



TOOL WEAR AND SURFACE ROUGHNESS ON MILLING CARBON FIBER-REINFORCED PLASTIC USING CHILLED AIR

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ABSTRACT

Carbon fiber-reinforced plastic (CFRP) composite is an expensive material that is widely used in aerospace applications because of its unique properties. During machining, several problems arise because of the carbon in CFRP. Abrasive wear occurs on the cutting tools during CFRP machining, thereby shortening the life of the tools and damaging surface quality. In this study, the performance of the solid carbide end tool and the surface quality of CFRP composite during the milling process were investigated. A cutting speed ranging from 160 m/min to 200 m/min and a feed rate ranging from 0.025 mm/rev to 0.05 mm/rev were used in the experiment. Results show that tool wear is higher at higher feed rates and lower cutting speeds, whereas longer tool life is achieved at lower feed rates and intermediate cutting speeds. Furthermore, a good machined surface is produced at higher cutting speeds and higher feed rates.

Key Words: Carbon fiber-reinforced plastic, Solid uncoated carbide tool, Tool wear, Tool life, Surface quality

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INTRODUCTION

The demand for carbon fiber-reinforced plastic (CFRP) composite has grown considerably in recent years in various fields, such as the aerospace, automobile, and aircraft industries (Klinkova et al., 2011). Fiber-reinforced plastic (FRP) has high specific strength, high stiffness or modulus, and good dimensional stability. This combination of properties is unusual and not easily obtained in alloys (Rahman et al., 1999). FRP composites are usually fabricated by molding (Kim et al., 1992). However, certain machining procedures, such as milling and drilling (Hintze et al., 2011), are needed to obtain close fits and tolerances, as well as to achieve near-net shapes (Mkaddem et al., 2008) in classical production processes. FRP composites differ from metals in many ways (Mkaddem et al., 2008) because composites have two phases of materials with drastically distinguished mechanical and thermal properties. FRP composites exhibit complicated interactions between the matrix and the reinforcement (Bagci and Isik, 2006) during machining. The machining process significantly affects these materials, thus leading to various modes of damages. The damages in these materials come in different forms, including fiber breakage, matrix cracking, and fiber pullout, among others (Illiescu et al., 2010). CFRP is extremely abrasive when machined, thus affecting the performance of cutting tools and surface quality. Therefore, the selection of cutting tools and cutting conditions is very important in the machining process of composite materials (Ferreira et al., 1999). The available literature on FRPs is very limited even though the demand for FRPs is increasing. In addition, few studies focused on the machining of FRP composites compared with those of other conventional materials (Santhanakrishnan et al., 1992) for minimum production cost and maximum productivity (Rawat and Attia, 2009).

EXPERIMENTAL PROCEDURE

Experiments were conducted on a CFRP laminate panel measuring 200 mm × 250 mm × 3 mm. The CFRP panel was constructed using the hand lay-up winding method and oriented at 0/45°. The CFRP panel consists of eight alternating layers of carbon fiber that had gone through an autoclaving process. Two flute solid uncoated carbide end mills (S2FE-080), with helix angles of 30°, lengths of 60 mm, and diameters of 8 mm, were used in the experiment. The cutting parameters used in the experiment are shown in Table 1. A computer numerical control machine with a 7.5 kW spindle power and maximum spindle speed of 12000 rpm was used in the experiment. Table 1 shows the experimental conditions for CFRP cutting. Tool wear was measured using a Nikon Measuring Microscope MM-40 during the milling operation. Data were obtained for each distance (100 mm). The milling operation was stopped and the cutting tool was discarded when flank wear (VB) or nose wear (VC) reached 0.3 mm or 0.5 mm, respectively (International Standard, 1989).

RESULT AND DISCUSSION

Tool wear and tool life analysis

Tool wear is one of the most important factors in evaluating maintenance accuracy in machining. Severe tool wear is a major problem in cutting CFRP. Figure 1 shows that tool wear increases when the feed rate rises from 0.025 mm/rev to 0.05 mm/rev. The increase in feed rate generates heat between the tool and the work material, which results in increased tool wear. The rise in feed rate during machining also increases chatter and results in incomplete machining at a faster rate, thus leading to higher tool flank wear (Palanikumar and Davim, 2007). The wear gradually decreases as cutting speed increases from 160 m/min to 200 m/min with a constant feed rate of 0.035 mm/rev.

