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Comparison Study on Side Milling of CFRP with AlCrN-based, Diamond-Like-Carbon(DLC), and Diamond-Coated End Mill

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AlCrN, DLC 및 다이아몬드 코팅 엔드밀을 이용한 탄소섬유복합소재의 측면 밀링에 관한 비교 연구

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ABSTRACT

Carbon fiber reinforced plastic (CFRP) is a composite material useful in the aerospace and automotive industries because of its light weight and high strength. In this study, side milling tests were carried out using AlCrN, diamond-like carbon (DLC), and diamond-coated end mills. Additionally, a comparison study according to the cobalt content was conducted. Thus, tool wear and surface quality were examined and the influences of using coating and a certain material type were analyzed. The surface roughness of the machined surface was measured. Microscope observations revealed that the CFRP fiber at the machined surface was not damaged even at a cutting distance of 3,000 mm. Therefore, this study showed that the diamond-coated end mill containing 6% cobalt is appropriate for milling CFRP.

Keywords : Carbon Fiber-Reinforced Plastic(탄소 섬유 복합재), End Milling(측면 가공), Carbide Tool(초경 공구), Diamond Coating(다이아몬드 코팅)

1. Introduction

Recently, the use of carbon fiber reinforced plastics (CFRPs) has been increasing in the aircraft, space shuttle, and automotive industries. A CFRP is a composite material comprised of carbon fiber and plastic resin. Generally, the specific gravity is 20% steel and the specific strength is very high, with more than 50% of the aircraft fuselage employing CFRPs. In the automotive industry, the use of CFRPs in car bodies and major components is gradually increasing[1].

A CFRP is held together by the bonding force

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between the fibers and the resin, although they may separate by machining. Uncut fibers may also occur, and tools may become abraded due to the strong polishing of carbon fibers[2]. Therefore, studies have focused on determining the optimal cutting conditions or comparing different end mill shapes for CFRP machining.

Previous literature is summarized as follows. In the study of Yashiro et al.[3], the variation of the cutting temperature in end milling was measured by three methods and the variation of temperature with cutting speed was also studied. Their results suggest that the glass transition temperature was exceeded when the cutting speed was 50 to 300 m/min, although the surface was not damaged. Hosokawa et al.[4] analyzed the fluffing area according to the helix angle of the end mill and obtained a smooth CFRP surface and little flank wear when the angle was 60° rather than 30°. Kim et al.[5] studied the surface roughness of the machined surface according to the routing conditions of the end mill. This study experimentally determined that fiber tearing defects increase due to the bending of the fiber as the feed rate increases. When the spindle speed was increased, in addition to fiber tearing in the layer with a －45° fiber angle, various modes of defects occurred and the surface roughness of the machined surface increased. However, by developing cutting tools, very different results can be obtained depending on the tool material, shape, and coating. Therefore, the development of the end mill for machining CFRP by considering important variables is necessary.

Previous studies have shown that evaluating the machinability of end mills for CFRPs has a significant impact on tool wear and CFRP surface quality depending on the end mill component, tool geometry, and general coating[6]. However, further research is needed to improve the tool life and confirm the correlation between tool grade and coating.

The present study was carried out using a zigzag-type end mill with different amounts of cobalt content (6 and 10%) and types of coating (AlCrN, Diamond-Like Carbon [DLC], and diamond) for the machining of CFRP. The tool wear, surface roughness, and burr formation were examined through our CFRP tests.

2. Experimental Preparation

2.1 Tool Design and Fabrication

The end mill has a zigzag shape and is designed with four blade edges. The cemented carbide has a cobalt content of 6% and 10%, and the particle size of tungsten is 0.65 μm. Fig. 1 contains a 3D model and a photograph of the end mill, which was manufactured by CNC Tool Grinder (TX7, ANCA CNC Machines, Austrailia). Table 1 shows the values for different properties of each type of cemented carbide. The coating was prepared using AlCrN and DLC, which are optimal for wear resistance and provide excellent high temperature hardness and stability against thermal shock. The physical properties for the coatings are illustrated in Table 2. Diamonds are characterized by high hardness and no coefficient of friction against steel.

