A Study on the Cutting Characteristics of the Glass Fiber Reinforced Plastics by Drill Tools

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Composite materials are widely used to make all kinds of machine parts, internal and structural materials of cars, aerospace components, building structures, ship materials, sporting goods and others. It is worth while to use composite space substitute material in various applications when compared with others. But the use of composite material is limited in the field of the mechanical processing because of the difficulties in processing.

Thus, it is proved that the surface is rough at the in and out sections of the hole processing when the GFRP is machined with HSS drill in the vertical machining center. And it is observed that the more it is processed, the more the fluid type long chip is changed into the powdered chip.

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1. Introduction

With the development of industrial society, there have been continuous efforts to make machine tools with precision and high productivity. Interests have increased in new materials that are lightweight and has high durability. Of composite materials, fiber reinforced composite materials invigorated by short fiber or continuous fiber have good fatigue, high strength and rigidity compared to the density as well as moderate price and great flexibility of form. In these respects, they are widely used to make all kinds of machine parts, internal and structural materials of cars, aerospace components, building structures, ship materials, sporting goods and others.[1-2]

Composite materials can be completed by primary process such as Compression Molding, Vacuum Bag Molding, Pultrusion, Resin Transfer Molding (RTM), Vapor Deposition, Foil Metallurgy, Casting and Electro-Deposition. However, nowadays, secondary process, for example, Turning, Drilling, Milling process and others is needed because of its versatile use. At the same time, numerous researches are in progress as the need for studies on the cutting characteristics of composite materials such as precision and figuration after machining.

As for the researches using composite materials, Namgung,[3] examined the drilling characteristics such as the influence of change of point angle of drill cutting blade on the exit and cutting force. Also, he investigated the frequency of cutting force signal according to the change of cutting force by the angle between the drill and fiber ply through experiments using carbon fiber epoxy composite materials. Dharan[4] in his study on carbon fiber epoxy composite materials, suggested the theoretical model of in and out processes, wear behavior of tools and thrust and torque according to fiber orientation during the hole processing using drill tools. Also, Kim,[5] et al. performed researches on cutting characteristics of laminated carbon fiber epoxy composite materials (prepreg) and investigated the characteristics of hole processing such as chip form, in and out processes depending on the cutting conditions and the influence of tool wear and cutting force during hole processing so as to minimize the defects that occur during hole processing using endmiling.[6] As mentioned above, though a lot of researches have been made, the application of composite materials in the machine industry is not enough compared to those in architecture and aerospace industry despite its high possibility to substitute other materials. Specially, quantitative researches on drilling characteristics of composite materials are insufficient.

In this paper, the cutting force, the matrix structure and surface roughness of processed workpiece, and chip form were observed according to various cutting velocity with HSS drill using a vertical machining center. The aim of this study is to provide the useful basis on drilling of GFRP composite materials by examining the cutting characteristics of GFRP and address the issues on in and out processed and cutting characteristics of drilling in order to increase the use of composite materials in the high-tech industry.

2. Experiment Equipment and Method

2.1 Specimen

Specimen was prepared as follows. Thermosetting polymer epoxy resin mixed with low viscosity epoxy resin modified by reactive diluent (BGE) and poly-amide epoxy resin hardener was applied to the bisphenol-A liquefied epoxy resin. Then, 50 layers of woven glass fiber were laminated on it. After curing for 24 hours at normal temperature, it was cured for 3 hours at 80℃ in the oven and baked for 24 hours at 50℃.

Table 1 shows the physical properties of glass fiber and epoxy resin and Fig. 1 depicts the shape of specimen after cutting.

