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A Study on the Wear Characteristics of End Mill for CFRP Processing according to the Tool Materials and Coating Types

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CFRP 가공용 엔드밀의 공구재종 및 코팅 종류에 따른 마모 특성에 관한 연구

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ABSTRACT

In this study, the wear characteristics of end mills for CFRP processing were investigated according to the tool materials and coating types. Three kinds of tool materials and two types of coatings were used for comparing the machining performance. The flank wear of the end mill tool and the surface condition of the workpiece were compared. The K6UF material shows the most excellent performance among the three materials used in the experiment. The Tetrabond coating showed better processability in comparison of two kinds of coatings.

Key Words : CFRP(탄소섬유플라스틱), End Mill(엔드밀), Tool Material(재종), Coating(코팅)

1. Introduction

In recent years, much attention has been paid to the carbon fiber reinforced plastic (CFRP) composite, which is a material created by combining more than two materials with different composition and form to yield an interface that distinguishes the materials, resulting in superior functions. The most characteristic feature of CFRP is its high strength-to-weight ratio, which has been increasingly sought after in various industries in recent years.[1]

In particular, the use of nonferrous metal and composite materials in the automobile industry has been required to increase fuel efficiency through lightweight materials, which is why CFRP has been the focus due to its excellent mechanical characteristics.

Despite its excellent mechanical characteristics, CFRP is considered a material that is difficult to cut due to its processing characteristics, such as failure and interlayer separation, caused by the

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composite materials.[2,3] For bonding and shape processing with metal materials, machining is achieved through cutting processes, such as drilling, milling, and end milling, and several studies have been conducted to solve the machining defects and improve the cutting characteristics.[4-6]

However, most studies have focused on CFRP materials, and few have been conducted on the surface states of materials and wear characteristics of cutting tools according to cutting machining and cutting conditions in drill and end mill machining. Thus, this study aims to analyze cutting characteristics according to tool grade and coating type using end mill tools on CFRP composites of the same shape, and it proposes a cutting method that is optimized to CFRP machining after analyzing the wear characteristics of machining tools.

2. Experimental device

2.1 CFRP workpiece

The CFRP composite material used in this study was a specimen (T700) manufactured by laminating a prepreg made by combining unidirectional carbon fiber manufactured by Toray Company with epoxy resin. The specimen was plate shaped, and its total size was 200x200x14 mm. The specimen was fabricated by laminating a carbon fiber repeatedly with a lamination angle of 0°/90°.

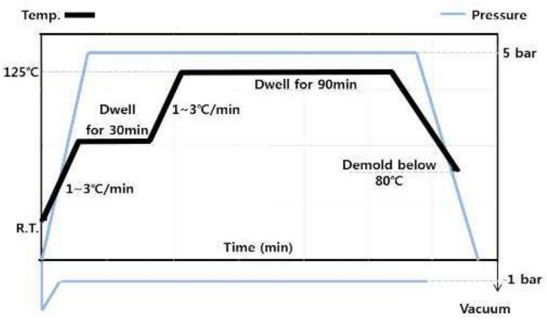

Fig. 1 Curing condition of CFRP

Table 1 Mechanical properties of CFRP(T700)

Tensile Strength	4,900 MPa
Tensile Modulus	240 GPa
Elongation	1.9 %
Density	1.82 g/cc

Description		Unit	ACE-VM410
Maximum Travel Distance	X	mm	820
	Y	mm	410
	Z	mm	510
ATC	Max.	Ea	24
	Type	MAS	BT40
Spindle	Rotation Speed	rpm	12,000
Feed Rte	Rapid Traverse Speer (X/Y)	m/min	30/30/24
	Cutting Feedrate	mm/min	16,000

Fig. 2 Experimental equipment

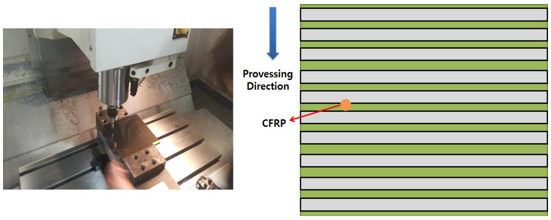

Fig. 3 Experimental set up for end mill process

The molding conditions were as follows: 125℃ curing point temperature (heat provided by a heater located inside the chamber, as shown in Fig. 1), 120 min curing time, and 5-bar pressure. Table 1 presents the mechanical properties of the carbon fiber prepreg.