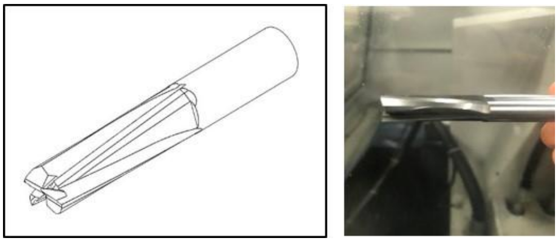


Fig. 1 The fabricated tools

Table 1 Specifications of tungsten carbide

Type	Tool A	Tool B
Co (%)	10.0	6.0
WC incl. doping (%)	90.0	94.0
WC grain size (μm)	0.65	0.65

Table 2 Specifications of coating

Type	AlCrN	DLC	Diamond
Material	AlCrN-based	CrN+a-C :H	Nano-crystalline
HV	3,200	6,000~7,000	10,000
Coefficient of friction	0.35	0.1	-

Table 3 Specification of CFRP

Items	Characteristics
Surface	WSN3K Plain -Tensile Strength : 850 MPa -Tensile Modulus : 60.7 GPa
Cabon Fiber	Torayca T700 -Strength : 4,900 MPa -Modulus : 240 GPa -Density : 1.82 g/cc
Deposition	UD 0/90 Repeat (Surface 3K Plain 1 Ply Deposition)
Process	Autoclave molding -RT→85°C (30min holding) →125°C (120min holding) →Natural Cooling

2.2 CFRP

CFRP composed of UD 0/90 (Repeat Deposition) was purchased from TCG. The properties and fabrication process of the CFRP prepared for the experiments are shown in Table 3. The size of the prepared CFRP workpiece is W200×L200×8T.

2.3 Process Conditions

Fig. 2 consists of a picture of the equipment, workpiece, and tools used in the actual experiment. Tapping equipment was used for the side milling experiments, and an acrylic case was made to prevent the CFRP fibers from scattering out so that CFRP chips and dust were removed through the inhaler. Fig. 3 shows a schematic diagram of the workpiece champing method and tool path for machining the CFRP. Machining was completed to 3M with 6 mm in the axial direction and 4 mm in the radial direction. A Tripple support and bottom plate were

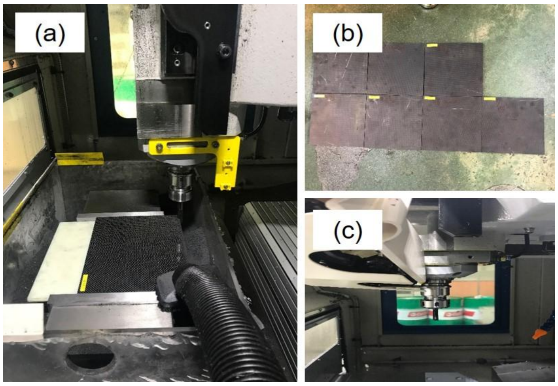


Fig. 2 Experimental set-up for end milling(a: machining, b: CFRP, c: holder)

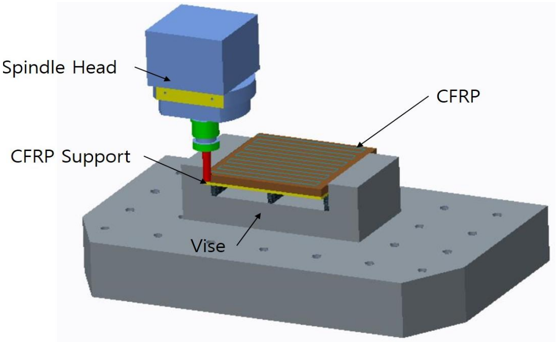


Fig. 3 Tool path for CFRP machining

Table 4 Experimental conditions

Type	Items
Equipment	Tapping Machine DST-36D(BT30)
Workpiece	3K Plain(200W×200L×8T)
Tool Diameter(	12
Machining conditions	Spindle speed : 2000rpm Feed rate : 0.04mm/tooth Radial depth of cut : 4mm Axial depth of cut : 6mm
Routing distance(mm)	3,000
Cutting fluid	Dry

used to stabilize the CFRP. Table 4 shows the processing conditions for machining evaluation. The cutting conditions were 12 mm, 2000 rpm, and 0.04 mm/tooth. The experiments were carried out in a dry machining environment.