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Table 1 Physical properties of glass fiber & Epoxy resin

Variety \ Item	Glass fiber	Epoxy resin
Tensile strength(kg$_f$/㎟)	35	7
Density(g/㎤)	1.74	-
Thickness(㎜)	0.2	-
Strain to failure(%)	0.5	-
Poisson's ratio(υ)	0.2	-
Viscosity(25℃,cps)	-	840
Specific gravity(25℃)	-	1.1
Equivalence(g/eq)	-	206

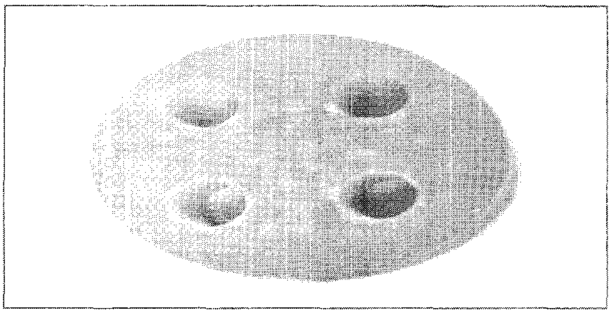


Fig. 1 Shape of specimen(after cutting)

2.2 Experimental Equipment

A vertical machining center was used for the cutting experiments and the specifications are found in Table 2. BT40-DPSN20-90 collet holder, which is a strong type spring collet, was used as a drill holder to fix the drill firmly. Cutting tool is a high speed steel drill which is a straight sank drill of ϕ 10× 90㎜× 130㎜ and the point angle is 130°, the relief angle is 11° and the twist angle is 38°.

Table 2 Specifications of machining center & servo motor

Specification	Dimension & Illustration		Specification	Dimension & Illustration	
Type	Vertical 3 axis M/C		Steady torque	4.87 kgf·m	
Model	Sirius-2 Fanuc korea. Co.		Rapid travel speed	X,Y,Z axis	30,000 ㎜/min
Table size	760× 430 ㎜		Feed speed	1 ~ 24,000 ㎜/min	
Table length	X axis	660㎜	Servo moter	Xaxis	1.4 ㎾
	Y axis	410㎜		Yaxis	1.4 ㎾
	Z axis	460㎜		Zaxis	2.8 ㎾
Main shaft rpm	80 ~ 8,000 rev/min		Table movable load	400 kg$_f$	

2.3 Experimental Method

The cutting speed was 31.4m/min, 62.8m/min, and 94.2m/min and the feed speed was 0.067㎜/rev, 0.1㎜/rev, and 0.2㎜/rev when processing reinforced plastics with high speed steel drill. After fixing the drill holder to the jig, drill and holder were attached firmly using the drill chuck keeper. The drill processing location was set to fixed intervals to minimize the influence of the cutting heat. 10mm drill was used and the processing method was the general feed cutting and step feed cutting.

Cutting force fluctuation components for each experimental condition were measured by piezoelectric tool dynamometer (Kistler, type9272) and the cutting force components obtained from the tool dynamometer was amplified. The amplified analog sign was converted into a digital signal by the A/D converter (DAS-16) and sent to the personal computer for data analysis. The transmitted sign was analyzed with cutting force measurement software.

The chips generated from the cutting process were observed with a tool microscope. The surface roughness was measured with a three dimensional measuring apparatus (Mitutoyo, BRT-S916) 7 times and the average of 5 measurements was taken with the exception of maximum and minimum. In addition, comparative analysis was made using a scanning electron microscope (Jeol, JSM840-A) after cutting with diamond wheel cutter to examine the changes of matrix structure after the hole processing.

3. Experimental Results and Discussion

3.1 General Feed Cutting

Thrust Fz and Torque Mz of GFRP according to the hole depth under the cutting speed of 62.8m/min and drill feed speed of 0.1mm/rev using the high speed steel drill of ϕ 10㎜ are shown in Fig. 2 and Fig. 3, respectively.

As shown in Figs. 2 and 3, the changes of thrust and torque in accordance with the hole depth are almost constant from 1.5㎜ to 13㎜ with the exception of the first and the last part, and the thrust and the torque in this section are 110N and 12N·㎝ respectively. And it is found that dynamic characteristic of torque is more changeable than thrust among the cutting forces.

