# Effect of Tool Shape on Precision Hole-cutting of Laminated Composite Materials

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**Abstract**

Carbon Fibre Reinforced Plastics (CFRP) has higher specific strength, modulus of elasticity and so on. In the newly application for wind turbines, CFRP will be remarkably used for rotor blades. It is already widely applied for aviation and automobile parts in these days. CFRP is laminated for production parts with some metals which are aluminium and titanium alloys. These manufactured parts have containing many holes for various purposes such as rivet holes. The precision hole-cutting process on the parts of laminated composite materials is a very important machining technology [1]. In this research, it is considered that the effect of tool shape on precision hole-cutting process of laminated composite materials in order to improve the quality of machined holes and the machinability of hole numbers.

Hole-cutting tests of CFRP laminated plates in our experiments are carried out using various types of end mill which have different shapes by helical cutting method on the machining centre. In these experimental results, the thrust forces Fz by using ball nose type of end mill is smaller than that by using square end mill and so on. When the ball nose end mill is applied, the thrust forces are reduced and the better surface roughness on the inside of machined holes is obtained without delamination and burrs of holes. Cutting edges and margins of the ball nose end mill used are worn by small and small in cutting processes. DLC coated ball nose shape of cutting tool is suitable for precision-cutting of laminated composite materials which are CFRP, aluminium alloy and titanium alloy.

## 1 Helical cutting of CFRP plate

Due to development of helical cutting techniques on laminated composite materials, thrust forces of cutting process are measured with dynamometer system. The

machined holes are evaluated by accuracy of the drilled diameter, surface roughness of the drilled inside and quality of the drilled exit side. They are observed with a digital microscope. Simultaneously, tool wear of the end mill cutter used in the experiments are also observed. The experiments are executed by helical cutting CFRP plates with a conventional cemented-carbide square and ball nose end mills set on a vertical type of machining centre. Cutting speed *Vc* and revolution speed *Vr* are set to 100 m/min and 600 mm/min, respectively, as shown in Figure 1 and Table 1.

The drilled hole of 9 mm which is made at 10th helical cutting process by using square end mill is clear without burrs on the exit sides as shown Figure 2 (b). On the other hand, there are many large burrs on the entry side of that hole. There are burrs

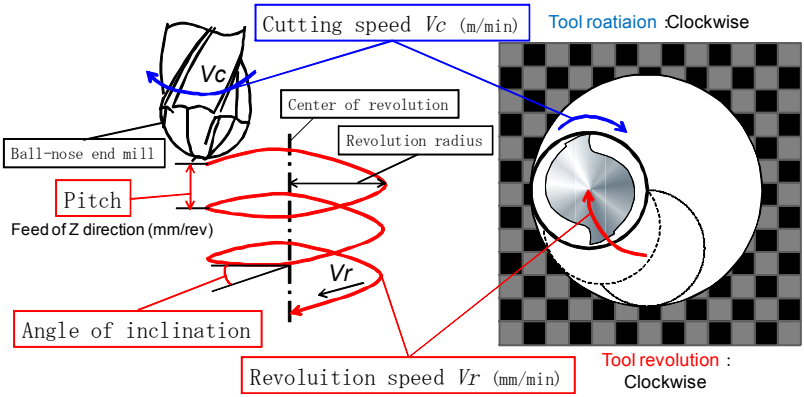



Figure 1 Helical cutting process by ball nose end mill

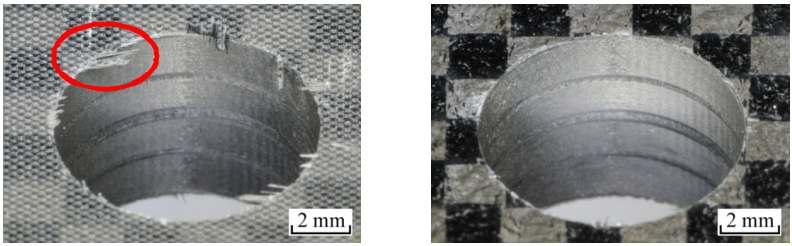
Table1: Experimental conditions

| | |
|---|---|
| Machine tools: | Vertical type of machining centre V56, SV-400 |
| Cutting tool: | Cemented-carbide square end mill<br>DLC coated cemented-carbide ball nose end mill<br>Diameter: $d$ = 6.0 mm, Number of cutting edge: 2 |
| Workpiece material: | CFRP, Titanium alloy, Aluminum alloy |
| Cutting fluid: | Dry |
| Cutting conditions | Diameter of drilled hole: $D$ = 9.0, 12.0 mm<br>Cutting speed: $Vc$ = 100 m/min<br>Revolution speed: $Vr$ = 600, 2400 mm/rev |

on the entry side of drilled hole on the CFRP plates by using square end mill which are worn and used after several times of helical cutting processes. When the ball nose end mill is used for helical cutting CFRP plates, there are no burrs on the both side of drilled holes after several cutting processes. The general trends of thrust forces are observed square and ball nose end mill, respectively, as shown Figure 3. The increasing thrust force at the first part of helical cutting process affected to make the burrs on the entry side of CFRP plates. Lower thrust force is kept at the start and end point of cutting by using ball nose end mill.