2.2 Experimental equipment and tools

For the experimental equipment, a vertical machining center (Doosan, ACE-VM410) was employed. Fig. 2 shows the experimental equipment and specifications, and Fig. 3 shows the overview of the end mill machining system. Fig. 4 shows the shapes of the tools used in the experiment. For the tools, a four-blade normal-type end mill and a four-blade zigzag-type end mill were used. Table 2 presents the compositions of the materials.

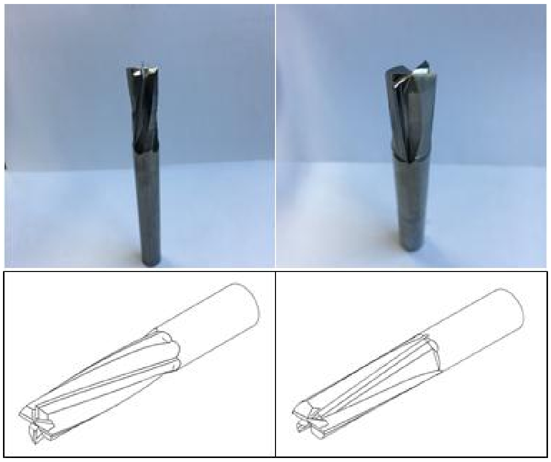

Fig. 4 Experimental tool shape
(Left: normal-type, Right: zigzag-type)

Table 2 Composition of tool materials

Grade Sorte	K40UF	K6UF	K55SF
Co(%)	10	6	9
HRA(ISO3738)	92.1	93.6	93.7
TRS(N/mm^2)	4000	3900	3800
WC grain size(μm)	0.65	0.65	0.20

Table 3 Experimental condition

Spindle Speed(rpm)	2,000
Feed Rate(mm/min)	300
Depth of Cut(mm)	4

2.3 Experimental conditions

The experiments were conducted to compare the machining characteristics according to grade and coating type(Diamond-Like Carbon(=Tetrabond) & AlCrN-based TiSiN(=Tisinos)) in CFRP end mill machining, and the characteristics after the machining experiments conducted under the same conditions were compared and analyzed. The experimental conditions are presented in Table 3.

3. Experimental results

3.1 Normal type end mill

To determine the machining characteristics of the end mill in relation to the CFRP workpiece, experiments were performed according to changes in grade and coating type.

The experimental results verified that the wear occurred the most in K55SF followed by K40UF and K6UF regardless of the coating type in the normal-type end mill, which exhibited different wear characteristics due to differences in cobalt content and tungsten carbide (WC) grain size among the grades. The WC grain size is the most important parameter to adjust the relationship between the hardness and toughness of the grade. That is, a finer grain size results in a higher hardness of a given binder phase. Thus, the above results indicated that the wear characteristics were revealed according to the correlation with hardness. In addition, the level of cobalt content plays a role in controlling the resistance against plastic deformation. When the WC grain size is the same, toughness is strengthened by increasing the binder amount, thereby facilitating plastic deformation wear. Thus, more wear occurred in K40UF, which had higher cobalt content compared to K40UF and K6UF, which had the same WC grain size. K55SF had relatively high cobalt content but a relatively small WC grain size, so it was characterized by relatively low wear occurrence. When comparing wear by coating, the Tisinos-coated tool had more wear than the Tetrabond-coated tool. Figs. 5–7 show the flank wear photos of the tools, and Fig. 8 shows the wear results. When observing the machining surfaces of the CFRP workpieces, the Tetrabond-coated cutting tool exhibited slightly better machining states than the Tisinos-coated tool. A slight burr was generated regardless of coating and material type. Figs. 9–11 show the photos of the surface states of the CFRP workpieces.

