µm of flank wear, followed by cutting tool with V_c= 113 m/min (0.064 µm) and V_c= 94 m/min (0.061µm) at the 3200 mm machining length. This indicates that the increasing of tool wear was caused by the increasing of contact length between the cutting tool and the workpieces during machining. Figure 4(i) shows the fresh tool whereas Figure 4(ii) shows the worn out tool after milling of CFRP.

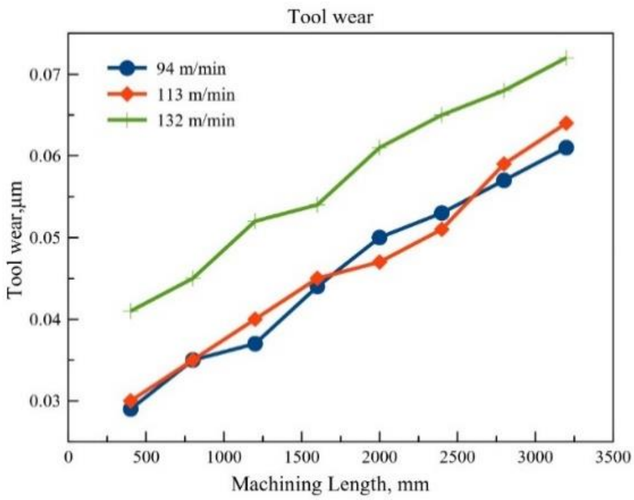

Figure 3. Tool wear against machining length.

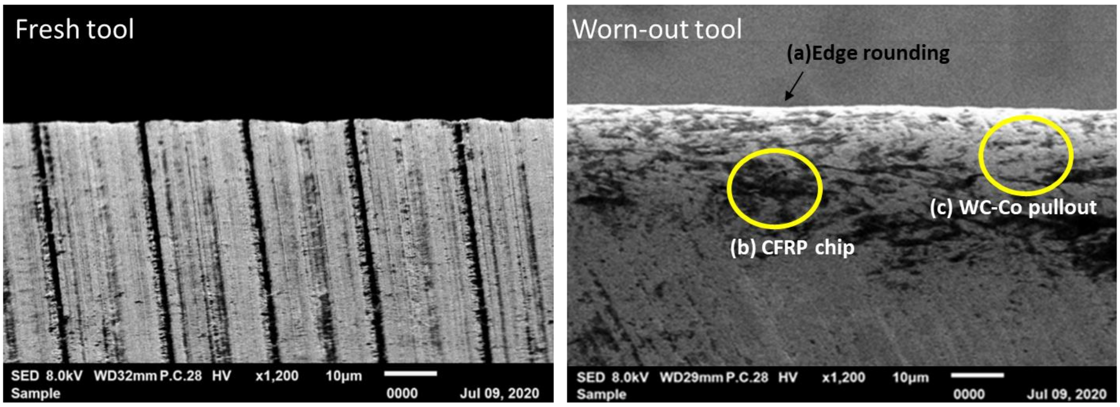

Figure 4. SEM images of (i) new cutting tool and (ii) worn out cutting tool after milling CFRP with 132 m/min after 3200 mm machining length.

Figure 4 (ii) shows that the worn-out cutting tool experiences edge rounding. It was also observed that adhered CFRP chip and matrix resin was observed at the cutting edge although the it has been cleaned with alcohol before the SEM examination was conducted suggesting that the matric resin have been thermally degraded during the milling operation. Furthermore, void was observed on the worn-out cutting tool due to the fractured chips of CFRP that abraded the tool surface causing dislodged of WC particles. This evidence proves that abrasive wear taking place as main wear mechanism during machining.

3.2. Surface roughness

The comparison of surface roughness progression when milling with V_c= 94, 113 and 132 m/min is shown in Figure 5. With regard with the effect of cutting speed, it was observed that high cutting speed of 132 m/min resulted 15 to 20% higher value of Ra when compared with lower cutting speed of 113 m/min and 94 m/min. At 3200 mm length, Ra value for V_c= 132 m/min was 1.45µm whereas, V_c= 94 m/min produced 1.25 µm Ra. Based on the surface roughness data presented in Figure 5, it was confirmed that the increasing of tool wear value as in Figure 3 affect the CFRP surface condition. This is an effect from the increasing of wear on the cutting tool radius that decreases the smoothness of the machining[7]. Therefore, the reduction in cutting tool sharpness resulted in degradation of the CFRP surface condition.

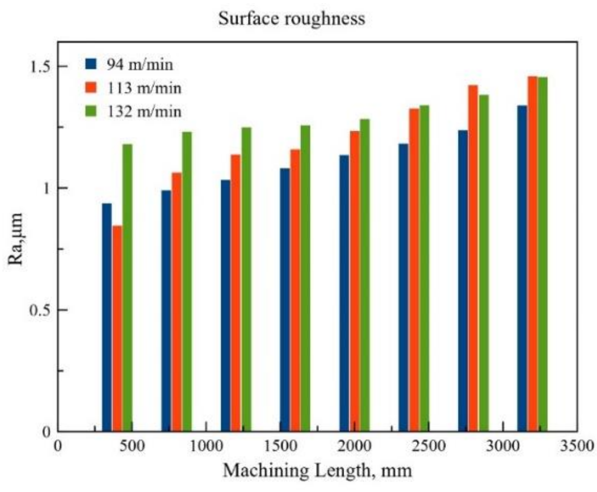

Figure 5. Ra against machining length.

