▶ BY TECHNICAL EDITOR CHARLES M. BOYLES, CPE

Designer Materials

There's something new under the sun for aerospace composites.

Composite materials are being developed to meet the growing and ever-demanding requirements of the aerospace industry. These new hybrid materials tend to be extremely hard and dimensionally stable over a wide temperature range, which makes them highly suitable to endure the stresses generated as they make the transition from Earth to outer space.

Among the parts made from these composites are insulators for critical electronic controls, sensors and bearing seals for jet engines.

Ceramic materials manufactured by Mykroy/Mycalex Ceramics, Clifton, N.J., are glass-bonded micas. The inorganic materials are talcum powder-like combinations of pulverized glass and mica that range in color from white to gray. Glass-bonded mica is a dimensionally stable, noncarcinogenic composite used as an electrical insulator in aerospace applications where high-temperature environments are a concern.

When blended together and compacted by high heat and extreme pressure, the glass flows and bonds with the mica, producing a machinable material. Glass-bonded mica, which has a coefficient of thermal expansion similar to many metals, machines like steel and requires no special cutting tools.

Cutting speeds must be held slightly lower than those for steel, because the composite has a tendency to develop hairline cracks when exposed to the heat generated during machining. As such, water is the best coolant and cutting lubricant when turning and milling glass-bonded mica.

Material-Removal Considerations

Carbide cutting tools produce the best machining results, given the abrasive nature of the composite's glass content. However, it can also be cut and drilled with HSS tools. When drilling glass-mica composites, peck drilling with a carbide tool—running at 2,500 rpm for holes up to ¼" in diameter and 1,500 rpm for holes up to ½" in diameter—produces quality results. Larger-diameter holes require proportionally lower speeds and higher feed rates.

Drilling straight through a workpiece generates burrs at the exit side of the hole. Therefore, when practical, it's best to drill halfway through the part, turn it over and drill a second hole that meets the first.

Tool-post grinders with diamond-impregnated wheels produce the best external threads in glass-bonded mica. Tungsten-carbide tools can produce a satisfactory thread as well.

An oversized pilot hole is needed for internal threading to avoid shard thread edges. Also, both ends of a through-hole should be chamfered to prevent chipping.

Silicon-carbide, resinoid-bonded wheels operating at manufacturer-recommended speeds are effective for surface grinding of glass-mica composites. Heavy grinding calls for soft, coarse-grained wheels, while hard, fine-grained wheels are best for polishing. If surface chipping is not a concern, glass-mica composites can be cut with a bandsaw.

Glass-bonded micas must be handled carefully, as they can crack or chip. Also, care must be taken during clamping to avoid point-loading the workpiece. Sometimes a small piece of wood can be used as a pad to distribute the clamping load.

Molded, near-net-shape parts made of glass-mica tend to be "glassy" and, therefore, more difficult to machine. Close-tolerance parts, repeatable to within ±0.0001", can be made from molds with a ¼° to a ½° vertical draft on the sidewalls to facilitate part extraction. Parts have the same finish as the mold's sidewall.

Harder Ceramics

There are harder ceramics than glass-bonded mica. They include silicon carbide, boron nitride and alumina.

Costa Sideridis, president of Ferro-Ceramic Grinding Inc., Wakefield, Mass., described these ceramics as "hard, abrasive and brittle materials—as in, you only get to drop them once."

The key to machining them is to apply tools that abrade the workpiece surface instead of producing conventional chips. Sideridis added that both the tool and part must rotate during nongrinding operations.

Harder ceramic workpieces can be turned on CNC lathes, but single-point tools are not applied. In lathe operations, rotating tools, including grinding wheels, are used while the part turns. The tool could be diamond-plated and have any configuration.

According to Sideridis, “On a milling machine, once you figure out how to hold the part, you can make holes, circles, slots or squares—any number of features—with a diamond-plated endmill, core drill or any round tool.”

The primary cutting fluids applied are coolants with rust inhibitors. Oils are not recommended, since most parts go to the micro-electronic and semiconductor industries, where oil would affect part performance—a critical element in aerospace applications.

A significant difference between machining metals and hard ceramics is that the latter group requires a shallower DOC. You can’t plow through ceramics. The DOC range for ceramics is from 0.0001" to 0.005" per pass.

