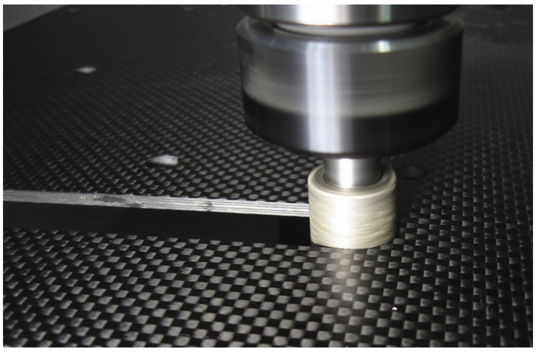
High-Performance Cutting and Grinding Technology for CFRP (Carbon Fiber Reinforced Plastic)



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Since it is not only a high-strength, but also light-weight material, carbon fiber reinforced plastic (CFRP) has recently been used in certain specific sectors including aircraft, medical equipment and other applications, while attracting attention to the expected future increase in its utilization volume for moderately mass-produced items, such as in the auto industry, as well. This is, however, a difficult-to-machine material which suffers easy delamination of fiber beds. It also shortens tool life and, therefore, studies on tools and cutting/grinding technologies are now under way at manufacturers and research facilities. We hereby report our successful materialization of a machining technology superior to any existing techniques in terms of machining efficiency and tool life.

1. Introduction

Carbon fiber reinforced plastic (CFRP) is a composite material fabricated by impregnating carbon fibers with resin and then curing and molding it. CFRP, a material boasting high strength and light weight at the same time, started to be practically used first in golf club shafts, fishing rods and other sports goods but in recent years, it has also become more widely used for industrial purposes such as aircraft materials and medical equipment.

Of late, CFRP has started to be used extensively in aircraft parts, one of our product categories. It was previously used only in structural portions, such as tail assemblies or floor structural materials, but thanks to the higher reliability brought by such improved materials, it has come to be used for entire structures as in the case of the latest B787 model.

There are a number of CFRP manufacturing processes, of which, for aircraft members, an auto-clave process of molding is more frequently used since it promises high strength and stable performance.

One of its features is the ability to fabricate large complex-shaped cast parts such as main wing panels and fuselage barrels, thus contributing to weight saving and reduced part counts.

On the other hand, feed material, which occurs in excess on the end face at the end of molding, needs to be removed. In addition, fasteners are used to assemble parts with each other and since it is difficult to make holes for such assembling at the time of molding, trimming and drilling become necessary in the post-process (**Figure 1**).

2. Higher efficiency of trimming

2.1 Present problems

AWJ (abrasive water jet) or an endmill is generally used for CFRP trimming, but the former has problems of limited shapes that can be machined and heavy initial investment/maintenance costs while the latter has difficulty in raising the trimming efficiency due to easy delamination of CFRP fibers, as well as short tool life (**Table 1**, **Figure 2**).

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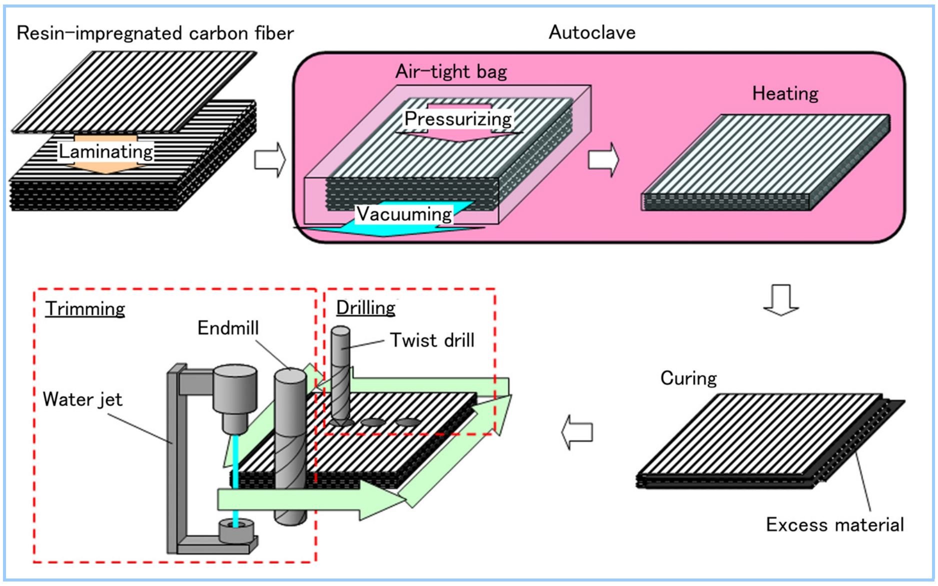

