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Development of a Drill Tool for CFRP Machining and Evaluation of Drilling Processing

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ABSTRACT

Carbon fiber-reinforced plastics (CFRPs) are extremely strong and light fiber-reinforced plastics containing carbon fibers. CFRPs can be expensive to produce, but are commonly used wherever high strength-to-weight ratio and rigidity are required, such as in the aerospace, automotive, and ship superstructure industries. In CFRP drilling, the tool performance greatly varies depending on the tool shapes, cutting conditions, and diamond coating. This study developed a new type of tungsten carbide drill with multi-blade edges to evaluate the surface quality of CFRP materials according to the coating thickness of diamond-coated drills. Experiments on tool wear, surface roughness, and burr formation were conducted. The bore exit quality of a 12 μm-coated drill was better than that of a 6 μm-coated drill. The superior effects of the 12 μm-coated drill and the good surface quality of CFRP were also demonstrated.

Key Words : Carbon Fiber Reinforced Plastic (탄소섬유 강화 플라스틱), Tungsten Carbide Drill (초경합금 드릴), Diamond Coating (다이아몬드 코팅), Surface Roughness (표면 조도)

1. Introduction

In the automotive, aerospace, machining, and medical industries, the cutting tools used are advanced, lightweight, eco-friendly, and miniaturized and have high component strength for energy saving. In the cutting tool industry, new technologies for difficult material processing, ultra-precision/ultra-fine processing technology, and new material and multifunctional material development are proposed as promising technologies in the future. Accordingly, related research is being conducted. Carbon fiber reinforced plastics (CFRPs) are increasingly being used in the aerospace industry because of their excellent tensile strength and fatigue strengths[1]. CFRP is a carbon fiber containing a thermosetting resin and made from a resin penetration processing

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material. However, the material is a product of the joining of different materials, thereby raising a concern that various processing defects may occur at the entrance and exit surfaces. The CFRP processing shows various defects, including delamination, separation, splintering, fiber pull-out, and uncut fiber. These processing defects should be reduced, and research on minimizing these defects during machining is essential, because the precision of parts and the machining quality must be excellent[2]. The demand for CFRPs is increasing in drilling machining, and the development of tools for CFRP machining is constantly in progress[3-5]. Many applications and studies on workpiece quality during CFRP processing have been performed according to the drill shape[6]. However, scholarly literature on related research is lacking, and much research is required.

After developing and fabricating a new type of drill tool for CFRP drilling, we then observed the wear condition according to the diamond coating thickness and analyzed the surface quality of the CFRP.

2. Materials and Methods

2.1 Drill Shape and Diamond Coating

Fig. 1 shows the drill shape. Tungsten Carbide (K10) materials from Konrad Friedrichs were used for the drill fabrication[7]. The drill shape was designed to eliminate the hole exit delamination by minimizing the thrust through the application of a two-stage point angle. A diamond coating(Oerlikon Balzers Company) with thickness of 6 and 12 μm was selected.

2.2 CFRP material

The CFRP material was manufactured by and from Carbon TCG Co., Ltd. in a Unidirection 0/90 repeat laminated (surface 3K Plain 1-ply laminated) structure and measured 200x200x8mm^3. Table 1 shows the physical properties of the CFRP.

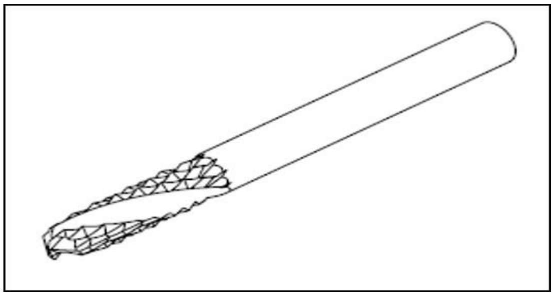

Fig. 1 Concept modeling of the fabricated Drill

Table 1 Characteristics of tool materials

	Characteristics	
Surface	WSN3K Plain	-Tensile Strength : 850 MPa -Tensile Modulus : 60.7 GPa
Inside	USN UD	-Tensile Strength : 2,686 MPa -Tensile Modulus : 128.3 GPa
Carbon Fiber	Torayca T700 -Strength :4,900 MPa -Modulus : 240 GPa -Density :1.82 g/cc	

