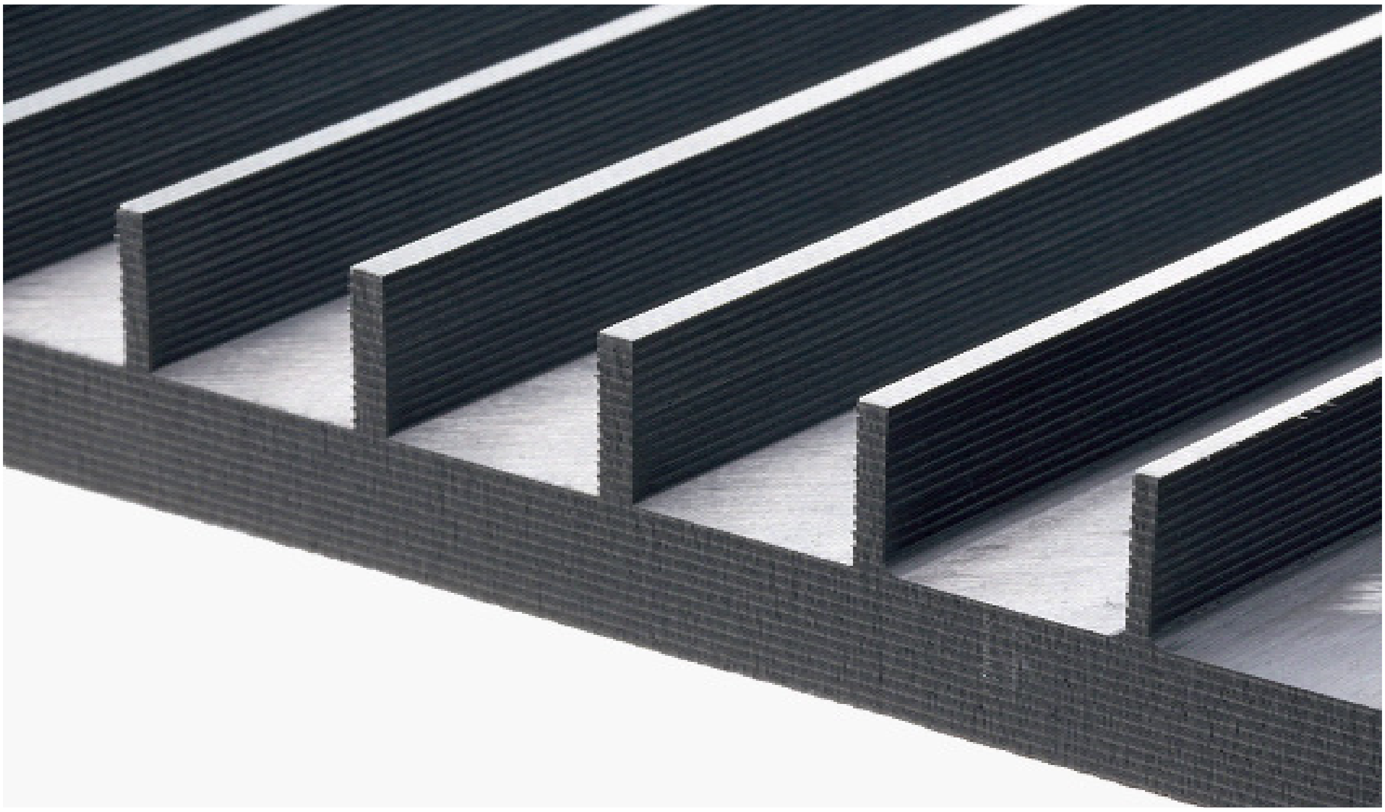
Technical Report for Aerospace Industries

