A 0.015" (0.381 mm) three-flute end mill with variable helix and variable index. (Provided by Advanced Tool)

The Challenge and Promise of Micro Tools

Cutting small holes or features sometimes only visible through a microscope requires special expertise from those supplying the cutting tools.

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It's tough to make a cutting tool only a millimeter, or smaller, in diameter. It's also a challenge to use such a tool. But when both sides of the equation do it right, the results are amazing: tiny features that can't be fully appreciated without a microscope. And the applications are growing.

Uwe Heinrich, new business development manager at Mastercut Tool Corp., Safety Harbor, Fla., observed that "micro tools play a very important role across all industries." Besides obvious examples like printed circuit boards and medical and dental devices and implants, Heinrich pointed to optics—not so much for cutting glass, but for making the tiny molds needed to produce parts.

Oliver Rapp, R&D manager at Ceratizit Group, based in Balzheim, Germany, said Ceratizit customers are using micro tools primarily in the medical, machine building and jewelry industries. Sherry DePerno, president and CEO of Marcy, N.Y.- based Advanced Tool Inc., said fuel nozzles and security fasteners for automotive and aerospace are a big part of their micro tool market.

Brent Broderick, senior manager of strategic accounts and national product specialist for solid round tools at ARCH

Cutting Tools, Bloomfield Hills, Mich., concurred. He added that Inconel and stainless steel fasteners in aerospace are another important use. Broderick also said end mills are the fastest-growing tool type, as micro drilling has "almost maximized." Plus "more and more companies are starting to use end mills as a drilling tool." He explained that for features like a small hole with a counterbore, advancements in tool technology and machine tools make it possible to plunge and interpolate a hole, combined with the counterbore, using a specialized end mill. Heinrich added that milling can also produce a more accurate hole than drilling. Threading is, of course, another key operation for these tools.

Tool Design Considerations

This quick survey points to a critical challenge for the toolmaker: how best to optimize tool geometry and material for each unique application, from the titanium and chromium molybdenum in medical implants to the Inconels in aerospace nozzles.

As Heinrich explained, "a key in machining is always to understand the machining characteristics of a certain material. For example, aluminum is fairly soft, so it should be fairly easy. But the machining characteristics mean that you typically have problems like built-up edge, where the chip would actually land on a portion of the flute and over time take the sharpness out of the cutting edge." This impairs the surface finish of the part and quickly leads to tool breakage.

Heinrich contrasted this with titanium, with its low modulus of elasticity. "You have a lot of vibration and typically three times the amount of heat because the heat is not being evacuated in the chip. So you need a micro tool that is extremely tough, with a geometry that reduces the vibration and a coating that can shield against the excessive heat."

Ceratizit's WTX-Micro drills feature through-coolant and deliver tight-tolerance holes down to 0.8 mm diameter at depths up to 30xD. (Provided by Ceratizit)

In short, Heinrich sees four significant parameters in the creation of a high-quality micro tool. First, it needs a geometric design that accommodates the machining characteristics of the workpiece. Second, the most suitable carbide grade must be identified. Third, grind the tool with the best possible surface. And finally, "top it off with a suitable coating." For a dental implant made with zirconia, the best coating is to "grow a carbon crystal (i.e. diamond) on the carbide substrate with CVD," he added. A metal cutting application might have a completely different PVD coating.

Although all the major players in this field have standard products, customization is becoming common. Broderick offered the example of needing to cut a feature with a depth of 0.020" (0.5 mm). "We would engineer a tool with a 25 or 30 thousandths length of cut, versus a standard tool with, say, a two millimeter length of cut." That's because for a given diameter, a tool with a longer length of cut would be weaker, all things being equal. And micro tools are inherently "gentle and brittle," said Broderick. "If you can make the tool specific to the application, more often than not you can greatly outperform a standard off-the-shelf product."

DePerno agreed. "The fastest and easiest way to save money and increase performance is by altering and optimizing the geometry, substrate and coating based on how the cutting tool is wearing during use. One small change to the geometry can have a major impact on performance." That's why Advanced Tool uses a "21-point inspection of edge wear and breakdown for the improvement of cutting tool geometry. This tells us exactly how a customer is using the end mill, how much of the mill they are using, what's working and what's not."

Rob DePerno, Advanced Tool's COO and director of manufacturing and engineering, elaborated. If, under high magnification, they see that the user is "blasting the corner on entry, we might put a corner radius there, or reduce the rake angle or the helix angle. There are 21 steps in the analysis, and many more things that can be changed on an end mill. It's just putting together the right formula." That might also mean recommending other changes to the process. "If the tool wasn't destroyed, we can see runout and the wear. And if there's enough there, we can measure whether the runout is in the tool itself or in the holder. … If I see uneven wear and the tool looks to be concentric, I tell them to work on their holders or their spindle before they do anything else."