2.3 Drill Fabrication and Cutting Processing

The drills were made using tool grinding machines (TX7+, ANCA, Australia) with a very high precision (9.8 mm diameter, 100 mm length, and 45 mm length). Fig. 2 shows the drill shape used in this study. Table 2 presents the general shape specifications of the manufactured drill. The point angle was 140°, while the helical angle was 30°. A tapping machine (DST-36D, Daesung HITECH Co., Korea) was used for the machining test. Fig. 3 depicts the tool preparation and experimental pictures for machining. An acrylic case was fabricated to prevent the cut chips from leaving the table. Table 3 shows the drilling conditions. The spindle speed was 5600 rpm. The table feed rate was 400 mm/min. The processing conditions for the performance evaluation were selected in advance, focusing on the productivity of hole machining. This study was conducted by

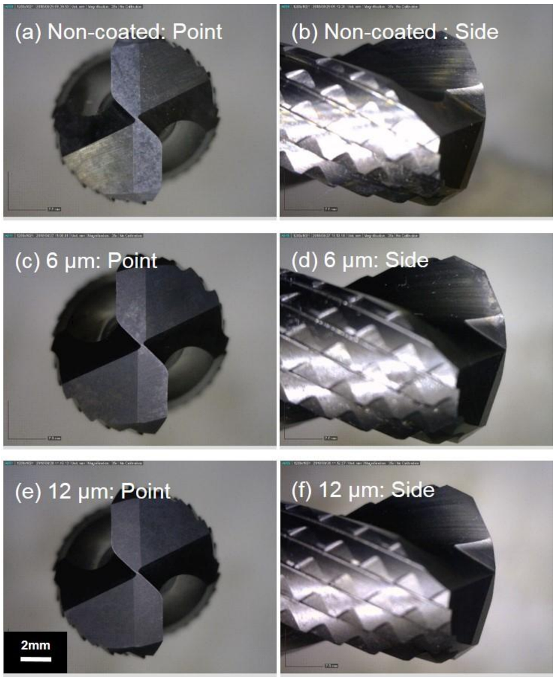

Fig. 2 Top and side view of drilling tools (a&b: Non-coated, c&d: 6μm coating thickness, and 12μm coating thickness)

Table 2 Parameters of drilling tools

	Value
Tool diameter(mm)	9.8
Point angle(°)	140
Helix angle(°)	30
Thickness of Diamond coating(μm)	6, 12

Table 3 Process parameters

	Value
Spindle speed(rpm)	5600
Feed rate(mm/min)	400
Thickness of cutting(mm)	8
Holes (Bores)	100, 200, 400, 600, 800

searching for the most suitable conditions. In the processing environment, processing was performed under dry conditions. A vacuum cleaner was used to remove the processing dust of the CFRP. In addition

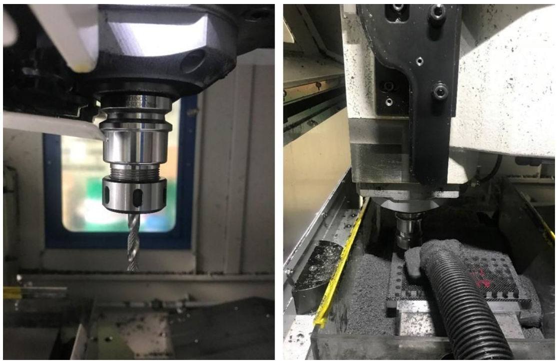

Fig. 3 Photography of tapping machine

to the side vise, a triple support was mounted on the bottom to ensure good CFRP clamping.

3. Results and Discussion

3.1 Development of the New Drill

A conventional drill has a general cylindrical surface without a cross-nick pattern on the flute body, while the new type of drill developed in this study has a sheath shape similar to the cross-nick pattern. The new drill also has many blades that stand up to easily cut the CFRP stacked in multiple layers and improve the surface finish. A two-stage point angle was added to reduce the cutting thrust during the CFRP machining. Fig. 4 is a photograph showing the exit surface of the workpiece after the hole drilling of the existing and new drills. Fig. 5 illustrates that the exit face quality was better with the new drill.