Fig. 5 Flank wear of normal type (K40UF) Left(Tetrabond), Right(Tisinos)

Fig. 6 Flank wear of normal type (K6UF) Left(Tetrabond), Right(Tisinos)

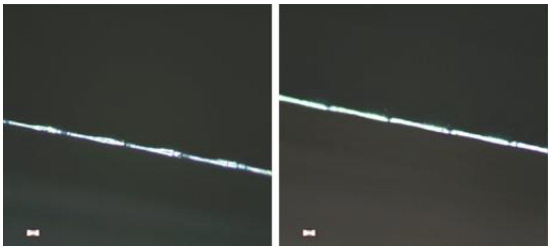

Fig. 7 Flank wear of normal type (K55SF) Left(Tetrabond), Right(Tisinos)

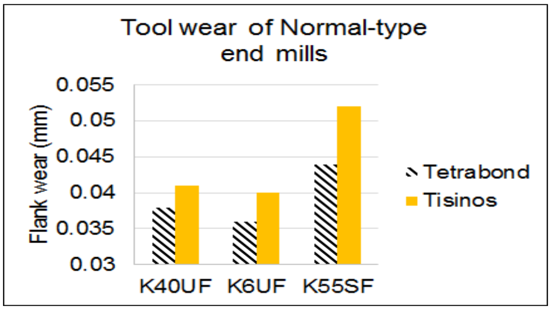

Fig. 8 Result of normal type end mill

Fig. 9 Surface of CFRP (K40UF) Left(Tetrabond), Right(Tisinos)

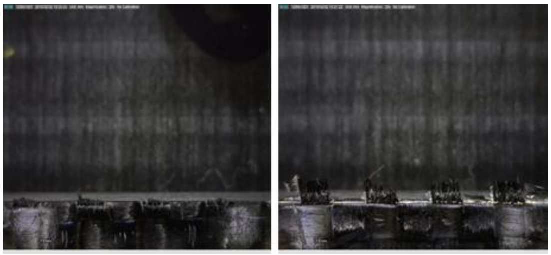

Fig. 10 Surface of CFRP (K6UF) Left(Tetrabond), Right(Tisinos)

Fig. 11 Surface of CFRP (K55SF) Left(Tetrabond), Right(Tisinos)

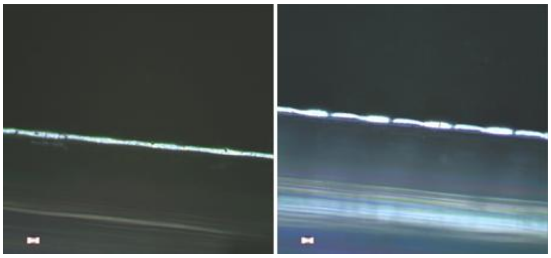

Fig. 12 Flank wear of zigzag type (K40UF) Left(Tetrabond), Right(Tisinos)

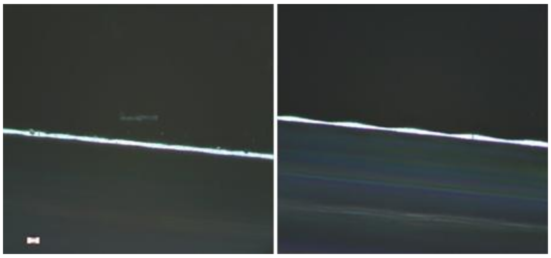

Fig. 13 Flank wear of zigzag type (K6UF) Left(Tetrabond), Right(Tisinos)