From this result, thrust and torque are inferred not to be influenced by the depth in the rest of the hole except for the first and the last parts. But it is considered that the reason for dynamic characteristic of torque being larger than that of the thrust is due to the accumulative chips created while processing, internal heat and the dominant influence of the friction between the outside drill and the inside of the workpiece.

3.2 Step Feed Cutting

In this experiment, the change of the cutting resistance according to step feed was investigated.

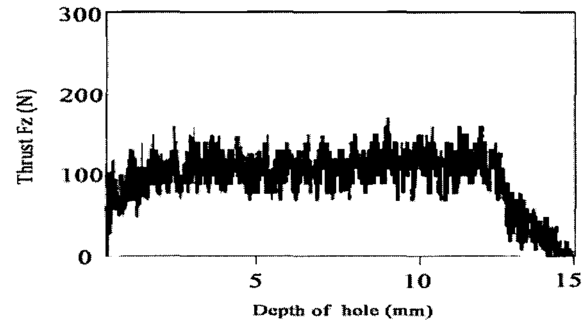


Fig. 2 Relation between hole depth and thrust on GFRP for HSS, V=62.8m/min, f=0.1㎜/rev

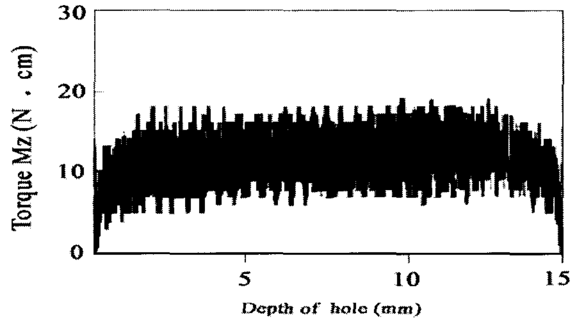


Fig. 3 Relation between hole depth and torque on GFRP for HSS, V=62.8m/min, f=0.1㎜/rev

Fig. 4 shows the thrust on GFRP when the cutting speed is 62.8m/min and the feed is 0.1㎜/rev after the 3 step feed cutting. The thrust is 130N and it is slightly higher than that of general feed cutting shown in Fig. 2.

The torque on GFRP shown in Fig. 5 goes up gradually as the depth of hole increases and it is less by 4N·㎝ compared to general feed cutting shown in Fig. 3. Step feed cutting readily discharges the chips that the rise in cutting heat is slow and this is thought to make thrust and torque on GFRP to decrease. And in the step feed cutting, the reason that the amplitude of torque varies upon the increase of feed is due to continuous micro-chipping at the tool nose by the shock of the step feed.

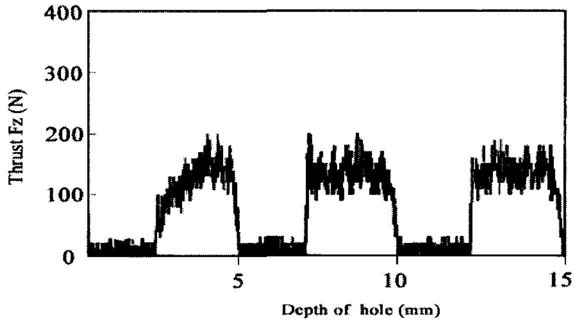


Fig. 4 Relation between hole depth and thrust on step feed for and GFRP, V=62.8m/min, f=0.1㎜/rev

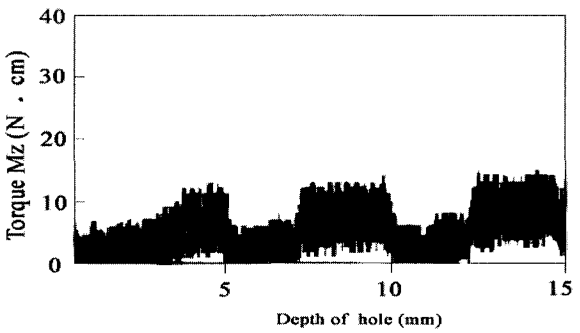
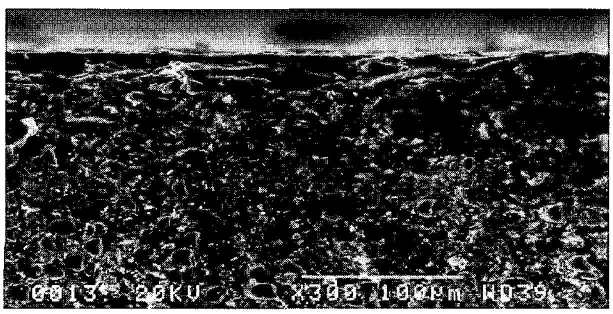