Figure 1　Process to manufacture CFRP (Auto-clave molding)
Auto-clave molding cures the resin under increasing pressure within the furnace for molding. Since excess feed material occurs at the end of molding, trimming and other finish machining are needed.

Table 1　CFRP machining method comparison

	Advantages	Disadvantages
AWJ	・Good quality of machined surfaces	・Limited shapes that can be machined. ・High cost (of initial investment as well as for maintenance)
Endmill	・Usable with general-purpose equipment	・Easy delamination ・Short life of tools
Diamond-electroplated tool	・Usable with general-purpose equipment ・Long life of tools	・Narrow chip pockets prevent high feed speed.

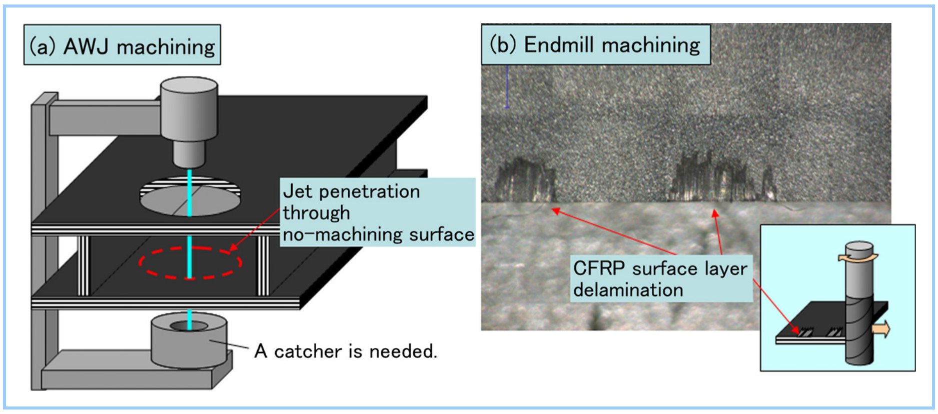

Figure 2　Problems with AWJ and endmill machining
(a) AWJ is capable of through-machining only and, in addition, requires a catcher to be arranged at the jet end, thus limiting the shapes that can be machined.
(b) Endmill trimming easily causes delamination since the cutting force works in the direction to delaminate fiber beds.

2.2　Solution

As a means to solve this problem, we focused attention on an electroplated tool, the same machining equipment as an endmill. The electroplated tool is a tool on which base metal surface fine diamond abrasives are fixed by electroplating them with nickel.

To prevent fiber bed delamination as a problem with endmills, shallow cuts are essential. If an electroplated tool is used, since a large number of diamond abrasives serve as cutting edges, the cuts per edge can be made shallower than in the case of endmills. Therefore, even if the feed speed is increased for higher-efficiency machining, the occurrence of delamination may be limited.

With respect to tool life, an electroplated tool also enjoys higher durability since its cutting edge is crystalline diamond, which is worn away more stably than coated and other thin films (**Figure 3**). Moreover, since machining of CFRP is less subject to loading than metalworking and the abrasive coating hardly flakes off, it seems that an electroplated tool is suitable for CFRP machining.