Figure 2 shows the condition of the cutting tool as tool wear reaches the allowable limit. The wear appears polished and shiny at the cutting edge because of excessive wear on the side relief face during machining (Palanikumar et al., 2009). Figure 3 shows that tool life is better at lower feed rates. The longest tool life is obtained at the lowest feed rate of 0.025 mm/rev with an intermediate cutting speed of 179 m/min, whereas the shortest tool life occurs at the feed rate of 0.05 mm/rev. The percentage difference between the longest and shortest tool life is 24%.

Surface roughness analysis

Figure 4 shows that the worst roughness occurs at the lowest cutting speed of 160 m/min. In addition, the surface becomes smoother as the cutting speed increases from 160 m/min to 200 m/min. The figure also shows that a better surface is obtained at the higher feed rate of 0.05 mm/rev compared with the lower feed rate of 0.025 mm/rev at constant cutting speed. A clearer view of the cutting speed can be seen in Figure 5. Surface profile shows that the highest and lowest peaks for the cutting speed at 160 m/min are approximately 2.375 μm and -1.5 μm , respectively. The highest and lowest peaks have a difference of 3.875, which is higher compared with the highest and lowest peaks of the 200 m/min cutting speed at approximately 1.25 μm and -2.25 μm , respectively. The difference of the highest and lowest peaks is 3.5. The pattern repetition of the surface profile for the cutting speed of 200 m/min is more stable and controllable compared with that of the cutting speed of 160 m/min. Thus, a higher cutting speed is better and may result in a slight melting of the matrix, which leads to lower roughness (Eriksen, 1999). Figure 6 shows that the suitable temperature for machining CFRP in this study is approximately 91.5 °C.

CONCLUSION

Wear and surface finish are important aspects in controlling the final form of the end product and in fulfilling customer requirements. From the experiment, tool wear is determined to be better at lower feed rates and higher cutting speeds. The wear is observed to be shiny and polished at the cutting edge because of excessive wear during machining. The life of a carbide tool shortens as feed rate and cutting speed increase. The surface is smoother at higher cutting speeds than at lower

cutting speeds because of the stable machining process. The suitable temperature for machining CFRP in this study is approximately 91.5 °C.

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Table-1. Physical properties for machining CFRP.

| | |
|----------------------------|------------------------|
| Tool material | Solid uncoated carbide |
| Work material | CFRP |
| Cutting speed (m/min) | 160, 179, and 200 |
| Feed rate (mm/rev) | 0.028, 0.035, and 0.05 |
| Depth of cut (mm) | 0.071 |
| Temperature of chilled air | -10 °C |

Figure-1. Tool wear at different cutting parameters.

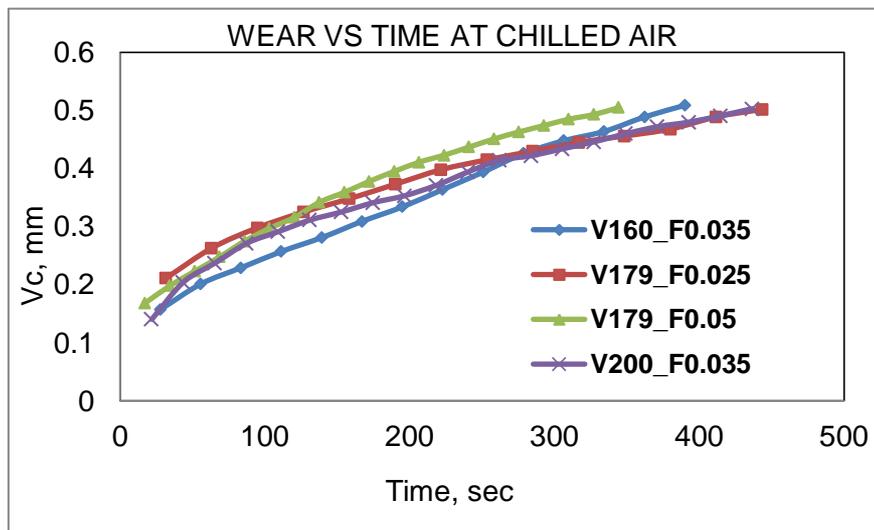
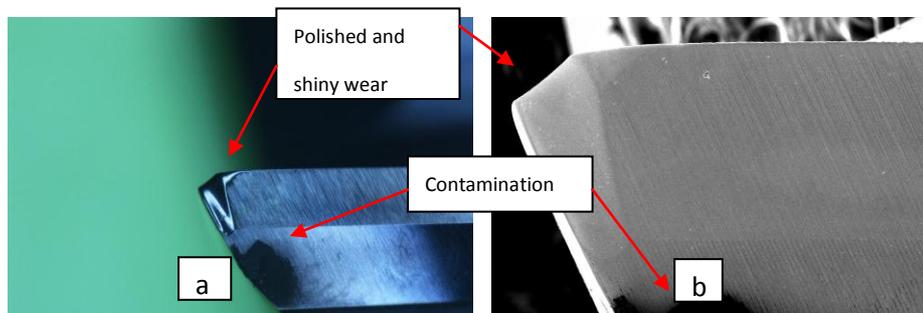


Figure-2. Cutting tool under a) optical microscope and b) scanning electron microscope.



