INSTRUCTIONS

CFRP (Carbon Fiber Reinforced Plastics) is well

known as a difficult-to-cut material which has

very strong physical and mechanical

characteristics. When the CFRP is machined by
cutting technique, cemented-carbide tool is

widely used. Furthermore, diamond cutting tools
and PCD (Polycrystalline diamond) tools are

also used in these days instead of cemented-
carbide tools in order to improve the accuracy of
high precision drilled holes. However the tool
life of diamond tools is too short to use as a
normal cutting tool for CFRP products because
tool costs are too expensive. Cutting tools for
CFRP which have long tool life are required by
several kinds of industries such as aviation
industry, automobile factories and so on [1], [2].
On the other hand, cutting tools are remarkably
developed for many kinds of difficult-to-cut
materials by the coating technology of cutting
tool which are Chemical Vapor Deposition
(CVD) coatings, Physical Vapor Deposition
(PVD) coatings and so on. In our research, it is
investigated that the various twist drill bits and
ball nose end mills are examined for precision
drill-out techniques of CFRP plates.

EXPERIMENTAL SETUP

The experiments are executed by drilling tests of
120 holes on CFRP plates with common twist
drills which are set on the vertical type of
machining centers “V33” or “SV-400” as shown
in Fig. 1. Each drilled holes on the CFRP panel
of 2.78 mm are investigated in terms of cutting
forces which are measured with dynamometer
system. The main experimental conditions are
summarized in Table 1. Drilling tests with the
various kinds of twist drills which are made by
cemented-carbide, high-speed steel, TiAlN PVD-
coated-cemented-carbide, DLC (Diamond-Like
Carbon) coated-cemented-carbide are carried
out in dry condition without cutting fluid. The
high-precision drilled holes are evaluated by
diameter of holes and quality of drilled exit side.
The drill-out holes are observed with the digital

TABLE 1. Experimental conditions

<table>
<thead>
<tr>
<th>Machine tools:</th>
<th>Vertical type of machining Center V33 (Makino), SV-400 (Mori seiki)</th>
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</thead>
<tbody>
<tr>
<td>Cutting tools:</td>
<td>Twist drill, Ball nose end mill: Cemented-carbide, High speed steel, TiAlN PVD-coated, DLC coated Diameter: (d = 6.0) mm Number of cutting edge: 2</td>
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<tr>
<td>Workpiece material:</td>
<td>Carbon Fiber Reinforced Plastics 8 Layers Thickness: (h = 2.78) mm</td>
</tr>
<tr>
<td>Cutting fluid:</td>
<td>Dry</td>
</tr>
<tr>
<td>Cutting conditions:</td>
<td>Cutting speed: (V_c = 100, 300) m/min Feed rate: (f = 0.05) mm/rev</td>
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by using the 4 kinds of brand-new twist drills are observed by microscope in Fig. 2. There are some burrs and chipping on the exit side of drilled holes in spite of first machined drilling hole. In case of cemented-carbide tool and high speed steel twist drills, burrs and chippings are very small size as shown in Fig. 1 (a), (b). When TiAlN PVD-coated-cemented-carbide twist drill bit was used, drilled holes in Fig. 1 (c) have huge burrs which are over 1.0 mm in length. The inside of drilled hole, however, has very good quality which is most clearly to see every layer of CFRP plate. Drilled hole by using the DLC coated-cemented-carbide twist drill also has small burrs and chippings. Inside of drilled hole with DLC coated tool is similar to results by normal cemented-carbide tool as shown in Fig. 1-

**FIGURE 2. Microphotographs of exit side on the drilled CFRP plate by using various twist drills [Vc = 100 m/min]**

![Exit side](image1)

- **(a) Cemented-carbide**
- **(b) High speed steel**
- **(c) TiAlN PVD-coated-cemented-carbide**
- **(d) DLC coated-cemented-carbide**

**FIGURE 3. Microphotographs of Twist drill bits cutting edges after 120 drilling processes**

(a)-right and (c)-right. Boundary lines of each CFRP layer inside the both drilled holes are not clear.