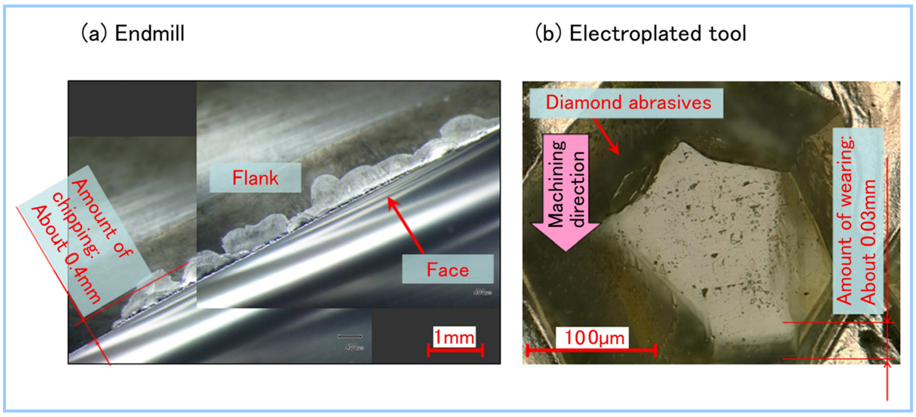

Figure 3 Post-CFRP trimming photo of cutting edge (abrasive) attrition
When trimming CFRP, an endmill suffers chipping at its edge section due to coating delamination while the electroplated tool is subject to stable attrition of its abrasive edge.

2.3 Problems with an electroplated tool

We conducted experiments on our test electroplated tool and the result was successful trimming without causing any delamination, even at speeds faster than endmill machining. But if the feed rate was increased until it reaches a certain level, sparks came off, thus preventing any more improvement of machining efficiency. We thought that the sparks were caused because the electroplated tool was loaded.

2.3.1 Mechanism of loading

Let us consider the mechanism of how the tool is loaded before taking measures against loading.

The tool is required to have chip pockets spacious enough for the amount of chips derived from trimming but such pockets of ordinary electroplated tools only have an abrasive protrusion size-equivalent of space (**Figure 4** (a)). Chips from electroplated tool-machined CFRP are in a powdered state, so their volume swells several times from before being machined. For this reason, we thought that the amount of waste chips acceptable by chip pockets was also small, thereby causing the tool to be loaded immediately upon attempting high-efficiency machining.

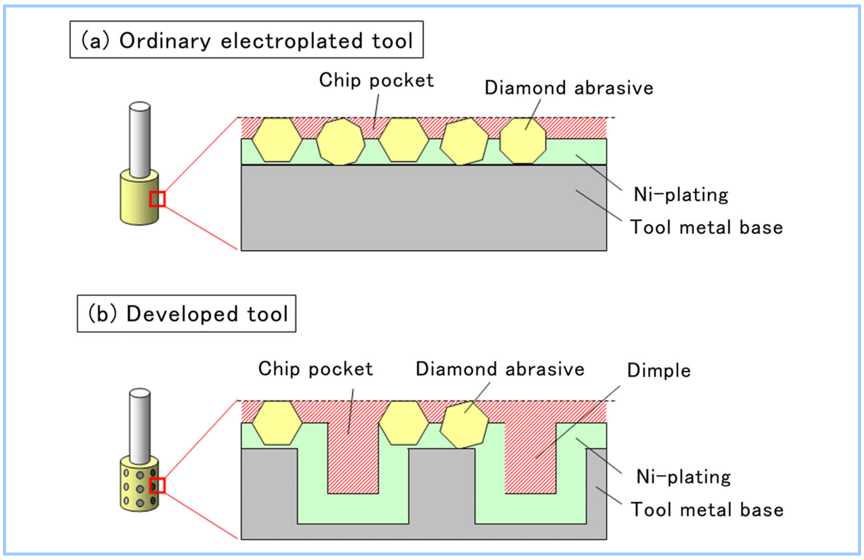

Figure 4 Chip pockets of an electroplated tool
(a) A conventional electroplated tool has chip pockets only equivalent in size to an abrasive protrusion and is, therefore, vulnerable to loading.
(b) The developed tool has a dimpled surface to ensure enough chip pockets, making loading unlikely.

