MARCH 2004 / VOLUME 56 / NUMBER 3

focus: making aerospace parts

▶BY GREG LANDGRAF, ASSOCIATE EDITOR

COMPOSITE DREAMING

Graphite-epoxy composites are challenging—but not impossible—to machine.

Boeing

Above: The forthcoming Boeing 7E7, shown in an artist's rendering, will be the first commercial airplane with a majority of its structure made from composite materials.

Composite materials have reached a major milestone in the aerospace industry. The Boeing Co.'s recently approved 7E7 Dreamliner, with its first passenger flight scheduled for 2008, will be the first commercial airplane with a majority of its structure made from composite materials.

Graphite-epoxy will be the primary composite used on the 7E7. It has already proven itself in airplane service, but it has also proven to be a difficult-to-machine material.

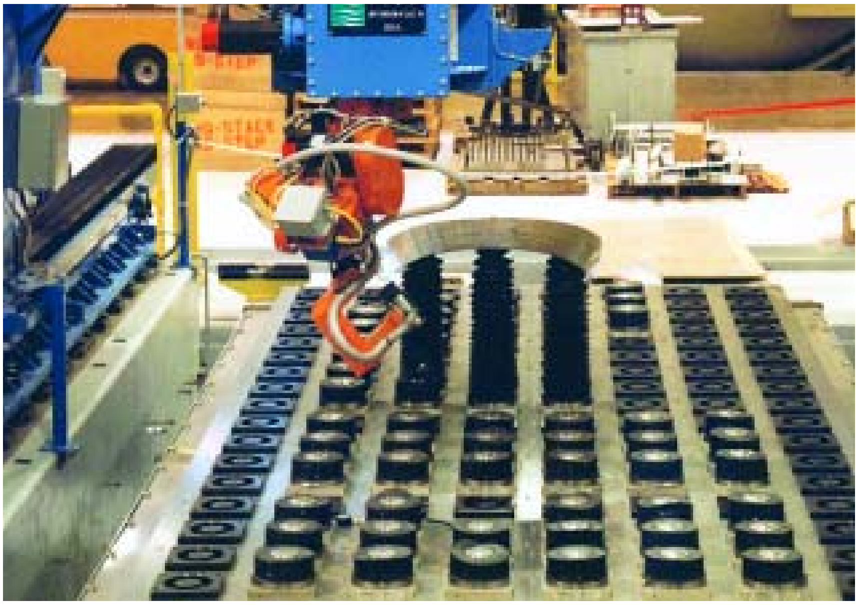
As the name implies, graphite-epoxy composite is a two-component system. The graphite fiber provides strength and stiffness, while the epoxy holds the fiber in place.

"The difficulty is that the two materials have vastly different qualities," said Brent Strong, professor of manufacturing engineering technology at Brigham Young University, Provo, Utah, and director of the school's Advanced Composites Manufacturing and Engineering Center.

The plastic component cuts fairly easily, Strong said, but the fibers are stiff and often tough. Tools do not react well to the change between materials with such different properties.

"The material is so abrasive, it wears tools quickly," said Rich Garrick, president of Spanish Fork, Utah, toolmaker Precorp Inc. Graphite fiber is prone to breakout, Garrick said, and worn tools exacerbate the problem. Jagged fibers on part edges can give handlers nasty, difficult-to-remove splinters, although gloves solve the problem.

Even the easier-to-cut plastic component is a challenge, because heat generated during machining can melt the resin, destroying the part. And aerospace parts can be big and expensive, such as a $300,000 wing section. "When you destroy one of those," Mark Saberton, chief engineer for abrasive waterjet machine manufacturer, Flow International Corp., Kent, Wash., deadpanned, "the customer gets moody."



Flow International

Proponents say AWJ machining of graphite-epoxy composites produces clean edges and simplifies collection of the abrasive graphite dust.

Successful Machining

Much of the processing of graphite-epoxy for aerospace parts involves laying up one ply at a time, and molding the plies to shape in a vacuum bag. "An autoclave provides high pressure to the laminate to cure the layup," explained Earl Benton, director of sales for composite supplier Toray Composites (America) Inc., Tacoma, Wash.

The traditional machining begins after curing. Parts typically require trimming and drilling.

"When you cut composites, you give up using any type of steel [tool]," said BYU's Strong. "Carbide is OK, but PCD is best by far. PCD has the hardness to go through the fiber, and it goes through plastic like butter."