THE CUTTING EDGE TECHNOLOGY IN AEROSPACE APPLICATIONS



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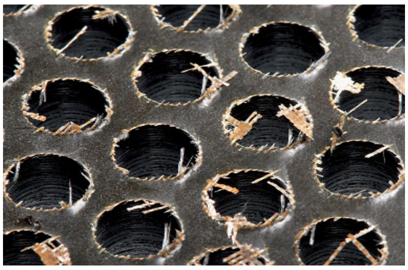
The expectation of the Japanese aerospace industry has been rapidly increasing in the last few years. This is because the use of Carbon Fiber Reinforced Plastic (known as CFRP) makes the next generation of fuel efficient airplanes possible and because CFRP requires advanced machining technologies that many Japanese manufacturers excel in. As the result, it is expected that more than the third of the airplane structures will be machined and built in Japan for years to come. This development is also initiating the plans of building the first national aircraft since the YS11 in the 1970's.
CFRP is considered very difficult material to machine, but it is not a recent innovation. Fighter jets from Europe and America have often used CFRP as its main structural part, and some even exceed over 80% of CFRP usage. This is the case for fighter jets where flight performance outweighs the cost of production. In the production of fighter jets, carbide tools are frequently swapped; and costly PCDs, despite its brittleness, are used in selected applications.
As the use of CFRP makes its way to commercial airplanes, the balance of flight performance and the cost of production has become a sensitive issue for the next generation commercial planes. As the structural size increases and the quantity to produce grows, the usage of CFRP will be in high demand. The fact that there is no other material as light and as strong as CFRP encourages the use of CFRP further more. Therefore, the need to machine CFRP both efficiently and effectively has grown, and this report covers how best to machine CFRP with the best cutting tools available in the market.

1. Difficulties machining CFRP

This report will first cover the difficulties common in machining CFRP and only in CFRP. Various aerospace machining applications can be summarized into 3 parts. The first is trimming outer profile of a part. The second is milling large diameter holes. The third is drilling holes for fasteners to bind parts together. Most, if not all, of quality problems originate from variations of de-lamination in carbon fiber layers. The act of de-lamination is best described as dismembering of compounded fibers or rupturing of fiber layers around the edges of drilled holes or profiled corners. Separation of fiber layers in the beginning and at the end of a drilled hole is also a common problem of drilling CFRP. There are also other problems



Picture 1.1 Uncut fiber

Picture 1.2 Pushed out layers

Picture 1.3 feathering of fibers

such as fiber breakout, uncut fiber and feathering of fibers. Pictures 1.1, 1.2, 1.3 illustrate common pitfall of machining CFRP. In picture 1.1, fibers from the last layer at the end of a hole remain uncut and are pushed out from the hole. Picture 1.2 shows a situation where a layer of CFRP is separated and pushed out at the end of a hole. Although much of the edge is clean, some parts of the edge shows ripping of fibers, rather than a clean cut. Picture 1.3 reveals a perfect example of feathering of fibers. These difficulties are caused by inappropriate setting of cutting parameters, tool wear from extensive usage and/or cutting tool itself.

2. Cutting tools for CFRP

What is the best cutting tool design to machine CFRP? The best way to answer this question is to identify the root cause of de-lamination in CFRP. When cutting, an axial cutting force is applied, and the counter force occurs from the material. Because this counter force is what causes feathering and de-laminating of fiber layers, what we need is a cutting tool that minimizes the cutting force, and even when the cutting force is applied, the cutting tool needs to evenly spread the force on its cutting edges to reduce the cutting force furthermore. The tool needs to do this while being durable enough to maintain a sharp cutting edge.

2.1 Trimming Routers

Successful trimming routers for CFRP require innovative geometry (see image 2.1).

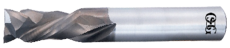


Image 2.1

Herringbone cutter for CFRP

If a normal right hand spiral end mill for steel applications were used on CFRP, then you will have a clean edge on the bottom end, but the counter force from the cutting edges will work to pull layers of fiber upwards (see left image in picture 3). This will cause the top edges to be de-laminated or contain feather-like edges with uncut fibers. On the other hand, if a left hand spiral end mill were used, you will experience clean edges on the top and dirty edges on the bottom. The counter force will work to push the layers of fiber down, causing de-lamination on the bottom end.
OSG's innovative solution is the Herringbone cutter. It is the combination of best of the two worlds by incorporating both right hand spiral and left hand spiral into one cutter (see right image in picture 3).
With such design, the Herringbone cutter creates a down force to keep the fibers down on the top layers of CFRP and upward force for the bottom part of the material to keep the layers intact. The Herringbone cutter produces low cutting force and the resulting surface finish is shown in picture 4. By employing and advancing the Herringbone cutter design, OSG has developed multi-fluted cutters with nicks (see images 2.2 and 2.3).