2.3.2 Measures against loading

In order to secure chip pockets spacious enough for our targeted-efficiency trimming on an electroplated tool, we have developed a tool with a dimpled grinding surface (see Figure 4 (b)). The optimum dimple shape (volume) is closely associated with the aforementioned amount of chips derived and, unless a certain volume or more is secured, loading occurs. It should be noted, however, that if the area of a dimple opening is made too large, the number of working abrasives becomes smaller, adversely affecting the accuracy of finishing and/or tool life.

Hence, for the developed tool, a parameter of volume ratio (volume of working chip-pocket sections/amount of chips coming out per revolution of the tool) was established and its relationship with loading was determined by way of work tests. Although the larger the volume ratio, the less likely loading is to occur, where dimples are arranged so as to secure chip pockets, even though the volume ratio is unchanged, if dimples are spaced too far apart, loading occurs to the area distant from the dimple, thus making it difficult for the dimples to have an effect. Dimples need to be equally distributed all over the working grind stone surface and, for the developed tool, consideration was also given to dimple spacing in determining the shape and layout of dimples (**Figure 5**).

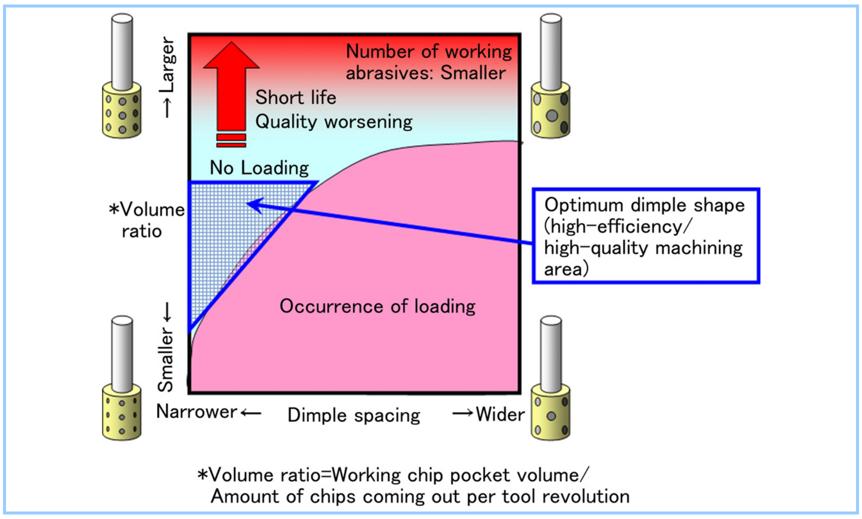

Figure 5 Relationship between chip pockets and loading
Unless the chip pockets are spacious enough for the amount of chips coming out and the space between the dimples is narrow, loading occurs.

2.4 Result of machining with the developed tool

2.4.1 High-speed machining test

Machining tests were conducted by grooving a CFRP board (aircraft member: around 10mm in depth), namely, by trimming it to a cut depth of 100-% tool diameter, and the roughness of machined surfaces was evaluated.

When machined, using an endmill, the surface roughness gradually worsened with increasing feed speed from its usual level of around 200mm/min until it surpassed Ra3μm at 1000mm/min. On the other hand, the developed tool permitted machining to achieve Ra1.5μm even at 2000mm/min, assuring the availability of work with efficiency five or more times higher than that of the endmill (**Figure 6**).

[Reference] AWJ-machined surfaces are good in quality free from delamination but the surface roughness was Ra4μm or so.

2.4.2 Life test

For life tests, the aforementioned CFRP board was subjected to the trimming of its end face at the feed speed of 2000mm/min via a repetitive reciprocating motion of up cutting and down cutting into the depth of 50-% tool diameter and, as in the preceding subsection, the roughness of machined surfaces was evaluated. Once machining started, the surface roughness gradually worsened until Ra2.4μm was marked at the end of 40-m processing (counted as one-round trip equivalent of distance) and thereafter, the CFRP board could be processed with almost no change in surface roughness (**Figure 7**).