Precorp's Garrick said a diamond tool will last 50 to 100 times longer than carbide when cutting composites.

To remove heat from the cut and prevent the plastic component from melting, Strong recommends a fast spindle speed and a low feed rate.

Loyal Peterman, president of cutting tool and grinding wheel maker Abrasive Technology Inc., Lewis Center, Ohio, agreed. He noted that managing the feed is especially important because the shape of many aerospace parts makes them difficult to back up. Backing up parts that are being drilled is a common method to prevent breakout.

Dan Jarvi, manager of technical sales for aerospace equipment, Ingersoll Machine Tools Inc., Rockford, Ill., concurred. He suggests feeds of 30 to 100 ipm, depending on the application. "Thicker materials with more backing may have higher limits," he said.

Jarvi said spindle speeds typically range from 18,000 to 36,000 rpm. Due to the high speed, he said toolholders need to be balanced to prevent damage to the spindle or tool.

Peterman said a fast cutting rate is necessary to prevent heat build-up when grinding. "Below 2,000 sfm you can get problems," he said, noting that the ideal speed is about 10,000 sfm.

Both Precorp and Abrasive Technology manufacture veined drills, in which PCD is inserted into a slot in the drill blank. "The diamond is fluted the same way a drill would be," Peterman said. "It's an integral part of the drill." He added that because of this, veined drills can maintain a tolerance of 0.0001".

Garrick recommends applying drills with positive rake angles to reduce cutting forces and to minimize or eliminate problems with fiber breakout. Appropriate point geometries also minimize breakout problems. He said that Precorp's most popular tool is the 84 series, which has an 84° point and a 118° blunt tip. "The long point angle reduces forces and cuts all uncut fibers," he said.

Peterman said a veined drill can be manufactured with any tip angle. His company's most commonly used geometries are a 120° tip with a 118° to 120° point, a 60° included point to reduce breakout, and a double-point tool with a 120° point and a 60° included point, which also minimizes breakout.

Machinery Issues

Graphite fiber turns to powder when cut, which is both a positive and a negative for keeping the machining environment clean. Removing the powder from the cutting zone is not difficult, but collecting and controlling the dust is absolutely crucial. "It's a health problem," warned Flow International's Saberton. "It can cause a black lung-type disease like miners get." The powder is electrically conductive and can destroy electronics, he added.

From a machinery standpoint, collecting the abrasive graphite dust is the

The following organizations contributed to this report:

Abrasive Technology Inc.
(740) 548-4100
www.abrasive-tech.com

Brigham Young University's Advanced Composites Manufacturing and Engineering Center
(801) 422-7878
http://research.et.byu.edu/acme

Flow International Corp.
(253) 850-3500
www.flowcorp.com

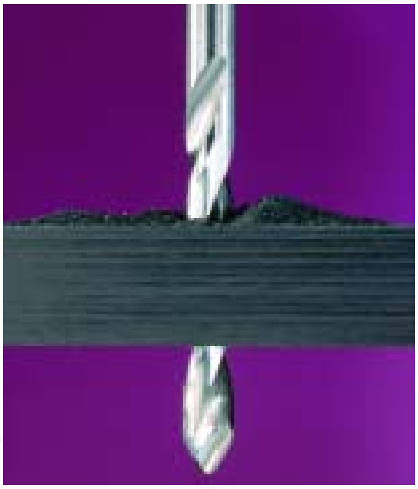
GPM Technologies Ltd.
(630) 208-1300
www.gpmtechnologies.com

Ingersoll Machine Tools Inc.
(815) 987-6000
www.ingersoll.com

Precorp Inc.
(801) 798-5425
www.precorp.net

Toray Composites (America) Inc.
(253) 846-1777
www.torayusa.com/tca

most significant challenge. “Good dust collection is one of the more difficult aspects of CNC machining, especially 5-axis machining. Putting a dust head around a 5-axis machine is very difficult,” said Bill Oberg, vice president of GPM Aerospace Products. GPM Aerospace is a division of West Chicago, Ill.-based GPM Technologies Ltd., which distributes Shoda machine tools. Oberg recommends that customers enclose the machine in a downdraft or updraft spray booth to keep the environment clean.



Precorp

The abrasive graphite fibers in a graphite-epoxy composite necessitate the use of diamond tools to achieve acceptable tool life.

Several machine systems need special care. Oberg said Shoda encloses ways in a full stainless steel cover and pressurizes the enclosure to keep debris out. He also suggests a full bellow cover on the bridge and over the ballscrew and way bearings, as well as a pressurized lubrication system.