Having said that, although the DePernos said their wear analysis makes predictable improvements based on specific measurements and their years of experience, they often offer the customer up to four new configurations to test at the next stage. Why? Because it's difficult to be sure about what will work best when there are so many factors at play. And as tools get smaller, it becomes increasingly problematic to apply special geometric features to them and to measure their effectiveness.

High Tech Geometries?

Efforts to dampen vibration or otherwise improve performance have led tool manufacturers to introduce esoteric geometric features like variable helices, unequal indexing and eccentric relief to standard-sized cutting tools. But how far such features can and should be applied to micro tools is questionable. Broderick said ARCH's KEO Micro Tool division makes end mills down to 0.005" (0.1 mm) in diameter with standard geometry, and they're "looking at some aspects of high-performance geometries on them. As we progress, we are going to be starting to use high technology, such as variable helix and variable index."

Rob DePerno expressed skepticism. While Advanced Tool routinely makes blueprint end mills to 0.015" (0.381 mm) with variable helix and indexing, it doesn't get many requests to analyze wear on such tools. "And," he mused, "if you're making a 15 thou [i.e. 0.015"] tool with a 35 thou length of cut, how much can you vary the helix along that path?" Yet, reported Sherry DePerno, customers are ordering tools with

Mastercut Tool Corp.'s PowerN Coating (nACo) nano-composite (nc-AlTiN)/(a-Si^3N^4) is designed for superalloys, hard material machining and high-heat applications (Provided by Mastercut)

such features. "Obviously, they're working, because people are purchasing them. But we sometimes ask ourselves if a standard geometry would have worked just as well. It hasn't really been tested."

As for the tiniest tools, it becomes physically difficult, if not impossible, to add some of these features, as Ylli Hysenlika, Mastercut Tool Corp.'s automated production director, explained. For example, look at the effort to create a sharp rake angle for cutting aluminum. "The smaller you go, the higher those angles are going to get because of the nature of the fluting process. But then as you approach the range of 50 µm, it becomes very difficult to apply many features on the tool. The more common features for these small diameters are a flute with the large rake, and an end face with just the gash and maybe an end relief. You have far fewer options as you get into the very small micro tools."

Tool Manufacturing Advances

Perhaps the biggest factor enabling the creation of today's smallest tools was the introduction of Rollomatic's Nano tool grinder. Hysenlika credits the technology with a ten-fold improvement in surface finish. "They are fully hydrostatic and feature a floating workhead," he explained. "This allows you to use a perfect V-block steady-rest system, with runout under 1 µm in most cases."

As good as these machines are, Heinrich hastened to add that you can't just buy a Nano, "plug it in, and all of a sudden become the champion in the micro tooling world." Grinding is a combination of understanding carbide grains and how they relate to tool capabilities, along with how best to grind each size grain. Said Hysenlika, "you have to understand tool geometries, coatings and how to dress and prepare the grinding wheel."

Don Babinsky, in his technical applications role at Mastercut Tool Corp., said coolant and coolant filtration considerations also play a role. "We saw dramatic improvements in grind finishes by upgrading our coolant." Heinrich added that improving surface finish reduces cutting forces on the tool, improving performance, and also contributes to better coating adhesion.

Coolant also figures into the end use of these tools, with micro tools as small as 0.8 mm in diameter often featuring internal coolant channels. Rapp said grinding machines are now better at orienting themselves to these incredibly small coolant holes using optical sensors. And though it's hidden from the grinder, carbide blank manufacturers (which include Ceratizit) have boosted coolant delivery by incorporating a larger chamber in the tool shank (typically 3 mm in diameter), from which the tiny channels emerge into the cutting diameter, he added.

Heinrich concluded that whether it's grinding equipment, QC, coating or anything touching the process, micro tool makers must invest heavily and stay on top of every detail to remain competitive. "Once you're behind the curve, it will be either very hard to come back or you're literally out. People who want to be successful in this space must have discipline and a commitment for a long-term future. Because you need to be active and engaged in every single aspect in order to have success," he said.

How Best to Use Micro Tools

Mastercut's Babinsky said the "most common mistake made using small-diameter tools, even as relatively large as 1/8" [3.175 mm] diameter, is the simple lack of sufficient spindle speed." If you're not cutting with a satisfactory surface footage per minute, "you're going to create a problem with built-up edge and dragging the workpiece material. Most people's problems will go away dramatically if they can double or triple their rpms."

The numbers become dramatic when you consider micro tool diameters. "As an example, an end mill may respond best to 200 sfm in a given material," explained Babinsky, "and that surface footage is every bit as important to a 0.005" (0.127-mm) diameter tool as it is to a quarter-inch end mill in that same material. But the spread in required rpms boggles the imagination: 200 sfm calculates out to 3,056 rpm for a quarter-inch end mill, whereas a 0.005" end mill calculates to a whopping 152,800 rpm. This illustrates the value of specialized machines and/or specialized spindle options that can grant 100,000 rpm or more to properly drive a micro tool."