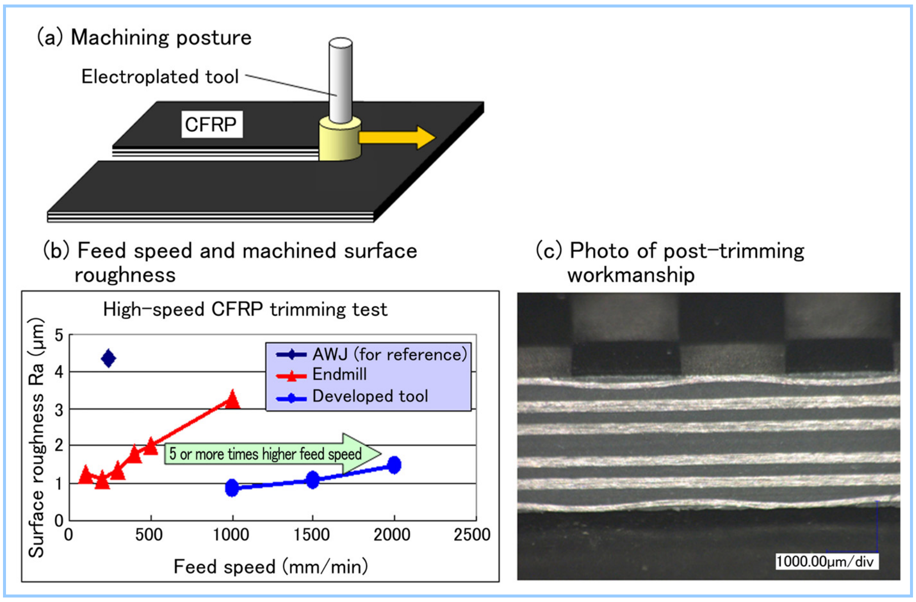

Figure 6 High-speed trimming test of CFRP
The developed tool permitted machining to achieve equivalent surface roughness even at a feed speed five or more times faster than that of an endmill.

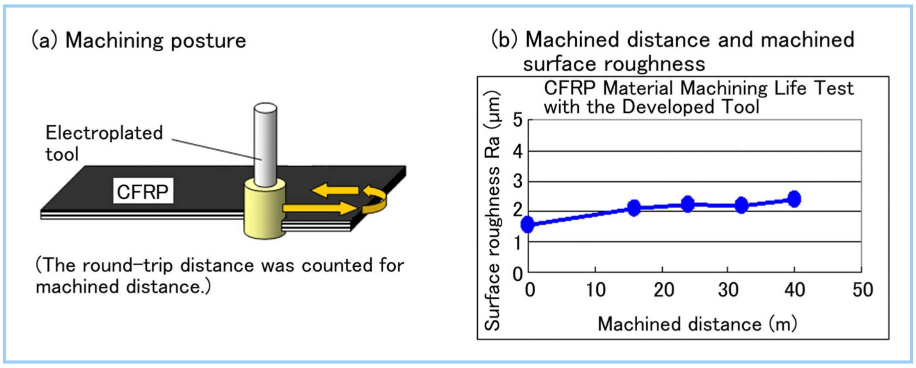

Figure 7 Life test of CFRP trimming
The developed tool had almost no worsening of surface roughness for any longer machined distance, permitting Ra2.4μm to be achieved even after 40m was machined.

3. Higher efficiency of drilling

3.1 Present problems

When drilling CFRP, twist drills are commonly used. But in drilling, since the cutting force is applied in a direction vertical to the material's machined surface, fiber bed delamination and uncut fibers occur on the material's surface, particularly, on the drill exit side, causing a great qualitative problem and hampering the enhancement of machining efficiency (**Figure 8**).