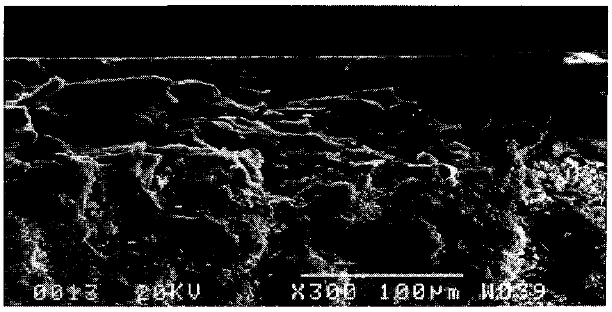
Fig. 5 Relation between hole depth and torque on step feed for and GFRP, V=62.8m/min, f=0.1㎜/rev

3.3 State of In and Out Sections

Fig. 6 shows the in and out section of the specimen obtained using the Scanning Electron Microscope (SEM) after hole processing at the cutting speed of 94.2m/min using a drill of ϕ 10㎜. Delaminated regions can be seen at the in and out sections after the hole processing and they are more easily found in the out section. This is because cutting heat accumulated in the tool expedited wear in the out section, which made the fiber and the matrix material to be in tension and get torn out instead of being cut smoothly.



(a) IN

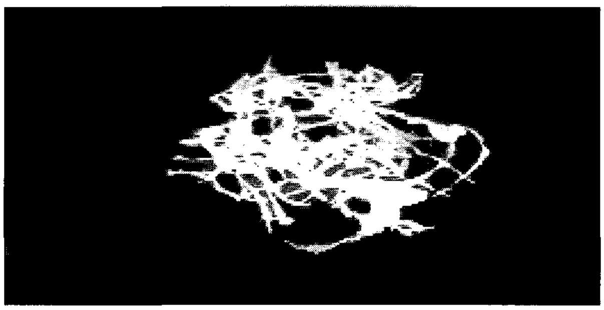


(b) OUT

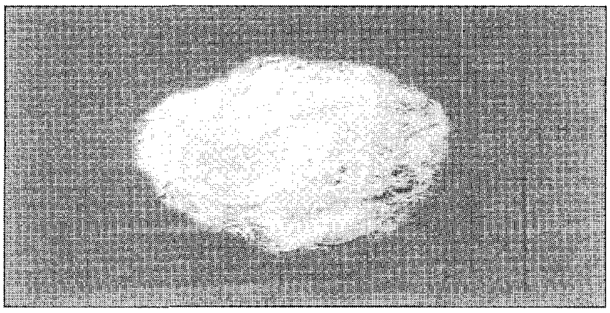
Fig. 6 Hole of GFRP, V=94.2 m/min

3.4 Chip Form

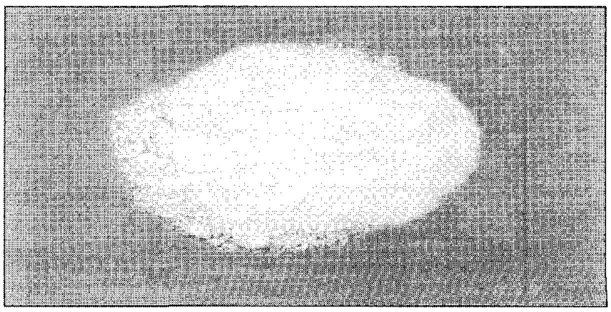
Fig. 7(a), (b), (c) depicts the chip schematics of GFRP at the cutting speed of 62.8m/min with a drill of ϕ 10㎜ after hole processing of 5, 52, and 112 holes, respectively. As shown in Fig. 7(a), the chip form of the 5th hole is continuous and this is mainly because the plastic resin was sufficiently contained.