Image 2.2

Diamond coated router for CFRP

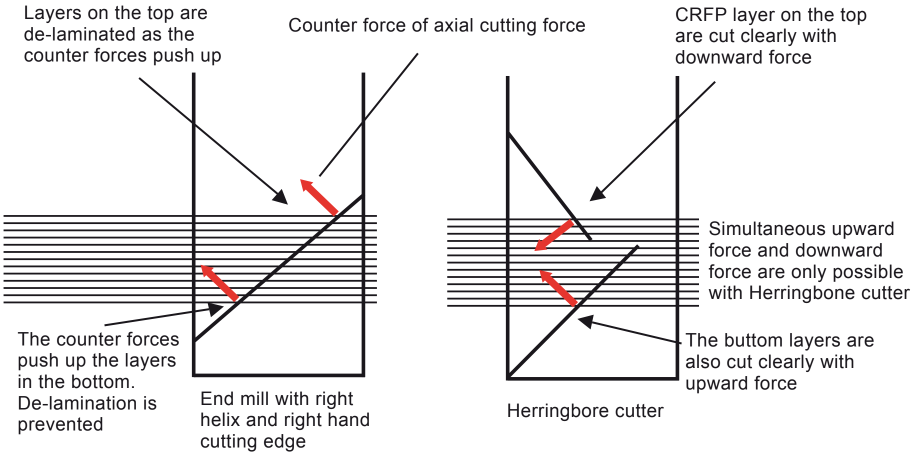
Image 2.3

Diamond coated router for CFRP

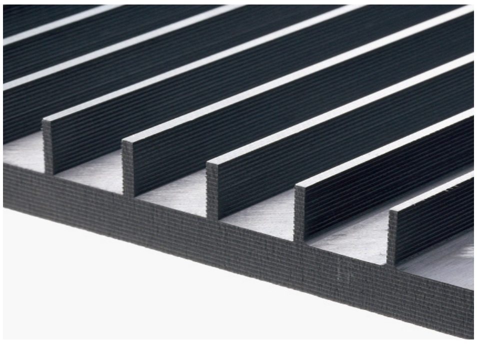
These are variations of multi-fluted right hand spiral cutters with shallow, left hand spiral grooves. The result is a high performance cutter with a formation of numerous trapezoidal cutting edges machining with upward and downward cutting forces. Image 2.2 is the patented fine-pitch cross-nick cutter and image 2.3 is the coarse-pitch cross-nick cutter. The two cutters work wonders with thin or thick CFRP. The cutter shown as image 2.4 is for finishing operations for compounded materials where tool rigidity becomes important.
All in all, these 4 trimming routers