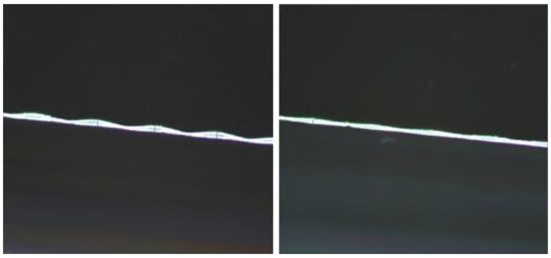

Fig. 14 Flank wear of zigzag type (K55SF) Left(Tetrabond), Right(Tisinos)

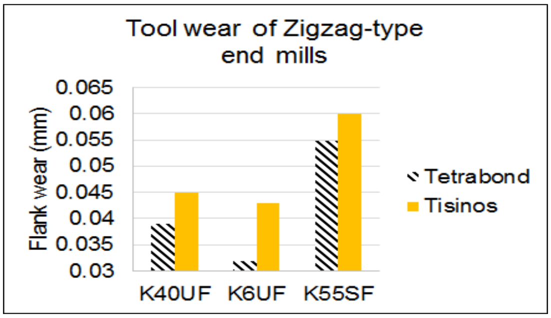

Fig. 15 Result of zigzagl type end mill

3.2 Zigzag-type end mill

The wear characteristics in the zigzag-type tool showed that the highest wear occurred in K55SF followed by K40UF and K6UF by grade, as with the normal-type cutting tool. In terms of coating, the Tisinos-coated tool had more wear than the Tetrabond-coated tool. The results according to tool material and coating type are the same as those

Fig. 16 Surface of CFRP (K40UF) Left(Tetrabond), Right(Tisinos)

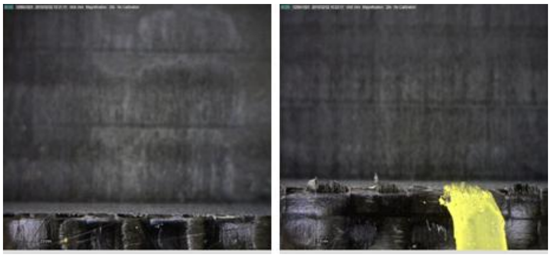

Fig. 17 Surface of CFRP (K6UF) Left(Tetrabond), Right(Tisinos)

Fig. 18 Surface of CFRP (K55SF) Left(Tetrabond), Right(Tisinos)

mentioned above. Figs. 12–14 show the flank wear photos, and Fig. 15 shows the wear results.

The surface of the workpiece was more precisely machined with the zigzag-type tool than the normal-type tool regardless of grade and coating type, and burr generation was rarely discovered. The wear of both the normal- and zigzag-type tools was observed, and the results showed that the wear of the zigzag-type tool was greater than that of the normal-type tool. This was because the blade of the zigzag-type tool was not unidirectional but fabricated as a zigzag shape, which increased contact with the surface of the workpiece, thereby improving the machining quality but increasing the wear of the tool. Figs. 16–18 show the photos of the CFRP surface machined with the zigzag-type tool.

4. Conclusions

This study analyzed the machining characteristics according to grade and coating using normal- and zigzag-type end mill tools, and the following conclusions were drawn from the experimental results.

1. The experimental results according to grade showed that K55SF had the greatest wear, whereas K6UF had the lowest wear regardless of the shape and coating type of the end mill tools.

2. The experimental results according to coating showed that both the normal- and zigzag-type Tetrabond-coated tools had the lowest wear regardless of grade.

3. The workpiece surfaces of the normal- and zigzag-type tools were checked, and the results showed that burr generation was reduced more with the zigzag-type than the normal-type tools.

4. The comparison of wear by tool showed that the zigzag-type tool had more wear than the normal-type tool, which verified that the result was related to the larger contact area of the zigzag-type tool with the workpiece than the normal-type tool and the reduction in burr generation.

Acknowledgments

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