(a) 5th hole



(b) 52th hole



(c) 112th hole

Fig. 7 Chip schematics of GFRP, V=62.8m/min

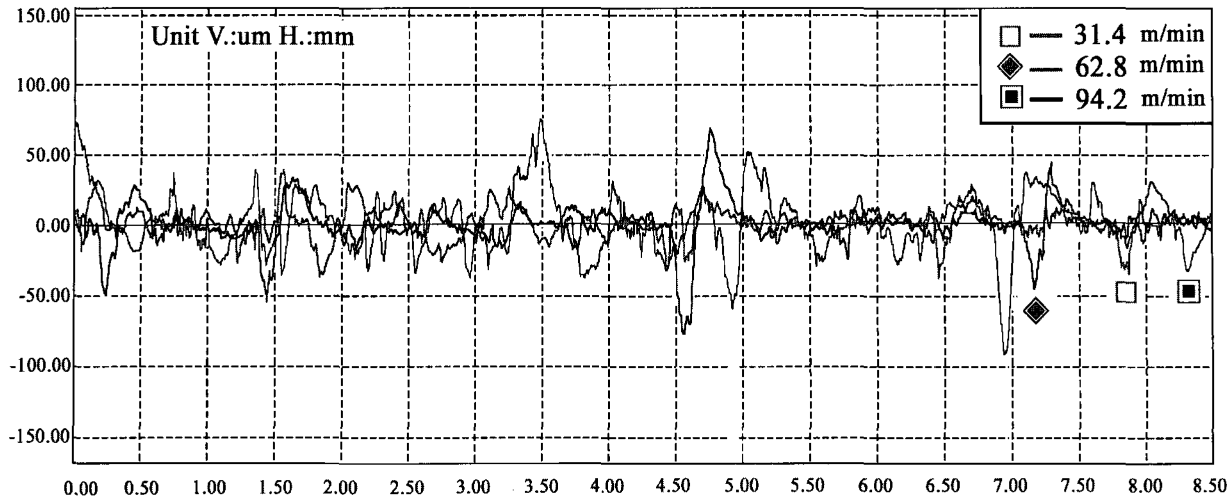
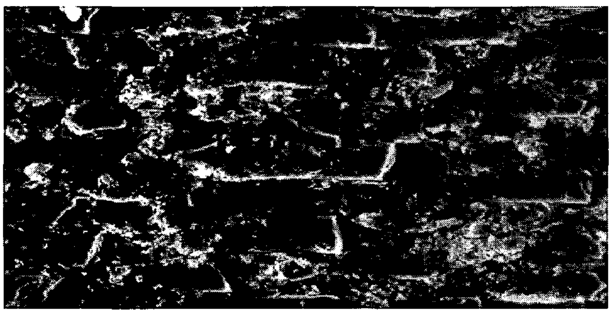
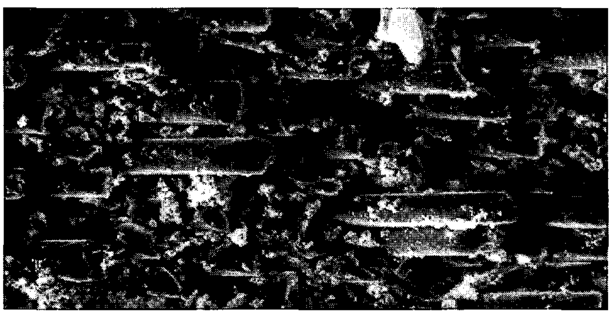


Fig. 8 Surface roughness with respect to cutting length at various cutting speeds of GFRP



(a) V=31.4m/min

(b) V=62.8m/min



(c) V=94.2m/min

Fig. 9 Scanning Electron Microscope images of GFRP

The chip form of the 52th hole as shown in Fig. 7(b) was significantly short and about 50% of the discharged chips were in the powder form. When the 112th hole was processed, the chip form was totally powder-like as shown in Fig. 7(c). This is because the main cutting edge of tool, the flank tip was so worn that the cutting performance was lowered and the cutting of the workpiece could not be completed well. Therefore, the heat from reinforce materials, carbon fiber and matrix materials, epoxy resin of workpiece during processing was accumulated in the tool and this made the temperature of the tool to rise so extremely that the life of tool was almost exhausted.