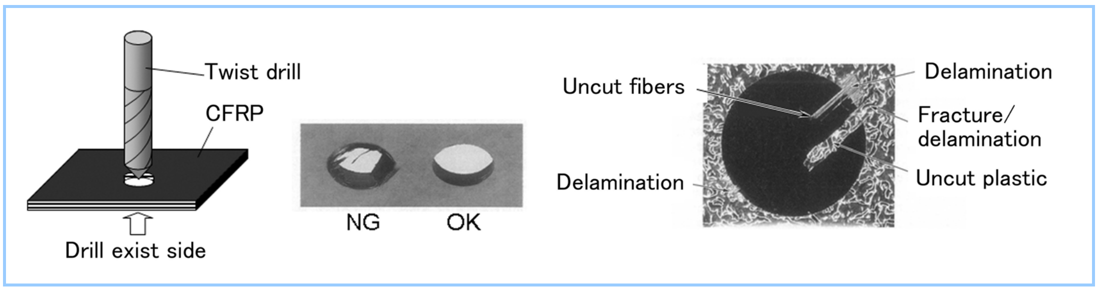

Figure 8 Delamination, uncut fibers accompanying CFRP drilling
Drilling easily causes delamination and other problems on the drill exit side.

3.2 Solution

Delamination and uncut fibers on the drill exit side may presumably be caused by the process where the uppermost fiber bed delaminates outside in the area wider than the drill diameter when the material becomes thin on the verge of drill penetration at the end of the work, and the delamination remains even though machined after complete drill penetration (**Figure 9** (a)). Also in the case of when the point angle of the cutting edge on the outer corner of the drill that eventually finishes the inner surface of a hole is large, the cutting force works heavily in the direction to delaminate fiber beds, inviting an easy-to-break-away condition (Figure 9 (b)).

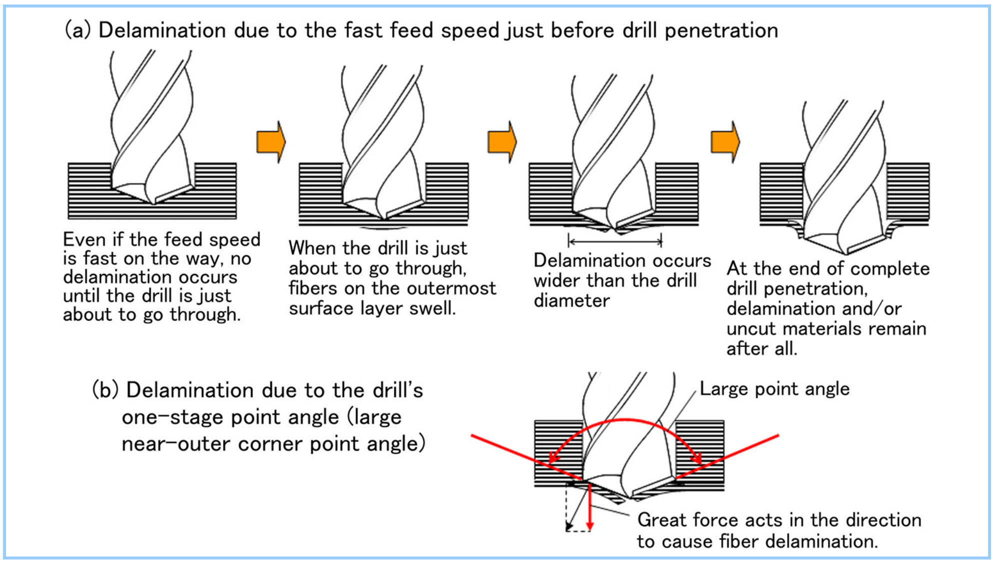

Figure 9 Mechanism of delamination, uncut fibers accompanying CFRP drilling
(a) The high feed speed just before drill penetration causes fibers to break away in an area wider than drill diameter, leaving delamination and uncut fibers even after complete penetration of the drill.
(b) Although the point angle should be large since the drill point needs to be rigid, great force acts in the direction to delaminate fiber beds on the verge of drill penetration if the point angle is large.

Due to the above reasons, the following two measures were taken to improve machining efficiency:

(1) The feed speed just before drill penetration should be made as low as possible to mitigate processing load **(Figure 10** (a)).

(2) The point angle on the drill's outer corner should be made small and in two stages (Figure 10 (b)).

Tool life is also based on whether or not the aforementioned delamination and/or uncut fibers occur.