Image 2.4

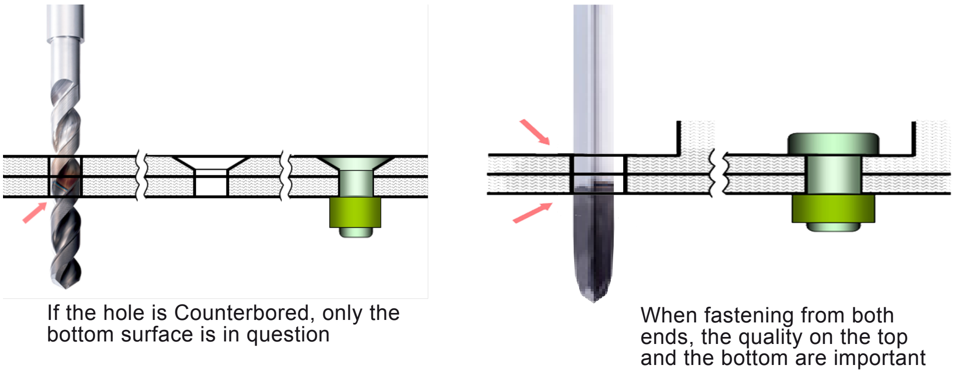
Diamond coated router for CFRP



Picture 3
Differences in applied forces: normal end mills and Herringbone cutter



Picture 4
Surface finish by Herringbone cutter



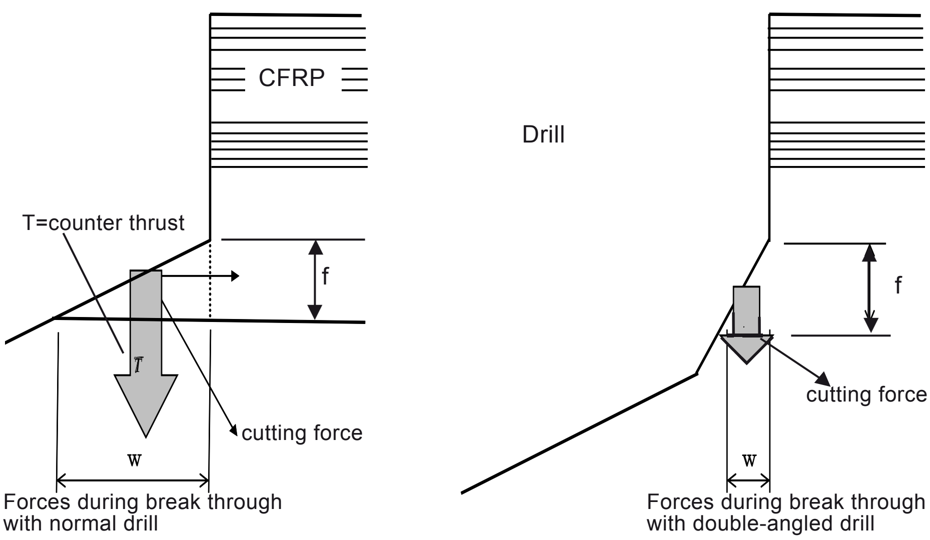
Picture 5
2 types of drills for CFRP

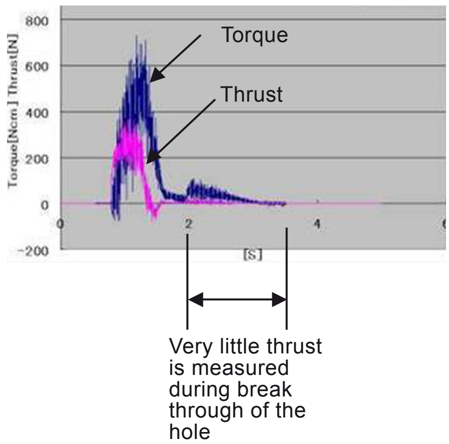
are designed to serve specific needs and a careful selection is required.

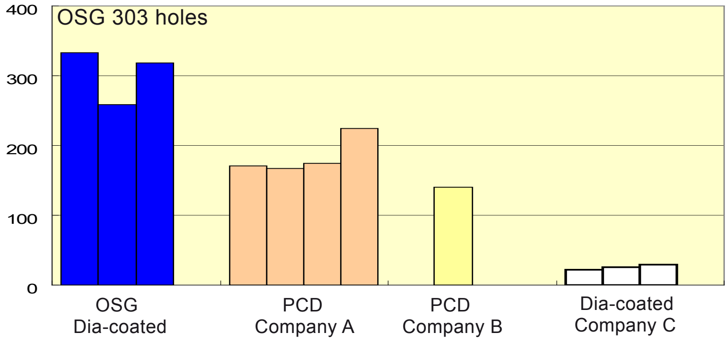
2.2 Drills

OSG offers 2 types of drills to prevent de-lamination while drilling CFRP. The first one is designed to prevent de-lamination on the exit side of the drill. The second is developed to prevent de-lamination on both entry and exit sides.
If a drilled hole is to be counter-bored to match special rivets, then the main focus is to avoid de-lamination during the breakthrough of the hole while retaining productivity. OSG's double-angled, high fluted drill is fitting for this purpose.
The diagrams in picture 6 illustrate the distribution of cutting forces during the penetration through the last layer of CFRP. The right diagrams show how thrust force T, a component of the cutting force, is the force that pushes the last bit of the CFRP layer out. If the aspect ratio of w/f becomes too large, the last bit of CFRP cannot support itself against the cutting force and is pushed out, rather than being cut out. This is the case shown in picture 6's diagram on the left.
On the other hand, if we modify the tool geometry to adjust the aspect ratio of w/f to be small like the diagram on the right in image 6, then de-lamination caused by T force is minimized. OSG's patent pending double-angled drill (see picture 5 left) and triple-angled drill are designed to control this aspect ratio of w and f.
This special geometry not only makes the cutting edge more perpendicular to material fibers but also diverts the cutting force sideways, rather than downward, which is more conducive to de-lamination. The line graph in picture 6 captures the fluctuations of torque and thrust during the entire CFRP drilling process. The graph shows minimal thrust during the breakthrough of the hole, and it proves the fact that the lower the thrust the less likelihood of de-lamination. Picture 7 is the result of tool life tests for OSG's double-angled drills and other PCD drills. The results show that OSG's diamond coated carbide drills out-performed PCD drills in tool life.
In order to prevent de-lamination in the entry and exit of a hole, the use of OSG's straight-fluted triple-angled drill (Pat. P.) is recommended. The triple-angled