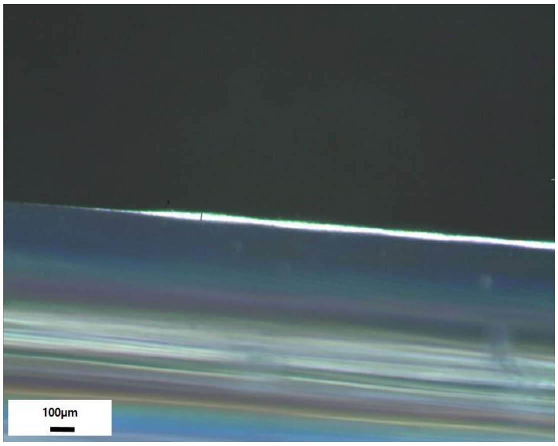
3. Results and Discussion

3.1 Tool Wear

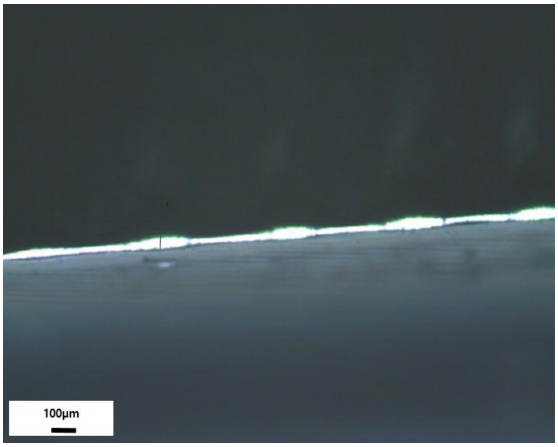
The tool life is the cutting time until the blade becomes dull due to the increased amount of wear. Tool wear is an important part because it directly affects the quality, processing efficiency, and cost of the workpiece. CFRP has low thermal conductivity, so the heat generated during processing doses not readily diffuse and is concentrated near the blade. As a result, if the blade temperature is too high, the blades can easily wear out[7].

Fig. 4 shows the blade of the tool after machining the CFRP. AlCrN end mills (Fig. 4a and b) appear to exhibit an amount of wear similar to DLC end mills (Fig. 4c and d), although irregular wear was greater in AlCrN end mills. Therefore, the wear resistance of DLC was judged to be superior to AlCrN. Moreover, Tool-B showed less wear than Tool-A in terms of cobalt content. On the other hand, there was no blade wear of the end mills, as shown in Fig. 4, frames e and f. Therefore, it is confirmed that there is no significant difference according to the cobalt content.

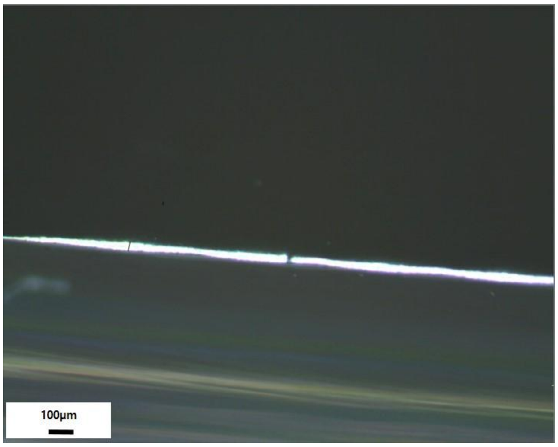
The wear amounts of the end mill are shown in Fig. 5. We found that the wear amount of the diamond-coated end mill was remarkably small. As the coating layer wears away from the tool, the cemented carbide is less wear resistant and uncut fibers are generated due to the collapse of the edges. The tool life of the end mills should be considered when the coating layer peels off and uncut fibers form. Therefore, for end mills used in CFRP processing, applying diamond coating can result in