(a) Conventional Drill (b) New-type Drill

Fig. 4 Images of conventional drill and New-type drill

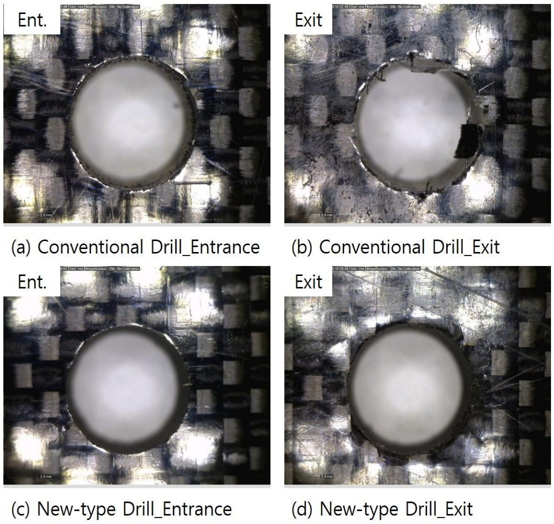

Fig. 5 Entrance(a, c) and exit(b, d) images of conventional drill and new-type drill

Accordingly, a new type of drill was fabricated based on these results.

3.2 Tool wear

The wear tendency of the point face was observed herein according to the number of drilled holes. Fig. 6 is a photograph of the wear of the cutting edge portion that increased as the number of machining holes increased and the coating thickness decreased. The un-coated drill exhibited an abrasion of the cutting edge of the first free surface of the carbide starting from 100 holes. The wear amount increased as the number of machining holes gradually increased. In the 6 μm coated drill, some wear on the blade started at 400 holes, but no major problem was observed with further processing. In the case of more than 600 holes, the blade damage was increased, which slightly influenced the exit surface quality of the CFRP. By contrast, abrasion that was less than that of the 6 μm coated drills was observed for the 12 μm coated drills. However, after 800 holes, the CFRP exit surface quality showed a tool life within 800 holes.

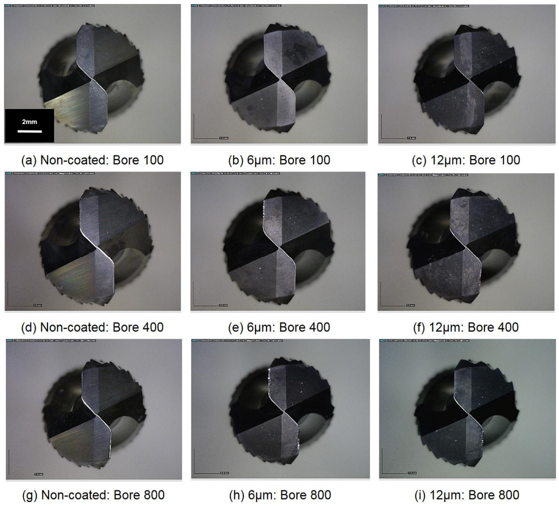

Fig. 6 Surface roughness values of bores

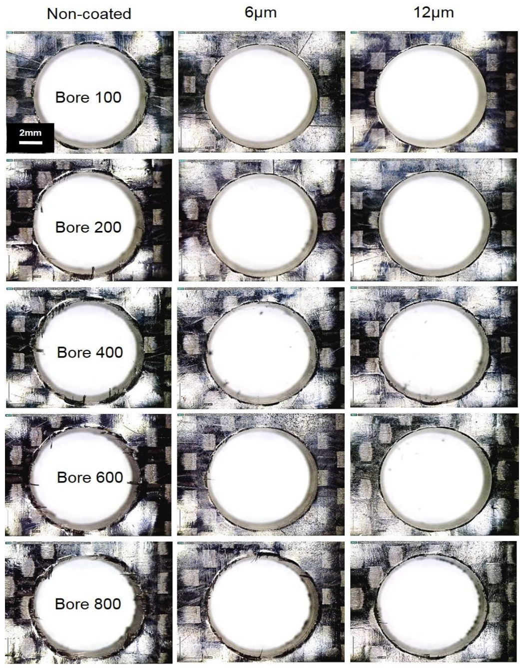

Fig. 7 Microscope pictures of bore exists

3.3 Observation of the Exit Surface

Fig. 7 is a photograph of the exit hole after drilling using a digital microscope. Most of the hole entrance surfaces showed good quality. The photo of the exit surface of the CFRP processed by the un-coated drill showed uncut fibers generated from 100 holes. The amount gradually increased as the length of the fiber increased. However, for the 6 and 12 μm coated drills, the exit surface of the CFRP was clear up to 600 holes. At 800 holes, the 6 μm coated drill had the worse surface quality. The cutting force of the 6 μm coated drill increased because of the coating wear. Delamination and fiber separation also slightly occurred.

