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▶ BY BILL KENNEDY, CONTRIBUTING EDITOR

Black Art

Advice on milling graphite electrodes.

All photos: B. Kennedy

The delicate ribs of a graphite electrode are machined at Keystone Tool & Machine. (What do you think the electrode was used for? The answer is at the bottom of the next page.—Ed.)

Graphite behaves differently than most other materials when cut. It forms black, dust-like particles—not chips. As a result, little heat or friction that can damage tools is generated in the cutting zone.

But that doesn't mean endmills and other cutting tools last indefinitely when applied to graphite. Graphite's highly abrasive nature causes tools to wear excessively, said Tim Curtis, mold specialist at Keystone Tool & Machine Inc., Carlisle, Pa.

Curtis, whose shop produces graphite electrodes for sinker electrical discharge machines, makes molds and builds custom machines, compared the machining of graphite to steel. "It's not so much that graphite is hard*, it's that it's brittle and abrasive. It wears endmills down. Typically, we use a carbide tool with a diamond coating. The diamond is strictly for wear resistance."

Put a Load On

Graphite's abrasiveness requires those cutting it to think counter-intuitively. Namely, they must increase the chip load to reduce tool wear. If the chip load per tooth is too low, the tool will burnish rather than cut the graphite.

Sp[3] Inc., a supplier of diamond-coated and polycrystalline-diamond tools, reports that tool wear accelerates rapidly when milling graphite at light

**Graphite's hardness is usually measured with a rebound-type testing device called a Shore Scleroscope. The ultrafine (1µm to 5µm) and angstrofine (<1µm) classes have hardnesses in the range of 76 to 87 HS, which converts to 57 to 63 HRC.*

Tools of the trade

Keystone Tool & Machine generally machines electrodes from EDM-3, an ultrafine class produced by Poco Graphite. There are four other major classes: medium, fine, superfine and angstrofine.

The average particle size of medium-class graphite exceeds 20µm, making it unsuitable for EDMing. The other classes' particles range from 11µm-20µm (fine) to <1µm (angstrofine).

Keystone applies diamond-coated endmills manufactured by The Leading Edge, Lake Orion, Mich. Their diameters range from 0.005" to 1.000". Keystone's mold specialist, Tim Curtis, called the 0.031"- and 0.062"-dia. mills his "workhorses."

These tiny tools produce the electrodes' delicate features. Molds for plastic parts often feature thin ribs that strengthen the final product. Keystone has machined ribs in electrodes that were as thin as 0.002" and ¼" deep.

The smaller and more consistent the graphite's particle size, the harder it is and the greater its flexural strength. Sufficient flexural strength enables an electrode with thin sections to withstand the forces of flushing, and high hardness allows it to keep a sharp edge longer while cutting.

Poco Graphite recommends using graphite with a flexural strength of 10,000 psi or better—ultrafine or angstrofine—for thin-rib applications. And because EDMing produces a mirror image of the electrode in the workpiece, a finer-grain graphite produces parts with finer finishes.

Generally, the finer and more consistent the grain size, the more expensive the graphite.

—B. Kennedy

Dust-busting required when machining graphite

The tiny particles and dust produced when machining graphite are more than a nuisance. They can permeate a shop, and their abrasive nature will wear machine components and scales. Graphite suppliers recommend that shops that cut the material install a vacuum dust-control system.

Graphite is usually machined dry, but Poco Graphite Application Specialist Jerry Mercer said some shops without dust-control systems presoak electrodes in dielectric fluid, or use dielectric fluid as a coolant, to control graphite dust.

—B. Kennedy

chip loads, but it will stabilize as the chip load increases.

Poco Graphite Inc., Decatur, Texas, recommends a roughing-cut chip load of 0.003" to 0.005" feed per tooth and a finishing chip load of 0.001" to 0.002" fpt.

To determine the spindle speed necessary to generate a certain chip load, Poco provided this equation:

$$\text{rpm} = \frac{\text{ipm}}{\text{No. of flutes x fpt (chip load)}}$$

Regarding surface speeds for milling with specific tool materials, Poco recommends 500 to 750 sfm for carbide tools and 500 to 2,000 sfm for diamond tooling. The equation for surface footage is:

$$\text{sfm} = \frac{\text{rpm x cutter dia. (in inches) x 3.142}}{12}$$

When calculating the rpm needed to produce a certain chip load, Sp^3, Mountain View, Calif., says to consider the actual path the cutting tool will take. For example, when the tool is entering a cut, the machine tool must have sufficient time to accelerate to the desired speed. Furthermore, the machine may never reach the spindle speed necessary to generate a sufficient fpt if complex part contours dictate a cutter path that requires reducing the speed.

Brakes on Breakout

The brittle nature of graphite can lead to chipping or breakout when the tool exits the cut, as occurs when milling cast iron. There are a number of ways to counteract such problems.

One solution is to back-mill, wherein the cutter briefly enters the workpiece at one end of the cut, then completes the pass from the other direction. Adopting this strategy prevents the tool from ever exiting the edge of the work while it is removing material. The machine tool also can be programmed to reduce the feed rate at the end of the cut, but that will reduce productivity proportionately.

