cover story

➤ BY ALAN RICHTER, EDITOR

Hole-some and Clean

Drilling composite materials can be problematic, but solutions are available for making high-quality holes.

Because composite materials are not metallic, they shouldn't be treated like metals when hole-making. Drilling a composite with a tool for cutting metal results in poor hole quality and excessive tool wear. End users need to apply drills specifically designed for tackling the abrasiveness of the material, which has a layered structure that tends to delaminate during drill entry and exit.

Composite Configurations

Composites provide a number of benefits for a variety of parts, such as those for the aerospace, automotive, medical and defense industries. Composites have high strength-to-weight ratios, reducing fuel consumption. They also resist the effects of fatigue and high temperatures, don't corrode and are electrically insulating.

Not all composites are created equal, though. "There's quite a variety and all of them machine differently," said Bob Maxey, vice president of business development for Onsrud Cutter LP.

Kennametal

In a test conducted by Kennametal, the toolmaker's Split-Point Fiber drill produced 300 through-holes in difficult-to-machine carbon fiber-reinforced polymer composite before burrs formed and delamination occurred compared to 150 holes for a PCD-veined drill.

hole-some and clean

The Libertyville, Ill.-based company specializes in making cutting tools for machining composites. "Even within what the aerospace industry utilizes, there are a variety of different composite configurations. Even on some portions of an airplane, there are different types of composites."

According to Kennametal Inc., usage of one type of composite is growing: carbon fiber-reinforced polymer (CFRP) materials. "The big players are using this material for aircraft," said Marcelo Campos, the Latrobe, Pa.-based toolmaker's product manager for holemaking. "We are also seeing a movement to use CFRP for medical parts and by some automakers."

CFRP, or carbon fiber as it is commonly called, consists of strong, abrasive, reinforcing carbon fibers within a relatively soft polymer matrix. For other composites, the matrices include metal and ceramic, and the reinforcements include glass fibers and polymers. Kennametal stated that in CFRP, the polymer can be either thermoplastic or thermosetting, and epoxy, a thermosetting polymer, is the most common.

Carbon fiber/epoxy composite has a tensile strength of 1,500 to 3,000 MPa and a density of 1.5 to 2.0 g/cm^3, compared to steel's tensile strength of 1,200 to 1,500 MPa and density of 8.01 g/cm^3 and aluminum's tensile strength of 600 MPa and density of 2.76 g/cm^3. These favorable properties have increased composites' structural weight percentage from 6 to 7 percent in existing aircraft to 43 percent in next-generation aircraft, according to Kennametal, which defines structural weight as the total weight of wing, fuselage, empennage, propulsion and landing structure. "Aluminum will drop from about 65 percent to 20 percent," Campos said.

Onsrud Cutter

Example of a clean hole entry when drilling a carbon-fiber composite material.

Drilling a composite with a tool for cutting metal results in poor hole quality and excessive tool wear.

Focus on the Fiber

Depending on how the carbon-fiber composite is fabricated, machinability varies. For example, Campos noted that when the fiber structure is like a woven fabric with a crisscrossing pattern, the material is easier to machine than when the fibers are in a unidirectional,

tape-laid pattern, which is more abrasive and more prone to delaminate and have uncut fibers when drilled.

Crisscrossing fibers limit possible delamination and reduce the material's sensitivity to thrust forces, but the tolerances for allowable delamination are tighter. (See table on page 51.) A material with unidirectional fibers requires applying a drill with sharp edges at a feed as low as 0.0015 ipr, Campos said. Kennametal recommends a 400-sfm cutting speed for producing a clean exit hole in difficult-to-machine composites and 450 sfm and a feed up to 0.004 ipr for improved productivity in easier-to-cut materials. When drilling composites that require a thrust force greater than 25 lbs., the speed and feed should be reduced.

Bulk resin-infused composite, another type of carbon-fiber material, exhibits higher thrust forces because of the material's high fiber density. Kennametal recommends reducing the speed and feed if a drill chips prematurely.

