# Machining Composites

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A composite is generally a material made from a matrix and reinforcing material with the reinforcing much stronger than the matrix. These materials are lighter and stronger than conventional material with the additional advantage that the user can tailor the strength and form to meet specific requirements. In experiments, researchers work with a wide spectrum of matrices and reinforcing material. However, as far as practical use is concerned, those based on an organic matrix are most commonly used with products ranging from lawn chairs to aircraft wing spars. In distant second place are the metal matrix composite (MMC) materials, chiefly based on aluminum.

Reinforcement may be directional or dispersed. Manufacturers position directional reinforcing material to give strength to the composite in specific axes. The other philosophy is to position the reinforcing material randomly to give a general increase in strength.

Organic matrix composites generally use fibers of carbon, glass or aramid with matrices of polymer or epoxy resin. They turn up most often in the aerospace industry, according to research by Sandvik Co. (Fairlawn, NJ). The light weight and strength are major benefits and offset manufacturing complications.

Most machining work with organic composites involves trimming or drilling because the part is normally formed to near-net shape. You can make the holes during manufacture, but such holes can deform the reinforcements and weaken the part.

Composites can be cut using lasers, water jet, electron beam, and EDM. For this article, however, only conventional machining techniques are considered (milling, drilling, and turning).

A conventional machine tool or grinder will work with composites, provided it has the necessary rigidity. However, tool configuration and feeds and speeds are different.

The make up of a composite varies through its cross section. Matrices have different properties than the reinforcement. Also the material is in layers, the wrong pressure can cause delaminations, and the most potentially damaging machining situation is to tear, rather than cut, the reinforcements.

Basic Machining. Machining composite parts differs from machining conventional materials.

* Near-Net Shape. First, the part is often made to near net shape through casting, pultrusion, or some other process. The machining, therefore, is a matter of trimming or improving the surface, rarely cutting from a solid mass.

Because composite parts are essentially formed to shape, say Sandvik researchers, some argue that progress in composite part manufacturer will eventually eliminate the need for any finishing. For the foreseeable future, however, the traditional finishing operations will be needed.

* Nonuniform material. The matrix which holds the reinforcing fibers has one set of properties and the fibers another. In addition, fiber orientation adds even more variety to the material. So the tool must be able to cut through a variety of radically different materials.

* Cutting speed. Because of the abrasiveness of composites, it may be necessary to mitigate wear by cutting very slowly. This minimizes heat and disturbance of the reinforcing fibers. Certain tool-tip coating designs unique to composites, chiefly versions of diamond, are available for cutting composites. Brittle materials cause cracks if cut too fast and local stresses can exist in layered material. These characteristics also force slow cutting, which is good for the product but bad for production.

In cases where the composite is attached to a metal element--as in many aerospace applications--it is necessary to allow for chips. These materials may require three tools to make a hole: a composite drill, a metal drill, and a reamer.

The Aircraft Market. The aerospace industry provides the greatest number of composite successes, chiefly because it can absorb the high cost of composite manufacture. Mike Shemenski, a Sandvik product specialist, notes that composites make up about 10% by weight of a typical civilian aircraft and 30% by weight of military planes, so there is plenty of machining to carry out.

"Tool life and component quality depend on the ratio of fibers to resin," according to Shemenski. The more fibers, the more abrasive material and the higher the risk of delamination. And not all fibers behave the same way. For example, while aramid fiber is less abrasive, it acts like soft bread and pushes away from the cutting tool. A special tool geometry is necessary to cut cleanly and prevent delamination and fuzz. It's important that fibers be cut cleanly. Dull tool edges break the fibers and cause delamination.

Cemented carbide is of ultrafine grain size, which maintains a shaper cutting edge longer. This sharpness reduces tool pressure, which in turn reduces delamination. For aramid fibers, a design called the Phi drill first lightly preloads the fibers, then cuts them cleanly and hooks them out of the work area. High-speed steels last only a few holes in these operations, while tungsten carbide does much better.

When machining composites, too low a cutting speed causes rubbing, overheating, and resin melting. Too high a speed may cause fiber breakout and delamination. Heat absorption becomes an issue. With a conventional metal part, typically 75% of the heat goes out with the chips. When cutting composites, about 50% is absorbed by the tools.