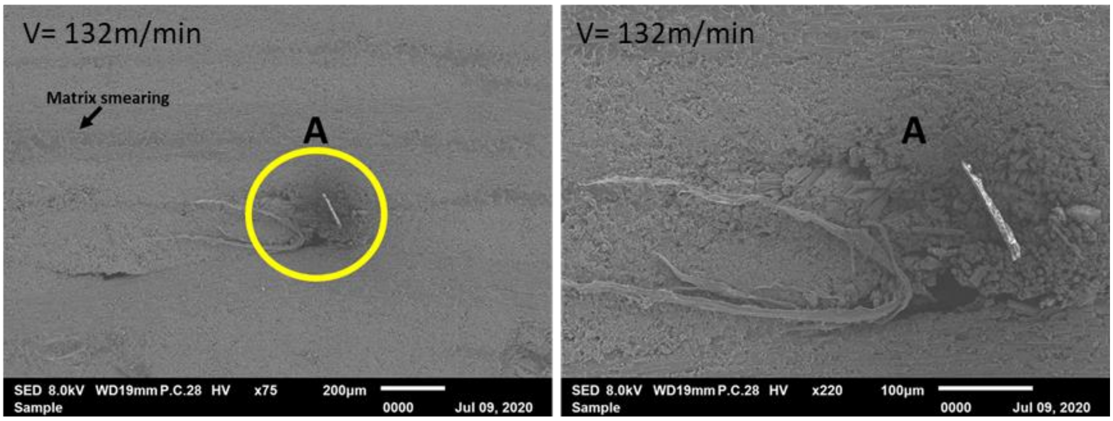

Figure 6. Surface damage that was observed after milling.

Matrix smearing and fibre pull-out was severely found on the CFRP machined surface when milling with higher V_c= 132 m/min as compared with other cutting speeds. This indicates that due to the worn out tool it is expected that the cutting force during milling was increased, thus resulted in deterioration of the surface condition as shown in Figure 6. Consequently, it is predicted that the heat generated caused by the worn out tool was then thermally degrade the matrix resin thus affecting the surface condition. It was also observed that fibre pull-out shown in Figure 6 occurred due to the thermo-mechanical failures between tool and workpiece. It is expected that high cutting temperature will be generated during milling operation at the cutting edge of WC-Co tool caused matrix interfacial shear strength decreased, that can lead in accelerate fibre pull-out. However, it was observed that the surface damage was less occurrence when milling with lower cutting speed.

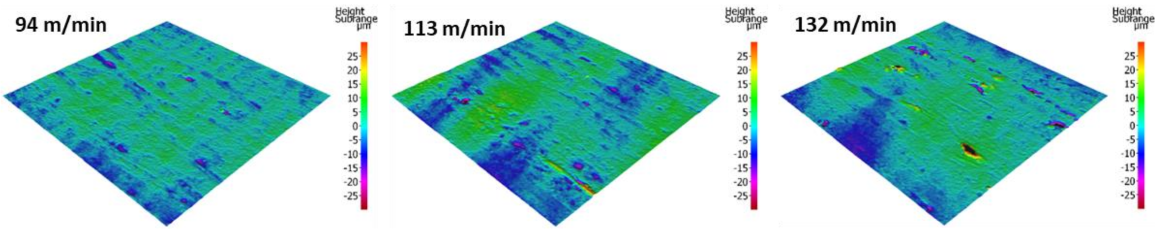

Figure 7. Image of surface profile observed on Alicona SL 3D profiler for 94, 113 and 132 m/min after 3200mm machining length

Figure 7 shows the surface profile observed by Alicona after milling with different cutting speed at 3200 mm machining length. The voids were severe on the machined surface with high cutting speed (132m/min) as compared with lower cutting speed. It shows that the machined surface for V_c= 132 m/min experienced the low surface profile quality after 3200 mm machined length therefore supported that the high cutting speed does resulted to fiber pull out that caused by the degrades of the matrix resin due to the heat generated.

4. Conclusions

The result of the effect of the cutting speed during milling of carbon fibre reinforced polymer using 6 mm end mill have been discussed. Some major observations are:

- Tool wear was measured up to 15% higher during milling CFRP with V_c= 132 m/min as compared with lower V_c = 113 and 94 m/min.

- The occurrences of delamination and fibre pull-out was less in lower cutting speed as compared with high cutting speed indicates that lower cutting speed is recommended to produce less damage.
- It was observed that milling of CFRP with lower V_c= 94 m/min resulted better surface roughness as compared with higher cutting speed where Ra value for V_c= 132 m/min was higher 10% than low cutting speed.
- The surface damage such as matrix smearing and fibre pull out on the CFRP machined surface was significantly observed when the value of tool wear increased.

Acknowledgement
This project is funded by International Islamic University Malaysia(IIUM) under RMCG20-027-0027 grant. A special gratitude to the supervisors and staffs of production lab, metrology lab and workshop of IIUM.

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