Tool Time

As previously noted, effectively drilling composites requires a tool designed for the specific workpiece material and hole quality criteria. Numerous options exist, but finding the one

Tool life up, cost per hole down

Manufacturers often switch to a high-performance cutting tool to increase productivity because the new tool enables higher machining parameters. That wasn't the case for one company when it switched from an uncoated solid-carbide brad-point drill to the new PCD-coated Split-Point Fiber (SPF) drill from Kennametal Inc., Latrobe, Pa., for machining carbon-fiber composite structural parts. "You can only drill the material so fast no matter what type of drill you're using," the manufacturer's CNC supervisor said. "But tool life was the big clincher."

With the brad-point drill, the company was only able to drill 150 to 200 holes through the 0.200"-thick material before tool wear caused unacceptable fiber breakout. Applying an SPF drill enables the company to drill as many as 2,200 holes. That reduced the cost per hole from 26 cents to 5 cents even though the special 3.3mm, 3.6mm, 4.0mm, No. 11, 5.2mm and 6.4mm drills cost from $215 to $315, compared to $15 to $20 for the previous ones.

One of the advantages of the SPF drill is that tool life can be extended by lowering the Z-axis height on the machine once the end of the tool starts to wear. The manufacturer usually drills 0.100" past the part edge, and by lowering the Z height 0.050", clean holes can still be produced even though the tip is worn. "That's how we got 2,200 holes. We dropped the Z height 0.100" more than we typically would," he said. "It didn't matter if we went ½" past the edge of the part with the old drills because once they were dull that was it."

A new SPF drill is applied "once the holes start getting a little sloppy, say off 0.001" or so," he added. Although the holes are pilot holes to be enlarged by another company, they must be clean on both sides and a random inspection of hole diameters on every part is performed using a pin gage.

The drills are run dry on a 5-axis mill and a CMS Aries 5-axis router, which don't have coolant systems, but cold air is blown on the drill to extend tool life.

One remaining challenge, though, is controlling the fine airborne dust produced when drilling the carbon-fiber composite material. At the end of every shift, operators need to interrupt production to vacuum the dust from within the enclosed equipment and wipe the toolholders. "Carbon-fiber dust goes everywhere," he said. "That is a problem and one we haven't quite solved yet." *[Editor's note: See "Larger Issues" article on page S1 in this issue's Machine Tool Supplement for a possible solution.]*

—A. Richter

that provides the best solution requires research. Maxey noted that companies manufacture a variety of drill styles and configurations for machining different materials in the metalworking industry, and any one of them can drill a hole, but one will drill that hole much more efficiently and effectively than another. "The same holds true for composites," he said.

As composites become more prevalent in the aerospace industry and for other applications, millions more holes will be drilled annually.

Starlite Industries offers tools specifically for drilling carbon-fiber composites, including the tapered drill reamer (top) and Dagger drill.

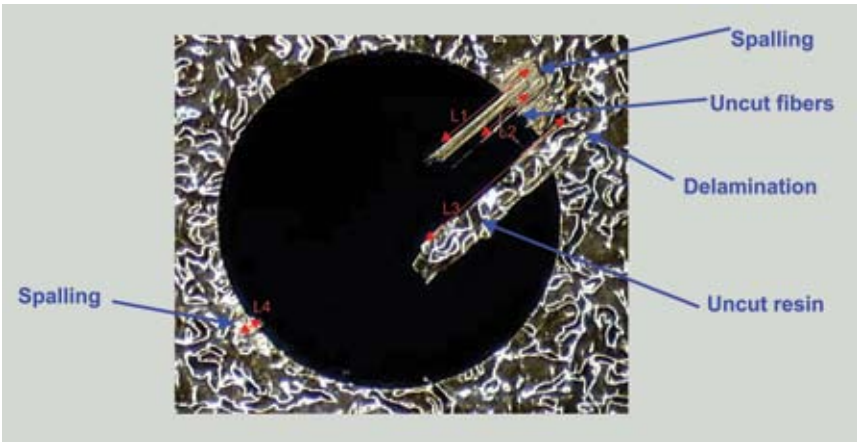
Because of the material's abrasiveness, toolmakers discount using HSS tools. For carbide tools, Maxey recommends a grade with lower cobalt content for abrasion resistance and increased tool hardness to withstand high temperatures in the cut. A tool with less cobalt has reduced toughness, but a high level of toughness isn't that critical when drilling composites because the tool experiences lower cutting forces than when cutting metal.