If you cut carbon fiber, tool life is directly proportional to cutting speed. The most economic tool is cemented carbide or polycrystalline-tipped tools.

Cemented carbide operates at up to 30 m/min for drilling and 300 m/m for milling in aramid fibers, according to Sandvik's Shemenski.

Extremely abrasive carbon and glass-fiber-reinforced composites need high wear resistant cutting tools such as cemented carbide and PCD-tipped tools. Carbon fiber is more than 1000 times more abrasive than a medium-carbon steel.

Three general rules to follow when setting up for composite machining:

* Look out for heat buildup.

* Determine the abrasive nature of the material.

* Avoid delamination.

Specialized Tooling. According to Sandvik, a drill entering a composite can act like a corkscrew and pull up layers of material. Spiral-point and split-point bits do less damage.

Bits get a different result depending on whether they are cutting perpendicular or parallel to fibers. When considering bit design, stressing the rake angle cuts horizontal forces and stressing the relief angle decreases vertical force.

Special Bit. A specialty bit designed for composites comes from StorageTec Composites Engineering and Manufacturing (Louisville, CO). Made on a dagger-like shaft, the bit uses two grades of diamond grit: a coarse diamond on the tip then fine on the shaft. It's a combination drill and reamer. Because the bit produces a grinding not cutting action, feed is slow, about an inch per minute. Each bit can make about 2000 holes. The company offers a similar router.

Other specialized machine tools, such at those made by the American GFM Corp. (Chesapeake, VA) are specifically designed to cut epoxy composites. They use ultrasound to cut in three or five axes. Cutting can be flat or sculpted, no routing is needed, and the cutting generates no dust.

There is also a CAD package available to define surfaces and help give a clean cut. It has the necessary stiffness for acceleration and deceleration, and its design is practical for those who have short production runs.

Navy Plane Parts. The GLCC, formerly the Great Lakes Composites Consortium, is looking at a number of composite projects, chiefly for the US Navy. Its goals are to make better use of the advantages of composites in aircraft. One of the tough problems to solve is breakout; when a drill cuts through a composite part, there's a tendency for the shell to shatter as the cutter exits.

Big and Small Parts. "When we use conventional machine tools to mill, drill, route, or saw carbon-fiber reinforced epoxy composites, we control the speeds and feeds. These rates are usually slower than conventional. We use a variety of carbide, diamond grit, and polycrystalline diamond cutters," says Dave Ledbetter, manager R&D for Lockheed Martin Aeronautical Systems Co. (Marietta, GA). "The big concerns are avoiding breakout and delamination. When composites are laminated with metals like titanium, a drill must pass through both and the speeds and feeds must change during the process. Our composite parts range in size from hand-held to beams over 25' (7.6-m) long. Sometimes they are large integrated structures, others are assembled from multiple components. Most are for the latest revisions of the C-130, known as the C-130J, and the new F-22.

"We looked at MMC briefly, for the vertical stabilizer for a new generic fighter. Initially, the material looked good because of strength and weight. We tried both continuous and discontinuous silicon carbide fiber, but we could not overcome the high cost."

Plastic Telephone Poles. Ebert Composites Corp. (San Diego) is making transmission towers from composites instead of wood. Indications are they will be easier to install, last longer, and save $700 in maintenance costs over the tower's life. Using a National Institute of Standards and Technology grant, the company designed a five-axis machine that links to a pultrusion system. A traveling gantry design, it has a 40,000-rpm spindle and uses a diamond-coated tool. Water removes debris.

The system makes the towers in segments with each segment weighing 90 lb (22 kg). In the process, reinforcing fibers impregnated with resin are pulled through a heated die. Completed parts snap together to make the finished 25-m-tall pole. The pultrusion system mated with a CNC workstation does the detailing of the parts and the computer stores designs for different parts.

The operation requires some drilling for attachments and machining of contours. Main considerations are the right tool surface, proper cooling, and proper tip speed for rapid material removal.

Working with Metal. MMCs are an idea whose time has not yet come. Aluminum MMCs seem to have the greatest potential now, particularly in the automotive area. The material can be drilled or milled with the ratio of fiber to matrix being important to the cutting action. The current goal is brake rotors, a job for which they would be ideal because they are light in weight, cool quickly, and are very strong.