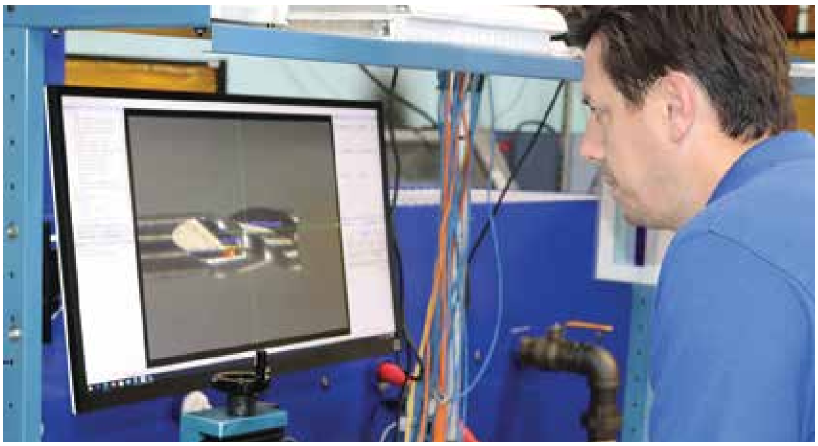
The second most important caution, said Babinsky, is "you've got to check TIR and indicate the tooling from the shank, rather than the cutting edge. You don't want to touch a carbide cutting edge with a caliper or a zirconium point if you can avoid it, and that's especially true with a micro tool." An optical presetter would be best, he said.

It perhaps goes without saying that the toolholder must be as rigid as possible with micro tools, with an absolute

A micro keyseat cutter from ARCH Cutting Tools (Provided by ARCH)

minimum in runout and imbalance. Said Babinsky, “thermal shrink-fit holders might offer one of the better approaches. In addition, the industry is now seeing the availability of hydraulic chucks with 3-µm runout, and collet chucks at 1 µm at the front nose. For perspective, a red blood cell is approximately 10 µm.”

ARCH’s Broderick said lubrication is vital with micro tools, and minimum quantity lubrication (MQL), which is a combination of air and coolant, is preferred. Flood coolant is another option. But high-pressure coolant would be disastrous, he explained. “If you’ve got a five or ten thou end mill and you get high-pressure coolant on it, you’re going to snap it.” But likewise, if you don’t have enough coolant or MQL, “it does not take much to snap a micro tool by recutting chips.”



Making micro tools is a challenging, multifaceted process. Alex Nokaj uses a tooling microscope to measure and inspect a 0.3-mm end mill at magnifications up to 145× (Provided by Mastercut Tool Corp.)

Broderick added that the coolant must be well filtered to prevent clogging of the coolant channels. Ceratizit’s Rapp suggested that the “filtering level should be equal or below 30 µm. If necessary, adapt your cutting values to the machining setup to achieve good chip evacuation. If there are through holes, reduce your feed rate by 50 percent before leaving the component to increase process stability.”

Broderick applauded CAD/CAM advances that not only simulate a tool but also a toolpath. “And you can calculate the chip load. And if you know the geometry of the flute, you can make sure that the tool can take the needed depth of cut.” Babinsky suggested that such software might also be used to enable high-efficiency milling (HEM) techniques but stressed that “HEM emphasizes significantly increased rpms and even lighter radial step-overs, both of which are already a challenge with such small diameters.”

Looking Ahead

Broderick predicted that “the technological advances in machine tools, toolholders, substrates, coatings and the small parts being machined” will all contribute to growing demand for micro tools. Rapp said we’ll “probably see that cutting depth will increase and cutting diameters will decrease, which makes things much more difficult.” But he also said there is “potentially new technology” that might further improve cutting edge preparation. He wouldn’t reveal the details, but said its application would contribute to “a more stable cutting process” and extended tool life. Babinsky thinks we’ll see “more refined PVD nano-composite coatings, targeting not faster rpms, but rather tool longevity goals.”

Advanced Tool’s Sherry DePerno envisions “more and more complex geometries transitioning to a smaller scale. Getting creative in solving problems is the name of the game. This includes complex forms and geometries that will solve whatever challenge our customers may be facing.”

Along that line, Babinsky predicted that the “dramatic success in five-axis machining and the use of tapered barrel, circle-segment cutters” will eventually be carried into micro tooling. “One can’t help but be impressed with the increases in metal removal rates with barrel cutters,” he said. “I think the standard ball-nose end mill will eventually be on life support. I see the introduction of much smaller-diameter segmental cutters.”

FYI

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