Speeds and feeds, however, are similar to those used for cutting metal. Speeds can range from 300 rpm up to 30,000 rpm for parts with small features. The majority of speeds are from 800 rpm to 3,200 rpm—a range familiar to most metalcutting shops. Feed depends on the part features and range from 12 ipm to 60 ipm.

For turning, cylindrical ceramic sections, like rods or tubes, are held in 3-, 4- or 5-jaw steel chuck clamps. Workholding is a challenge when milling, because most machines have magnetic chucks and ceramics are nonmagnetic.

However, there are other ways of holding ceramic workpieces, including clamping, fixturing, toggle clamping and waxing. Waxing is somewhat peculiar to ceramic machining. Basically, the part gets waxed onto the surface for machining with one of four or five different waxes. Dental plaster has also been used, but it’s time-intensive compared to wax.

Success Factors

Machining the harder ceramics is considerably more time-intensive than machining metals. Machining a ceramic part could take 15 to 16 times longer than machining the same part in steel. So it’s extremely important to ensure that the process stays on track.

Sideridis emphasized that you don’t want to work on a part for hours only to discover that you made a mistake and have to start over again. Therefore, in-process inspection is a critical facet of machining ceramics.

There are two aspects of inspection when machining the harder ceramics: the cutting tools and the part. Both must be inspected to ensure the part conforms to specifications. Monitoring tool wear is critical because the diamonds are set in a matrix, which is expected to wear.


Ferro-Ceramic Grinding

Harder ceramics must be ground or cut with abrasive-type tools.

In addition, ceramic parts can easily shrink 25 percent during molding. A standard operating premise with many ceramics is that they shrink up to 17 percent linearly and up to 34 percent volumetrically when molded. Beyond the nominal shrinkage, additional material must be included because the machining process is expected to consume 10 percent of the balance of the molded, near-net shape. Nominally, between 0.025" and 0.050" extra material is on each side or feature.

On linear dimensions, Ferro-Ceramic holds ±0.001" on about 90 percent of its work and considers ±0.005" to be “a walk in the park.” Tolerances of ±0.0001" are held on the remaining 10 percent of its parts. Additionally, it holds tolerances as close as ±0.00005" on some small diameters and lengths.

Ceramic finishes normally are between 16 R_a and 24 R_a on every feature. But grind-polish finishes as fine as 4μin. to 6μin. are also achieved.

Skill Factors

Companies that machine ceramics tend to be comprised of people who have been in industry for up to 30 years. There’s not much in the way of formal training programs.

The educational emphasis has been on making the material, and there’s been little focus on machining it. Ferro-Ceramic has tried to quantify the machinability and grindability of ceramics and generate empirical data.

Sideridis said: “You should be able to come up with some sort of formula that you can teach anyone. But, regretfully, it doesn’t work that way. Machining ceramics is a combination of art and science. It’s a skill-laden process. If it wasn’t for our employees, we wouldn’t be here.”

For Ferro-Ceramic, success lies in its ability to supply near-net shape parts. The value is added in the machining. In metal machining, value can be 50 percent labor and 50 percent material. In ceramics, that might be the target ratio in production, but in prototype work, material might represent 5 percent and labor 95 percent, if machining the parts takes a week.

Also, trade-offs must be made between machining and molding to near-net shape. The choice depends on available time and part volume. If there is a near-net-shape blank, then only finish work is needed. If a customer wants parts in 3 to 4 weeks, the answer is machining. If he is willing to wait 8 to 12 weeks, Ferro-Ceramic gets a mold, presses the parts and then machines them.

Like many machine shops, Ferro-Ceramic’s greatest challenge is making its operation more cost-effective, especially when some customers are unable to distinguish between price and true cost. It’s not always easy to convince people to buy a ceramic component at twice the cost of a metal component, even though the ceramic part might give five times the service life. Inevitably, though, most customers learn their lesson.

The following companies contributed to this report: ***Ferro-Ceramic Grinding Inc.****, (800) 638-8235, www.ferroceramic.com; and* ***Mykroy/Mycalex Ceramics****, (800) 638-8235, www.mykroy-mycalex.com.*