Two of the MMCs making some progress are Duralcan from Alcan (Montreal, Quebec, Canada) and Lanxide (Newark, DE). Both have been rigorously tested and both offer a number of advantages including strength, light weight, and high conductivity. In both cases, however, raw material manufacturing cost remains a major barrier. The most likely near-term volume application is brake rotors. This application has seen some success in lower volume cases such as the Daimler-Chrysler Prowler, but has yet to be widely accepted.

GE Superabrasives Worthington, OH has been exploring the machining situation with Duralcan. Their researchers find that their GE 1500 Compax coarse-grain diamond tool achieves the optimal performance for turning and milling. This grade of PCD provides the best combination of abrasion and impact resistance. Experiments show that tool life depends on reinforcement volume, type of ceramic particles, aluminum matrix alloy, and heat-treat condition.

PCD materials were the most effective. Conventional tool materials lasted only a matter of minutes because the silicon-carbide reinforcing particles rapidly wear the tool. In one test, sandcast Duralcan with 20% by volume silicon carbide machined well with a 1500 Compax tool at speeds of 400 m/min, feeds of 0.31-0.36 mm/rev, and DOC of 2 mm for roughing and 0.4 mm for finishing. GE Superabrasives typically recommends slower speeds in conjunction with higher feed rates to achieve optimal PCD cutting tool performance in abrasive MCC materials.

Kennametal (Latrobe, PA) has worked with these materials, especially the aluminum-matrix Duralcan materials with dispersion-strengthened reinforcing. Manager of Superhard Technology Dr. Ed Oles sees the MMCs as a potential major market in the auto industry. When machining, not much needs to be changed in the machine tool, except to improve stiffness. The main difference involves the use of diamond cutting tools. Kennametal is building a quantity of brake rotors for evaluation. They are also looking at some titanium-based MMC materials.

The Word from Oak Ridge. "We have machined several MMC samples under proprietary contracts using a variety of cutting tools including diamonds and ceramics," says research engineer Harold Fell from the Y12 operation at Oak Ridge (Oak Ridge, TN). "After trying a variety of head configurations, we found that whisker-reinforced ceramics did the best job. Diamonds were too delicate to use. They were done after five passes, while the reinforced ceramic lasted for 60.

"The reinforced ceramic ate that composite material alive, although it was like trying to cut a grinding wheel. Aluminum in the material clogs the wheel while the abrasive reinforcement makes it too abrasive for a single-point tool. Unfortunately, the project is on hold for now because of the costs."

Lotus Uses It. One of the first commercial uses of MMCs was on the British Lotus. Brake rotors made from reinforced aluminum have been on that car since 1996 and they are still being used. Provided by Lanxide Corp. the material is made by an infusion process. First a near-net-shape part is made from the reinforcing material, either silicon carbide or aluminum oxide and placed in a container. Then aluminum floods the form in a non-pressurized operation and infuses the reinforcement creating the part. The manufacturer machines the part using polycrystalline-diamond tools. "Cost has been a major limiting factor," says senior vice president, Jonathan Hinton. "However, we have been able to cut costs of the material and reduce the cost of manufacture. We did this by selectively placing the reinforcing so there is no need to cut the unreinforced sections with diamond.

"If the California CAFÉ regulations are applied to trucks, we may see a greater emphasis on fuel economy and light weight in vehicle design. This emphasis, in turn, may lead to greater interest in Lanxide."

ADDED MATERIAL

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One of the few practical uses of aluminum MMC is in the brake rotors of the Lotus Elise. The material is from Lanxide.

GE Superabrasives researchers have extensively evaluated the problems involved in machining Duralcan, one of the aluminum-based MMCs.

Pultrusion operation combined with a machine tool are used to make elements for a new type of composite telephone pole.

**WANT MORE INFORMATION?**

SME offers a conference related to composites: Composites '99 Manufacturing and Tooling Conference in Anaheim, CA Feb 8-10. Related publications include: Handbook of Plastics, Elastomers, and Composites, C. Harper; Composites in Manufacturing, A. Strong; and Introduction to Composite Technology, S. Luce.

There are also two videos: Tooling for Composites, and Composites in Manufacturing. For more details, call Customer Service at 800-733-4SME 8 am-5 pm Eastern time, Monday through Friday. For more information on the products of these companies, circle the appropriate number on the reader service card.

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