Sp^3 suggests limiting the depth of cut to one-third, or less, of the endmill's diameter to minimize breakage of material at the end of a cut. The toolmaker also recommends applying square endmills with a small corner radius (0.010" to 0.015") to strengthen the cutting edge and provide extra durability.

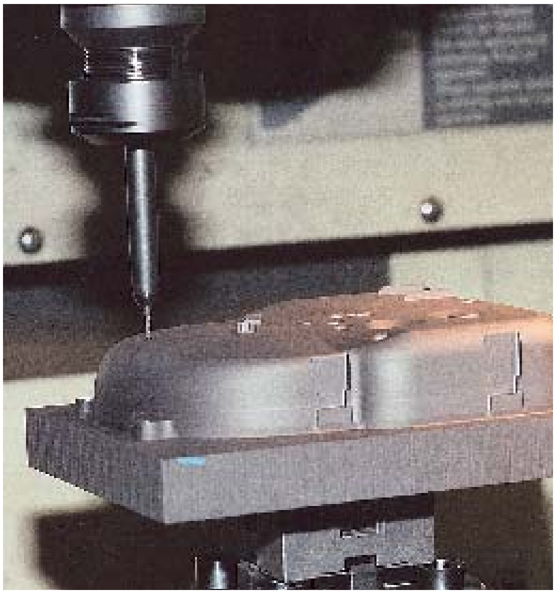
Climb milling, where the mill cuts in the same direction as the table feed, is recommended. It's also a good idea to rough with 2-flute endmills. They facilitate the flow of material from the cutting zone and minimize the chance of tool breakage due to flute packing.

Keystone's Curtis said that a good, sharp tool helps minimize chipping, but some will almost always occur. He said he often can control chipping by manipulating the order of the cutting operations. "I do all the Z-axis work first, and I do my side cutting last," he said.

Achieving fine finishes on graphite electrodes requires running at high speed and feed rates, Curtis said. "You

Answer to question on first page: The electrode was used to burn a die that crimps and cuts the paper wrappers that hold Reese's Peanut Butter Cups.

An assortment of diamond-coated tools Keystone Machine uses. Their diameters range from 0.010" to 0.125".



An electrode for producing a plastic mold is milled on a Makino SNC64 machining center at Chicago Mold Engineering.

want a real fine step-over so you don't get any tool deflection. You need the speed to compensate for the really close step-overs. For example, if I'm running a 0.031" endmill at 13,000 rpm, then it's feeding at 125 ipm to do a finish cut on a part. It's stepping over 0.001"."

Fine Finishes = Big Programs

The CNC programs needed to handle the complex contours and multiple light passes involved in producing complex electrodes can eat up a lot of computer memory. Curtis said the reason is 3-D cutting, adding, "I've had programs as big as 20 MB."

The average 1"-long electrode usually can be cut in 30 minutes. Curtis recalled machining an electrode about 20" long that was used to make a mold for the top of an automotive battery. "It was one of the longest cuts we've had in the machine," he said. "It took us 10 hours to cut it." Keystone's machining time, though long, was significantly shorter than the time spent by another shop that had machined 40 different electrodes to produce a similar mold.

Graphite, EDMing … and sheep markings

The story of graphite's discovery sounds like a Monty Python skit. Legend says a severe storm in 16th-century England uprooted a tree, revealing a vein of silvery-black mineral. Local shepherds thought it was coal, but it wouldn't burn. They later discovered that the mineral—graphite—was an excellent medium for marking sheep.

Over the ensuing five centuries, many "higher-tech" applications for graphite have appeared. Today, graphite's unique properties make it an excellent material for the electrodes used in sinker (or ram) EDMs. The mold and die industry, especially, exploits graphite's ability to be machined into complex shapes and used to "burn" molds and dies.

EDM electrodes take two basic forms: continuously spooling wire that moves around and through the workpiece, or a 3-D ram that moves into the work via a servo. The ram electrode creates a mirror image of itself in the workpiece.

Early electrodes were all made of brass or copper. They tended to wear out quickly, mainly because the metal electrode melted at temperatures well below that of the spark.

Graphite electrodes came into use in the mid-1960s. Early graphite electrodes were inconsistent in quality, and performance varied according to the orientation of the grains in the material. Today's graphite electrodes are generally easy to machine and relatively inexpensive, and they remain solid at much higher temperatures than their metallic counterparts. The development of high-strength, fine-grain, isotropic graphite set the stage for graphite's wide acceptance as an electrode material.

According to Poco Graphite, use of graphite as an electrode material has grown from less than 20 percent of the U.S. market in the late 1960s to more than 80 percent today. Metal electrodes are still employed on lower-temperature workpieces, such as aluminum, copper and brass, as well as on tungsten and other alloys that require high frequencies to EDM.

The isotropic polycrystalline graphite currently used begins with a calcined petroleum coke (amorphous carbon), a byproduct of oil. "When they bring it in, it's in the form of black gravel," said Poco's Jerry Mercer. "We break it down into a very fine dust, and mix it with an agent that binds it together during the manufacturing process."