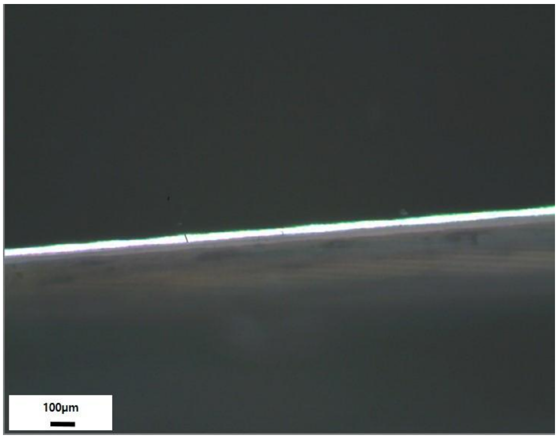
(a) Tool A_AlCrN



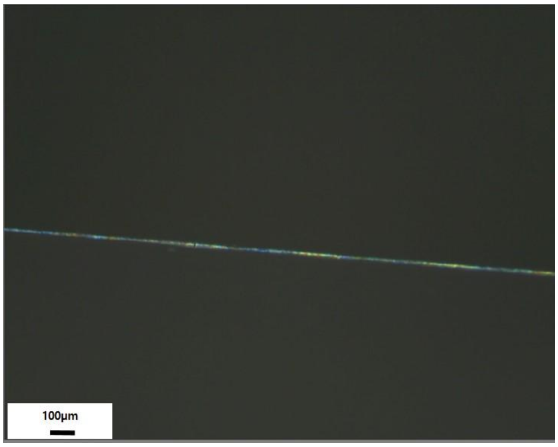
(b) Tool B_AlCrN



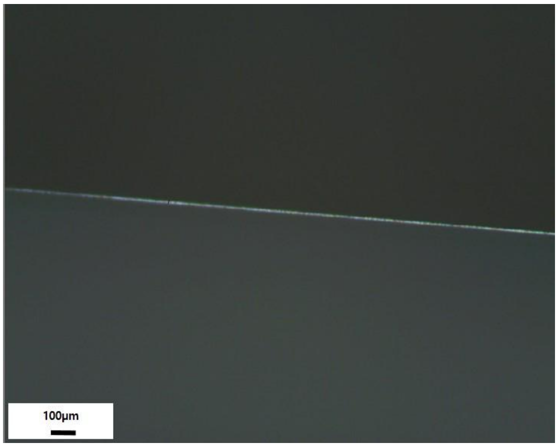
(c) Tool A_DLC



(d) Tool B_DLC



(e) Tool A_Diamond



(f) Tool B_Diamond

Fig. 4 Microscope images of end mills

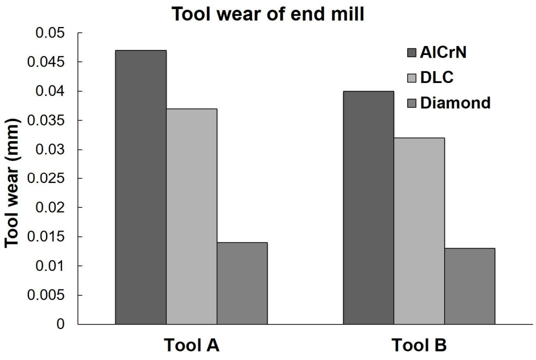


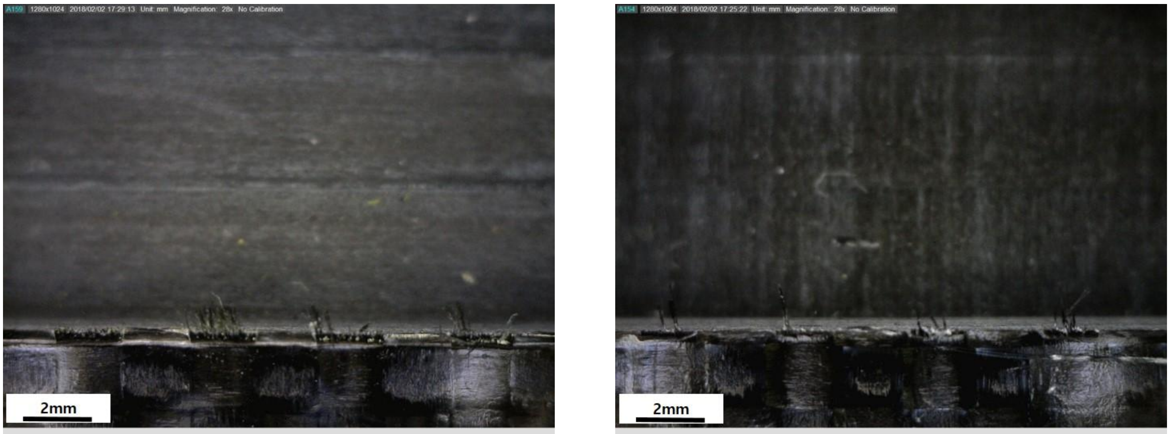
Fig. 5 graphs of Tool wear

excellent machinability. Finally, the coating thickness of the end mill used in this study was 6 um, although it is necessary to apply more than twice this thickness to increase the tool life.