3.4 Bore Diameter

The bore diameter was obtained by measuring the holes at three points (2, 4, and 6 mm sections) using a three-dimensional measuring instrument(MH20i, RENISHAW, UK)(Fig. 8). The outer diameter of the un-coated drill reduced at 400 holes because of the rapid tool wear. On the contrary, the hole diameter of the 6 μm coated drill was increased to approximately 9.84 mm when the number of holes was increased to 600 holes. In the 12 μm coated drill, however, the hole diameter increased to 9.85 mm. while processing, the outer diameter increased to more than 600 holes because the CFRP cutting caused by the tool wear was not good. The graph changes in the outer diameter dimension of the 6 and 12 μm diamond-coated drills were similar. The difference in value was attributed to the coating layer thickness.

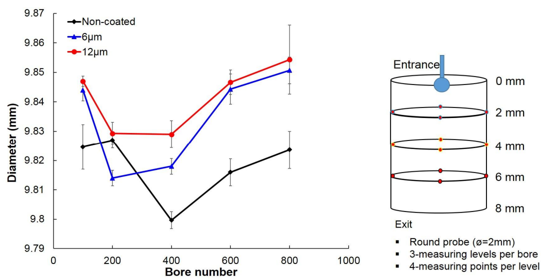

Fig. 8 Bore diameter measurements with coordinate measurement machine

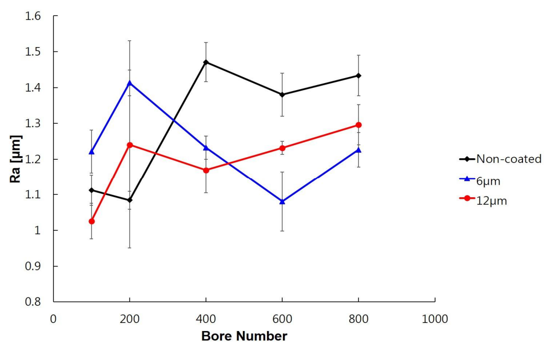

Fig. 9 Surface roughness values of bores

3.5 Surface Roughness

Fig. 9 shows the surface roughness(Ra, μm) value according to the diamond coating thickness and the number of holes using a surface roughness meter (SJ-210, Mitutoyo, Japan). At this time, the cut-off was 2.5 mm; the reference length was 2.5 mm; the stylus feed rate was 0.5mm/s. The surface roughness value of the un-coated drill increased at 400 holes. The surface quality of the un-coated drill was also reduced. The surface roughness of the CFRP was measured within 1-1.4 μm when all the coated drills were processed up to 800 holes. Consequently, the surface quality was found to be excellent.

4. Conclusions

This study developed a drill for CFRP drilling and investigated the surface quality and tool life of the CFRP using the developed drill. The following conclusions are drawn:

1. The drill with a cross-nick pattern was more effective at the CFRP outlet than that with a general cylindrical surface.
2. Uncut fiber and delamination were observed and increased in all the diamond-coated drills of the exit surface exceeded 600 holes. However, the hole quality of the 12 μm coated drill showed better conditions compared to the 6 μm coated drill.
3. Except for the un-coated drills, the hole diameter measurement showed a value of approximately 9.8

to 9.94 mm up to 600 holes. The hole dimensions were also larger than those of the 600 holes when viewed at 800 holes. Therefore, machining up to 600 holes was determined to be optimal considering tool wear and CFRP quality.

4. A somewhat superior surface roughness value of 1 to 1.4 μm was obtained when the roughness value of the inner surface of the hole was measured during the processing of up to 800 holes.

In the future, the tool life and the surface quality of the CFRP workpiece will be evaluated and analyzed according to the arrangement angle and material type of CFRP fibers.

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