## 2 Helical cutting of CFRP + Al + Ti plate

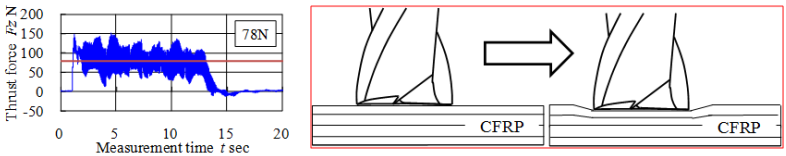
The ball nose end mill is applied for helical cutting of CFRP + Al + Ti laminated composite materials. Cemented-carbide ball nose end mill is worn after a few drilled



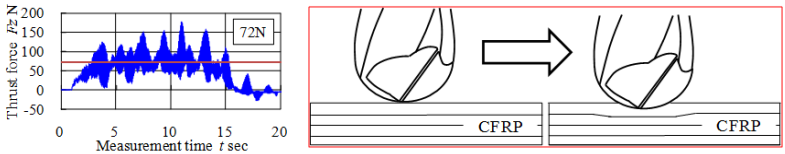

(a) Entry side view of drilled hole (b) Exit side view of drilled hole

[ $d$ = 6 mm, $D$ = 9 mm, $Vc$ = 100 m/min, $Vr$ = 600 mm/min, Dry ]

Figure 2 Drilled hole of 10th helical cutting process by using square end mill



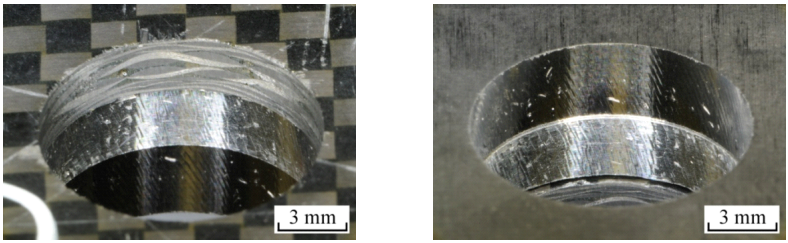

(a) Sqsuare end mill (worn)




(b) Ball nose end mill (worn)

[ $d$ = 6 mm, $D$ = 9 mm, $Vc$ = 100 m/min, $Vr$ = 600 mm/min, Dry ]

Figure 3 Difference of thrust forces at the start point of cutting process on CFRP

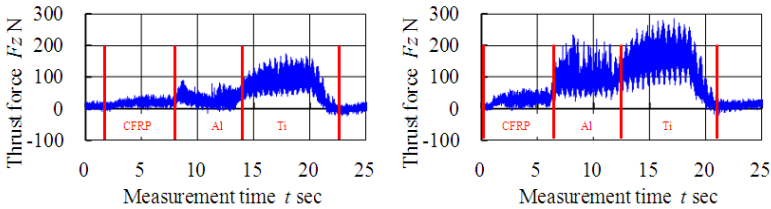



(a) Entry side view of drilled hole (b) Exit side view of drilled hole

[ $d$ = 6 mm, $D$ = 12 mm, $Vc$ = 100 m/min, $Vr$ = 2,400 mm/min, Dry ]

$t$ = 2.78 (CFRP) + 3.0 (Al) + 3.6 (Ti) mm

Figure 4 Drilled hole of helical cutting by using DLC coated ball nose end mill




(a) 1st process (b) 5th process

[ $d$ = 6 mm, $D$ = 12 mm, $Vc$ = 100 m/min, $Vr$ = 2,400 mm/min, Dry ]

$t$ = 2.78 (CFRP) + 3.0 (Al) + 3.6 (Ti) mm

Figure 5 Helical cutting process by using DLC coated ball nose end mill

processes of these laminated materials. The smooth drilled holes are obtained by DLC coated ball nose end mill without any cutting fluid as shown Figure 4. Thrust force during the cutting process of CFRP plate is very low in Figure 5.

## 3 Conclusion

It is found that precision drilled holes of laminated materials are made by lower thrust forces of ball nose shape end mill cutter. The DLC coated ball nose end mill is suitable for helical cutting process of laminated composite materials which are CFRP, aluminium alloy and titanium alloy.

## References:

[1] B. Denkena, D. Boehnke, J.H. Dege, “Helical milling of CFRP–titanium layer compounds”, CIRP Journal of Manufacturing Science and Technology 1 (2008) 64–69.