The increasing sophistication of graphite-manufacturing technology facilitates the production of materials that allow higher metal-removal rates, greater precision and greater wear resistance.

In addition, some graphite grades are copper-impregnated. This gives them the added strength necessary to burn special workpiece materials.

—B. Kennedy

The following companies contributed to this report and the accompanying sidebars:

Chicago Mold Engineering Co. Inc.
(630) 584-1311
www.chicagomold.com

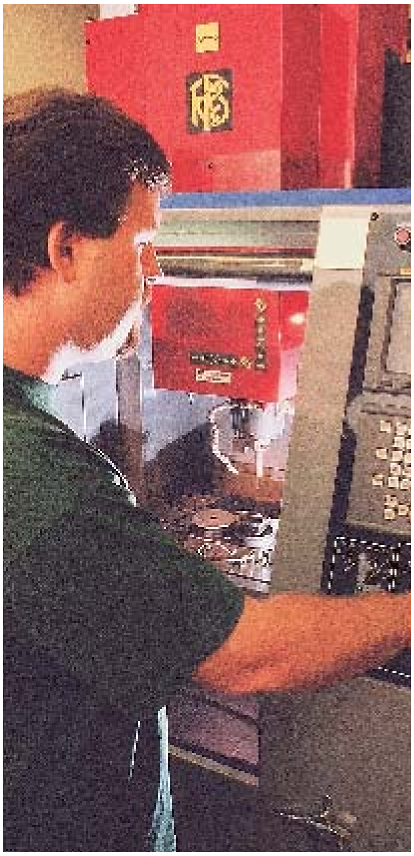
Delcam International Inc.
(800) 664-3506
www.delcam.com

Keystone Tool & Machine Inc.
(717) 241-9222
www.keystonetool.com

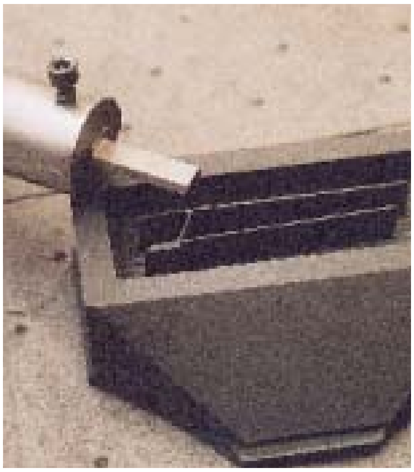
Poco Graphite Inc.
(877) 762-6336
www.poco.com

Sp3 Inc.
(800) 773-9940
www.sp3inc.com

The Leading Edge
(248) 814-9290
www.tledge.com



Keystone's Tim Curtis at the control of the company's Roku-Roku graphite-machining center.



Keystone Tool used this custom broach to machine the internal corners of the graphite electrode it's resting on.

"They were taking 40 or 50 hours to make all the electrodes, then they had to burn them all separately," said Curtis.

When programming tool paths, it's important to tailor them to accommodate graphite's unique mechanical properties.

The goal when machining electrodes is to minimize hand finishing, said Ralph Oswald, CEO of Chicago Mold Engineering Co. Inc., St. Charles, Ill.

"Some of these electrodes are so close in tolerance and so delicate that you can't handle them after you machine them," he said.

The key to minimizing post-machining handwork is smooth operation of the machine tool and elimination of tool overruns or dwells. After Chicago Mold acquired a Makino SNC64 high-speed graphite-machining center to produce electrodes for its EDM operations, the company evaluated a number of 3-D machining software packages that could create tool paths from its engineering group's CAD designs. Chicago Mold chose the PowerMill package from Delcam International Inc., Windsor, Ontario.

"We relied on the input of the machine's operator," Oswald said. "He said that program reacted best to high-speed machining. The [tool's] exits and entries are radial, and the machine operates smoothly."

Special Machines

Some machine tool builders offer equipment specially engineered for graphite machining. Chicago Mold's Makino SNC64 is one such example. It features a high-speed spindle, CNC control with look-ahead capability and auxiliary hard drives, shielded ways and ballscrews, and comprehensive dust-containment and -evacuation systems.

Keystone Machine operates a Roku-Roku graphite-machining center. Its specific features include a 15,000-rpm spindle, an airtight enclosure and a vacuum dust-control system, and a 1.2-GB Data Server hard drive on the machine's Fanuc 16 M control.

The Roku-Roku holds tolerances of 0.002" and has 0.0008" repeatability. It gives Keystone the capability to mill electrodes for outside customers as well as its own sinker EDMs.

A special feature of the machine is a broaching head that permits machining of electrodes' internal corners. After an area is roughed with an endmill, the broaching head, fitted with an appropriately shaped broach, is located over the intended sharp corner. A canned broaching cycle programmed into the machine directs the broach movement up and down, scraping the graphite about 0.002" on each pass until the desired dimension is achieved.

These types of internal corners, which produce an external corner in a mold cavity, generally require hand scraping or the creation of another electrode.

This capability that the Roku-Roku offers jibes with today's focus on developing multifunctional equipment that creates a "hands-off" environment in which to produce increasingly complex parts.