Although coatings are common in metalcutting drills, that's not necessarily the case for composites. "The coating adds additional cost to the tool. We don't get many requests for coated drills," said Jay Rosenbluth, president of Starlite Industries Inc., a Rosemont, Pa., company that produces diamond and carbide tools for drilling composites. "We find that the quality of the carbide and the quality of the grinding

give the best tool life results."

One of the lines Starlite offers for drilling most laminated composites (other than straight Kevlar) is the tapered drill reamer, which is available in standard sizes for producing holes from 0.0980" to 0.2510" in diameter. The self-centering tools are held to a +0.0005"/-0" tolerance on diameter. "Both the point angle and the reaming-quality design leave a fuzz-free entrance and exit hole when drilling carbon fiber," Rosenbluth said. For Kevlar laminates, the company offers a brad-point drill.

He said the drill reamer produces "the best results," but Starlite also offers the Dagger drill for holemaking in the same diameter range. According to Starlite, the Dagger drill drills holes within a +0"/-0.0005" tolerance in a single operation, can be reground repeatedly without thinning the point and can be reconditioned into shorter lengths and smaller diameters.



Kennametal

The defects that can occur when drilling carbon fiber-reinforced polymer composites include spalling, delamination and uncut fibers and resin.

For larger holes, Rosenbluth recommends diamond holesaws because of the high cost of larger solid-carbide tools.

Diamond Drilling

While not universal, coated drills, such as PCD-coated and PCD-tipped drills, can be effective with composites. To successfully coat a drill with diamond, selecting the appropriate carbide grade is vital, said Doug Mueller, general manager of Diamond Tool Coating, a North Tonawanda, N.Y., toll coating service. "Diamond is mechanically bonded to the substrate,

so we have to get carbide that we can coat," he said.

Mueller indicated that the best carbide for PCD coating has 6 percent cobalt, has an average grain size of 1 to 3 microns and lacks grain-growth inhibitors, such as vanadium or chrome carbide. To enable the PCD to mechanically bond to the carbide, the company removes some cobalt at the surface layer, creating a rough surface where diamond crystals form and grow between the carbide matrix. "The crystals wedge themselves within that matrix and continue to grow until they form a continuous layer on the surface," he said.

The thickness of the resulting coating is 8 to 12 microns. The appropriate thickness depends on the application because drilling composites often requires sharp cutting edges and the thicker the coating, the more the edge rounding.

"The concern is always edge

Workers at Lockheed Martin join two drilled composite components for the F-35 Lightning II stealth fighter.

Lockheed Martin

rounding because when we remove some cobalt in our pretreatment process, carbide also falls away and then we're putting a rather thick coating on that cutting edge," Mueller said. "The end result is about 20 microns of edge rounding."

Because the diamond coating creates a radius on the cutting edge, Onsrud's Maxey noted that a tool's edge prep shouldn't be more than 0.0005". "The key is to have as keen a cutting edge as possible, so the carbon fibers are cleanly sheared and not torn," he said.

Many end users may want to avoid the cost of a PCD-coated drill, but Mueller maintains that PCD coating is a wise tooling investment. "With an uncoated tool, they can't drill an acceptable hole that has the quality they're looking for," he said. "With a diamond coating, they're able to do that and do it 10 times as long."