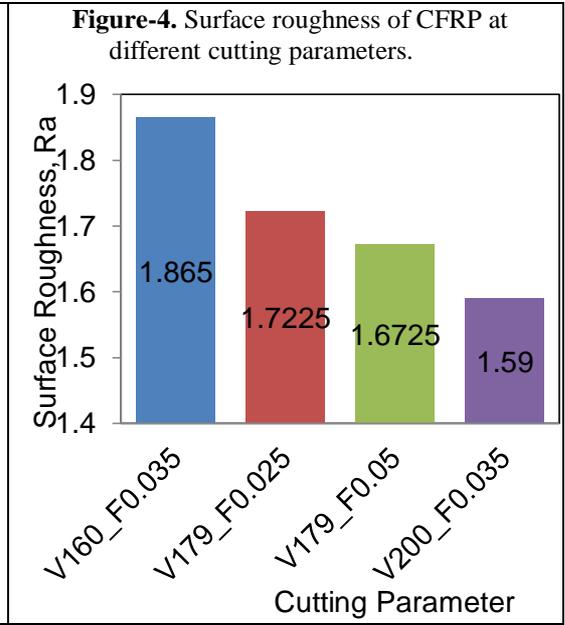
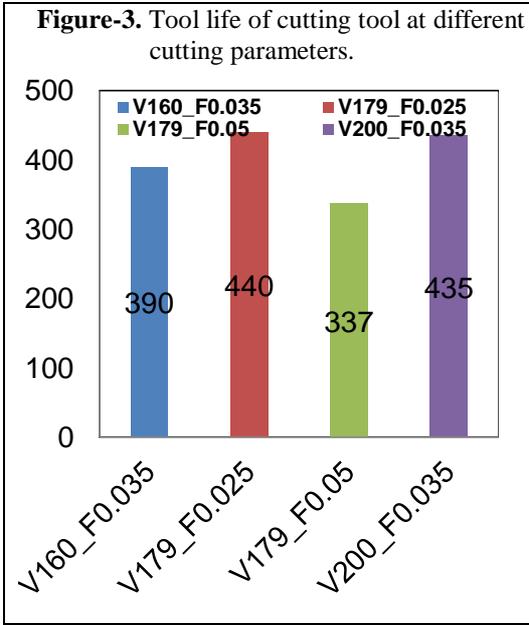


Figure-5. Two-point surface profile at cutting speeds of (a) 160 m/min and (b) 200 m/min with a feed rate of 0.035 mm/rev.

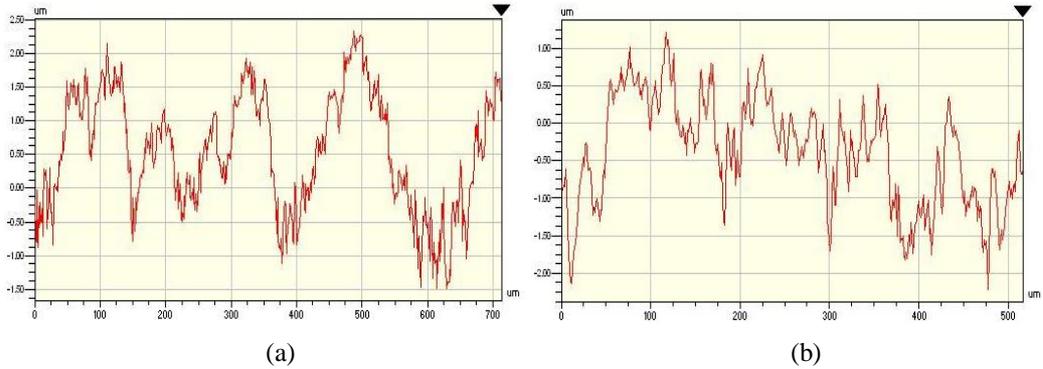


Figure-6. Temperature during CFRP machining.