**EFFECT OF SHARPNESS ON CUTTING EDGES**

Tool wears of twist drill bits are observed after the 120 drilling processes. Flank wears of cemented-carbide and high speed steel twist drills are shown in Fig. 3. Flank wear of cutting edge on the top of cemented-carbide twist drill bit is smaller than that of high speed steel. There are huge flank wears on the cutting edge and margin of high speed steel twist drill bit. The bigger wears exist on the outer side of twist drill bit. In case of high speed steel twist drill, the quality of drilled holes is remarkably downgrade after very short drilling processes which are about only 10 drilling holes. It is declared that cemented-carbide tool is more suitable for CFRP drilling. Cemented-carbide tool can be used for CFRP drilling processes without cutting fluid at least 100 drilling holes. Sharp cutting edge of brand-new high speed steel twist drill is more effective for CFRP drilling because good result of drilled hole is obtained.
High speed steel, however, has not enough hardness to cut composite materials like CFRP.

Due to find out the effects of coated materials TiAlN PVD and DLC coated-cemented-carbide twist drills which are used for 120 drilling processes of CFRP plates are also observed by microscope as shown in Fig. 4. Both of the coated tools have obviously worn the coating material on the cutting edge and margin. Width of flank wear on the cutting edge and length of worn area on the margin are almost same. Thrust forces in drilling processes with every kind of twist drill bits are summarized in Fig. 5. Every thrust force is increasing slowly with the number of drilling holes. But there are great differences on the trend of thrust forces. Until the 20 drilling holes the thrust forces used with TiAlN coated twist drill bit are slightly bigger than other two kinds of drills which are cemented-carbide and DLC coated-cemented-carbide twist drill bits. The thickness of coating layer on the twist drill bit affects on the quality of drilled holes and thrust forces in the drilling time. DLC coat is very thin below 1 micro-meter. TiAlN PVD-coat is, on the other hand, almost 5 micro-meters. TiAlN coated tool lose sharpness on the cutting edge because of thickness of coating layer. When the cutting edges on the every twist drill are roundly worn after the 20 drilling processes, the thrust forces are close to same levels. DLC coating is very thin and efficient for keeping the sharpness of cutting edges.
EFFECT OF CUTTING SPEED
When cutting speed is changed to 300 m/min, flank wears are obtained similarly as shown in Fig. 6. Thrust forces are almost same level by comparison with difference in cutting speeds $V_c$ of 100 and 300 m/min in Fig. 7. Furthermore, ball nose end mills are applied at the high speed cutting of 300 m/min. The best quality of drilled holes without burrs and chippings is obtained by using both of cemented-carbide and DLC coated-cemented-carbide ball end mills as shown in Fig. 8. The layers of CFRP are also clearly machined inside the drilled holes. Thrust forces are measured until the 301 drilling holes as shown in Fig. 9. Thrust forces with DLC coating ball end mill are lower than that with cemented-carbide ball end mill. By using ball end mill the thrust force is below 200 N until the 150 drilling processes. The ball nose end mill is useful for precision drilling techniques of CFRP. At high cutting speed the ball end mill is also suitable to drill-out process of CFRP panel. DLC coating ball end mill is better tool than solid one because thrust forces are stable and drilled holes have better quality. Tool life of DLC coated tool is, however, as same as that of cemented-carbide tool.

CONCLUSIONS
It is evaluated that the various twist drill bits and ball end mills affect to the precision drilled holes of CFRP plates. The main conclusions are summarized as follows:

1. The sharp cutting edge of brand-new high speed steel is effective for CFRP drilling until the depth of 27.8 mm when the tool wear is not huge on the cutting edges.

2. The thickness of coating layer on the twist drill affects on the quality of drilled holes and thrust forces in the drilling time because the coating has made the roundness of cutting edge. DLC coating is very thin and efficient for keeping the sharpness of cutting edges.

3. Ball nose end mills are suitable for CFRP drilling at the high cutting speed of 300 m/min. DLC coating ball end mill is also useful to drilling technique of composite materials like CFRP panels.

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REFERENCES