Combination Cutter

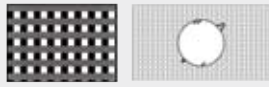
Not just any PCD-coated drill is effective for cutting composites, according to Kennametal's Campos. Like in a machining system, various elements of a drill function in concert to achieve success. With that in mind, Kennametal introduced its Split-Point Fiber (SPF) drill that has a combination of substrate, geometry and coating designed to machine CFRP composites with, reportedly, a substantially lower

Keywords

composites:
Materials composed of different elements, with one element normally embedded in another, held together by a compatible binder.

drilling:
Operation in which a rotating tool is used to create a round hole in a workpiece. Drilling is normally the first step in machining operations such as boring, reaming, tapping, counterboring, countersinking and spotfacing.

—CTE Metalworking Glossary

CFRP material	Comments	Recommendations
Unidirectional tape laid 	Large delamination possible.	Low feed for good-quality exit hole.
	Prone to uncut fibers.	Sharp cutting edges required to produce a clean hole.
	More abrasive.	Low drilling thrust required.
Fabric weave laid 	Easier to machine.	Start with higher feed to improve tool life and speed.
	Breakouts not as severe.	
	Possible delamination limited by crisscrossing fibers.	
	Less sensitive to thrust.	
	Allowable delamination specs are tighter.	

Kennametal

cutting force than other PCD drills while reducing the cost per hole by 50 percent.

"Because of the high cutting force, there's a lot of delamination when you use, let's say, normal PCD drills," Campos said. "It took more than a year trying different kinds of geometries and coatings to find the best combination."

The drill's solid-carbide substrate is coated with a smooth CVD multilayer diamond coating. The tool's low point angle reduces axial forces to minimize or eliminate delamination, and special point thinning increases the drill's centering capability and reduces thrust to improve hole quality, according to Kennametal.

In one Kennametal test pitting an SPF drill against a PCD-veined drill, the SPF tool drilled 300 ¼"-dia. through-holes in 0.3"-thick difficult-to-machine CFRP plate before burrs formed and delamination occurred, compared to 150 holes for the other drill. The tools were run at a 400-sfm cutting speed and a 0.0015-ipr feed without coolant on a Makino A55 horizontal machining center.

The tool also has a shank with an H6 tolerance to minimize TIR. "It needs to have low runout," Campos said. "We suggest using this drill in a hydraulic chuck or shrink-fit holder, or if you use a collet, it needs to be a high-precision collet." In addition, the SPF drill is for CNC machine applications. "It should not be used in hand tools or other manual devices because they're not rigid enough to support the drill," he noted.

Chips Away

Typically, the so-called chips

The following companies contributed to this report:

Diamond Tool Coating
(716) 693-5050
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Onsrud Cutter LP
(847) 362-1560
www.onsrud.com

Starlite Industries Inc.
(800) 727-1022
www.starliteindustries.com

Toray Composites (America) Inc.
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generated when drilling composites are a dry dust or sand. But, depending on the material's density, the chip can be small and granular, noted Onsrud's Maxey. "The variety of different types of materials, like anything else, generates different types of swarf," he said.

Maxey added that the key to successful drilling is to form the chip, accommodate the chip and evacuate the chip. To assist in evacuating the chips and allowing the tool to operate at a lower temperature, shop air is often directed around the tool.

Flood coolant is an option but generally not required or preferred, in part, because composites have a tendency to absorb coolant. However, that occurs only at the surface, said Earl Benton, director of sales and marketing for composites supplier Toray Composites (America) Inc., Tacoma, Wash. "It's not like a sponge," he added. "Coolant isn't carried deep into the laminate. Unless the laminate is exposed to cutting fluids over long periods, pickup is [inconsequential]."

When coolant is applied, though, it's generally done using minimum-quantity lubrication techniques, such as through-tool misting. "Typically, people thought through-coolant tools would not be commonplace for these types of applications," said Maxey, "but more and more in the production mode, manufacturers are doing MQL or air through a coolant-fed drill."

As composites become more prevalent in the aerospace industry and for other applications, millions more holes will be drilled annually. "We are really moving forward in using this lightweight material," said Campos. "That should result in a big, big change in the metalworking industry." △

Onsrud Cutter

Diamond Tool Coating coated this composite-cutting drill from Onsrud Cutter with thin-film diamond.

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