It is considered that a twist drill, until its life comes to an end, follows the process that [Processing load concentrates on the drill's corner]⇒[Coating on the drill's corner breaks away]⇒[Starting from this, delamination or chipping of the parent material occurs]⇒[The cutting edge becomes blunt]⇒[Delamination occurs on the drill exit side].

Measures were, therefore, taken to extend lifespan by:

(3) Rendering the cutting edge shaped as to cut better and reduce cutting resistance, thereby limiting load concentration on the corner.

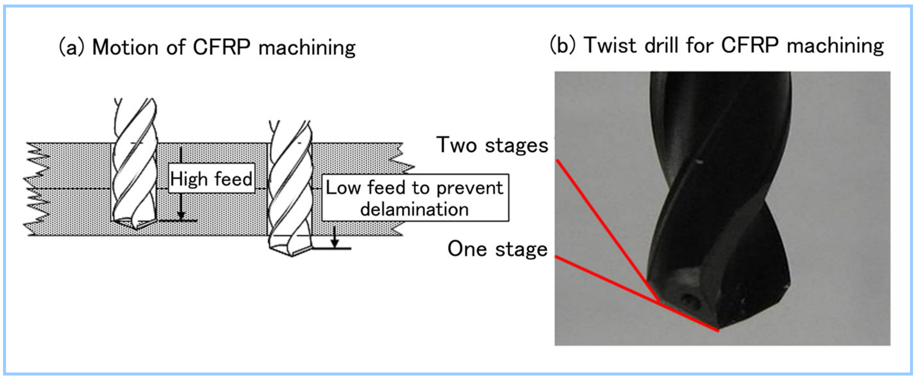

Figure 10 Drilling tool, machining efficiency-related measures
(a) Processing limits on the drill exit side should be kept lower to prevent delamination.
(b) The point angle on the drill's outer corner should be made small and in two stages.

3.3 Machining test result

Also in drilling work, the aforementioned CFRP board was tested for machinability as in the case of trimming. Diamond-coated cement carbide twist drills from several tool makers were used and any presence of delamination or uncut fibers on the drill exit side was examined as the base to determine quality and lifespan.

As a result, with an optimally shaped twist drill, quality could be maintained until machining efficiency became a maximum of 22 times higher than before. It was also ensured that lifespan might well be extended as far as the number of holes that could be bored increased by four or more times from existing drills (**Figure 11**).

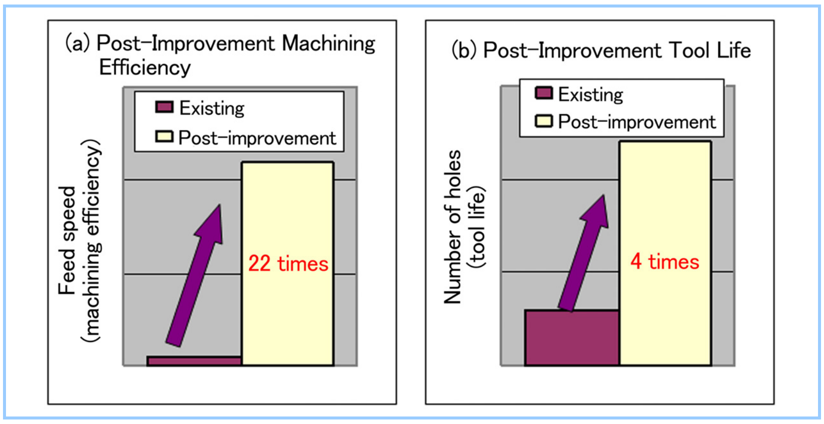

Figure 11 Effect of CFRP drilling improvement
A better tool for and method of drilling could improve (a) machining efficiency a maximum of 22 times and (b) tool life, 4 times.

4. Conclusion

In order that trimming and drilling of CFRP can be performed with high efficiency, we have been engaged in development from both aspects of tools and cutting/grinding methods. Recently obtained results on aircraft materials prove that efficiency can be several to several tens of times higher than conventional rates, and tool life can also exceed existing levels. Toward the future, we would like to further develop machining technologies that can be effectively used in industrial fields other than aircraft and, at the same time, continue to offer optimum machining applications to our customers.