3.2 CFRP Observation

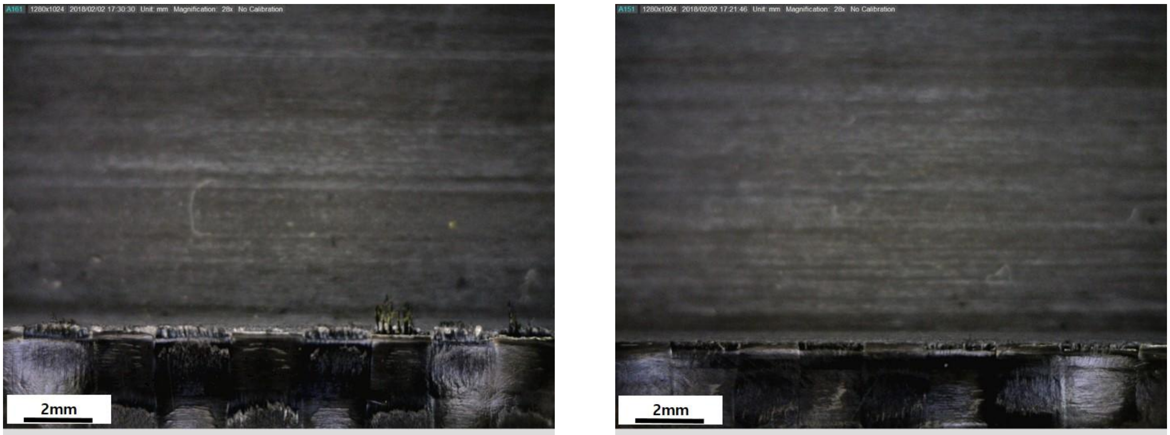
A microscope was used to observe the CFRP top face after side milling. Fig. 6 contains images of CFRP workpiece after processing with each type of end mill. In the case of AlCrN coating, uncut fibers with similar area and lengths occurred in 3M in both Tool-A and Tool-B. DLC-coated end mills showed less uncut fiber at 6% cobalt and a large amount of fiber retained at 10%. However, uncut fiber and delamination were not observed in the diamond-coated end mill, as shown in Fig. 6e and f, furthermore, no wear of the tool occurred in 3M.