Ingersoll Machine Tool’s Jarvi agreed with the need to enclose way systems, particularly when machining dry. Normally, however, he said composites are machined wet to improve tool life—although fluids present their own difficulties.

Oil-based fluids can seep into the layers of the composite material, so the fluid used is generally water with a rust inhibitor. In addition, “you need a finer filter [than when cutting aluminum], because the graphite dust is finer,” he said. Jarvi estimated that composites require a filter 20 percent finer than aluminum. “You may need to allow more settling time for the fines, because the carbon is lighter than aluminum,” he added.

Jarvi said that another way to improve tool life when trimming a part’s perimeter is to move the cutter axially to use the entire cutting edge. It’s a simple compensation to make in a 3-axis machine program, he said, and worthwhile because the composite material is so tough on tools. “You probably wouldn’t think of it in machining aluminum,” Jarvi said.

Abrasive Technology

Like cutting, grinding of graphite-epoxy composite requires diamond tooling and high speeds.

Not the Same Grind

A representative of manufacturing R&D for a major aerospace manufacturer said his company uses brazed diamond abrasive for grinding composites for both military and commercial operations. (Due to the proprietary nature of the work, he requested that his name and the company name not be used.)

Abrasive routers are applied for trimming edges and making holes on very large machines. The largest routing machine is a 90' long × 20' wide, gantry-style machine. All machining is done with flood coolant to control dust. “If the cutter is moving fast enough, the vacuum can’t keep up,” the representative said. “Nothing escapes the fluid.”

The spindle speed is 20,000 to 40,000 rpm. Feed rates depend on material thickness.

The aerospace manufacturer uses a multigrit-diamond system, one for roughing and a finer grit for finishing. The representative said wear is a relatively minor problem. “Diamond grit doesn’t wear conventionally,” he said. “It doesn’t really dull, it’s more like it falls out,” making it clear when replacement is needed.

Edges that are too rough to grind economically are pretrimmed on a bandsaw, usually mounted with a diamond-grit blade. The company also does some holemaking with PCD drills.

Nontraditional Machining

As graphite-epoxy is not a traditional material, it’s not surprising that there are nontraditional methods used to cut it as well. One of those is abrasive waterjet machining.

AWJ machining cuts with a high-pressure stream of water. Flow International’s Saberton said his company’s machines send water at 60,000 psi through a diamond orifice that’s about 0.010" in diameter.

The water travels through a mixing tube and to the workpiece at three times

Composite use growing

Composites are attractive materials for commercial aerospace applications because of their high strength and low weight. Chicago-based Boeing promises a 20 percent fuel savings for its 7E7 and improved passenger comfort because a stronger structure will allow higher humidity in the cabin.

Because of these attractive qualities, composite usage in airplanes has been growing for some time. Toulouse, France-based Airbus Industrie’s A380 model, which is scheduled to enter passenger service in 2006, will be about 40 percent composites. Earlier models like Boeing’s 777 and its next-generation 737 series each contain smaller quantities of composites.

—G. Landgraf

the speed of sound, creating a vacuum that draws abrasive into the stream.

As with other cutting methods, waste must be recaptured after cutting. Saberton said a catcher cup opposite the nozzle collects the mix of water, garnet, resin and graphite that results from AWJ machining. The mixture is sent to a separator to remove the liquid from the solids. "There's not much waste," he added.

Saberton said that unlike other cutting methods, fiber pullout is not a problem with AWJ. "Many people associate machining composites with machining metal," he said. "It's not—you don't shear or peel it away, you remove it by fracture."

Saberton likened the fracture mechanism to how wood breaks when bent: Slowly bent wood has a jagged edge when it breaks, while wood that's snapped quickly breaks clean. Because the water jet is traveling so quickly, he concluded, the carbon fibers fracture cleanly as well.

Glamorous Potential

Aerospace is a relatively small, but growing, market for composites. BYU's Strong estimated that fewer than 10 percent of all composites are used for aerospace applications.

The aerospace industry also takes on an importance greater than its relative size. "The value of aerospace components is high," Strong said. "Aerospace has glamour. Most of the technologies for working with composites are developed in aerospace, and then they migrate."

CUTTING TOOL ENGINEERING Magazine is protected under U.S. and international copyright laws.
Before reproducing anything from this Web site, call the Copyright Clearance Center Inc. at (978) 750-8400.