3.5 Surface Roughness

The surface roughness and morphology of GFRP specimen are shown in Fig. 8 and Fig. 9, respectively, after the hole processing at the cutting speed of 31.4m/min, 62.8m/min and 94.2m/min and the feed rate of 0.1㎜/rev with the high speed steel drill. The value of surface roughness(Ra) is 7.37㎛, 8.87㎛ and 14.65㎛ for the three speeds, respectively. The surface is unstable as shown in the picture and gets worse as the cutting speed goes up. It may be concluded that the process could not be completed well because the thermosetting resin used as matrix materials of workpiece was welded to the blade of drill during the cutting process and the heat generated by the high cutting speed exerted bad influence on the tool and the surface of the workpiece.

4. Conclusions

Hole processing of GFRP specimen was performed with high speed steel drill through general feed cutting and step feed cutting to observe the cutting force, the change of matrix structure, chip form and surface roughness. The results obtained are follows;

1) Thrust and torque on GFRP obtained was 110N and 12N·㎝ respectively and changed constantly from 2.5㎜ to 13㎜ of length for hole processing.

2) Thrust increased by 80N and torque decreased by 4N·㎝ in step feed cutting compared to those in general feed cutting.

3) The form of the in section was good but serious delamination was found at the out section after hole processing.

4) In the beginning, continuous chips were created but changed to powder because of the serious tool wear after the 112th hole processing.

5) As the cutting speed increased , the surface roughness got worse and the values of surface roughness were 7.37㎛, 8.87㎛ and 14.65㎛ at the cutting speed of 31.4m/min, 62.8m/min and 94.2m/min, respectively.

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REFERENCES

1. Moon, C. G., "Polymer Composite Materials," Sigma Press, 2000.
2. Bang, K. G., Kim, H. S., Lee, D. G. and Jeon, H. S., "Development of Guide Roller Using Electroplated Carbon Fiber Composite for Thin Polymer Film Processing," Composite Structures, Vol. 38, pp. 321-328, 1997.
3. Namgung, S., Kim, H. C. and Lee, W. Y., "A Study on Effects of the Fiber Orientation and Point Angle on Drilling Characteristics of Carbon fiber Epoxy Composite Materials," Journal of the Korean Society of Precision Engineering, Vol. 14, No. 4, pp. 119-125, 1997.
4. Ho-Cheng, H. and Dharan, C., "Delamination During Drilling in Composite Laminates," Transactions of the ASME, pp. 236-239, 1990.
5. Kim, D. H., Kim, W. S. and Kim, K. W., "A Study on the Machining Properties of CU175NS Composite Laminates," Transactions of the Korean Society of Machine Tool Engineers, Vol. 10, No. 1, pp. 88-93, 2001.
6. Nig, W. K., Wulf, Ch., Graβ, P. and Willers cheid, H., "Machining of Fiber Reinforced Plastic," Annals of the CIRP, Vol. 38, No. 1, pp. 119-124, 1989.
7. Wang, D. H., Nakayama, K. and Arai, M., "Improvement of Surface Finish in the Cutting of GFRPC," Proceedings of the First International Conference on New Manufacturing Technology, pp. 33-38, 1990.
8. Sakuma, K. and Seto, M., "Tool Wear in Cutting Glass Fiber Reinforced Plastics," The Relationship between Fiber Orientation and Tool Wear, Bulletin of JSME, Vol. 26, No. 218, pp. 1420-1427, 1983.