The surface roughness of the CFRP is an important factor in evaluating the quality of machined product surfaces. Three random measurements were taken on the CFRP workpiece surface obtained through machining, and the average surface roughness values were considered. Fig. 7 is a graph of the CFRP surface roughness (Ra). It was found that the surface roughness of Tool-A end mill was worse than that of Tool-B. In addition, the surface roughness of DLC-coated end mills was lower than for the AlCrN-coated ones, while the diamond-coated end mills produced a much surface roughness than the



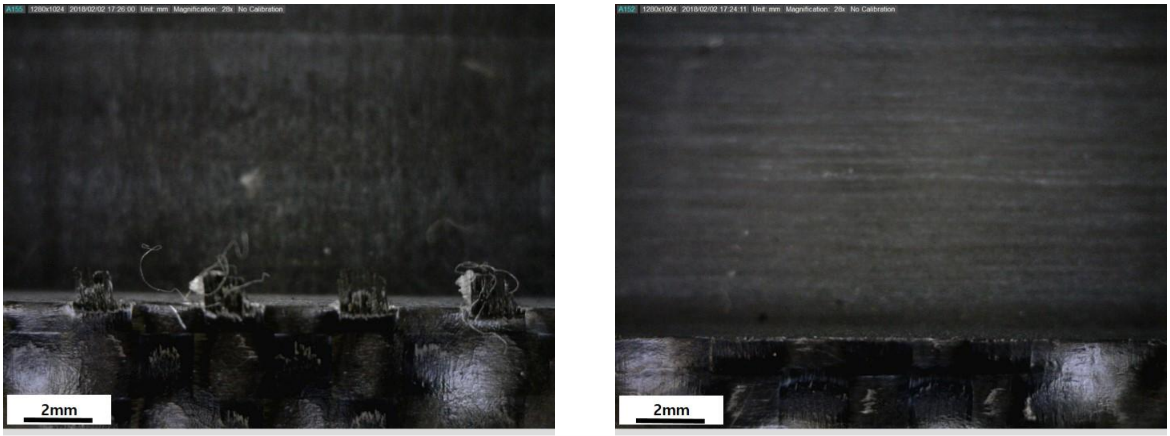
(a) Tool A_AlCrN

(d) Tool B_DLC



(b) Tool B_AlCrN

(e) Tool A_Diamond



(c) Tool A_DLC

(f) Tool B_Diamond

Fig. 6 The used CFRP workpiece

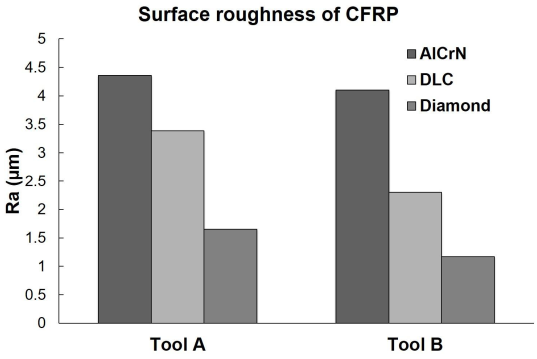


Fig. 7 Graph of surface roughness

other end mills. In other words, we showed that the wear of the tool affects the surface roughness of the workpiece. Therefore, the surface quality can be predicted through the correlation between the amount of wear of the tool and the uncut fiber in the CFRP.

4. Conclusion

In this study, we observed and analyzed the wear, uncut fiber, and surface roughness using the end mill tools with different types of cemented carbide material and coating in the side processing of CFRP. The following conclusions were drawn:

1. It was confirmed that the amount of wear of the tool was smaller when the cobalt content of the cemented carbide was 6% rather than 10%. DLC coatings showed lower wear than AlCrN ones in all end mills, while the diamond-coated end mill showed no wear.
2. Uncut fibers occurred in CFRP when processed using AlCrN- and DLC-coated end mills. However, CFRP processed with diamond-coated end mills did not form uncut fibers.
3. Measurements indicated the surface roughness was lower in Tool-B than in Tool-A and in the following order: AlCrN<DLC<diamond.

In the future, the tool life of diamond-coated end mills will be assessed according to cutting distance and coating thickness.

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