Picture 6
Relationship of forces during break through







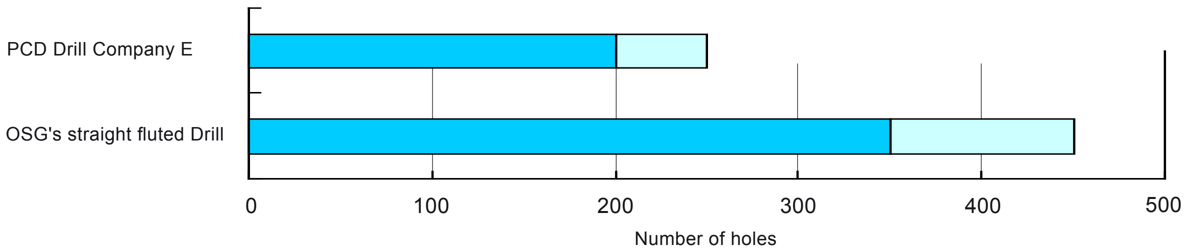
Material: CFRP Depth: 7,1 mm Dia.: 6,375 mm
Cutting speed: 60 m/min Feed: 0,076 mm/rev
Dry cutting

Picture 7
OSG's double-angled drill and other drills

drill's cutting edge is perfectly perpendicular to the surface of a hole, thereby eliminating any fiber break out on the entry and layer ruptures on the exit. Drills with high-helix spiral flutes perform better during the exit of the hole, but the spiral flute will exert lifting forces on the entry of the hole. Image 8 shows the test results of OSG's triple-angled drill against a PCD drill. An improvement of 75% in tool life with quality holes was achieved by OSG's triple-angled drill

3. Cutting tool materials

In machining CFRP, even tools of carbide material experience rapid wear and tear. Thus, many customers and tool manufacturers have opted to use PCD as tool material, diamond coating as surface treatment, electro-plated diamond as cutting edge and diamond tipped tools. OSG offers not only diamond coated carbide tools, but also PCD and electro-plated diamond tools. PCD can achieve one of the sharpest edges and thereby perform excellent surface finish and achieve high tolerance. However, a drawback of using PCD is that it is expensive, and the use of PCD tool is limited to fully automated machines as PCD is too brittle for hand-held machines.
Electro-plated diamond tools, which have similar characteristics as PCD, are often used in applications where a certain surface finish is required to accommodate joint-fitting for other parts. These tools are also well fitted to perform chamfering and machining extremely thin CFRP.
As this report has illustrated, the biggest factor to control is the cutting force when machining CFRP. The best cutting tool is the one that controls the direction of its cutting force without sacrificing surface finish and tool life. The advantage in working with diamond coated carbide tools is its high flexibility in adjusting the helix angle, helix direction, rake angle and number of cutting edges. This flexibility gives cost performance advantage for diamond coated carbide tools over other tools. Every test data in this report confirms that OSG's diamond coated carbide tools perform 10 to 50 times better than other carbide tools and often exceed the performance of PCD tools which are far more expensive.
In conclusion, machining CFRP requires diamond coated carbide tools that come equipped with technologies designed to cope with abrasive nature of CFRP. If an improper tool is chosen, then an improper quality finish is expected and adjusting machine parameters will do little help. Machining CFRP is all about selecting the right cutting tools for the right purpose. If the tools are chosen poorly, the consequence will show in your ballooning tool cost. A very careful selection of tools is required when working with CFRP.



Material: CFRP Depth: 19 mm Dia.: 9,525 mm
Cutting speed: 100 m/min Feed: 0,08 mm/rev
Water cutting

Picture 8
Performance of Straight Fluted Drills

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Tool specifications subject to change without notice