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cover story

Dry Goods

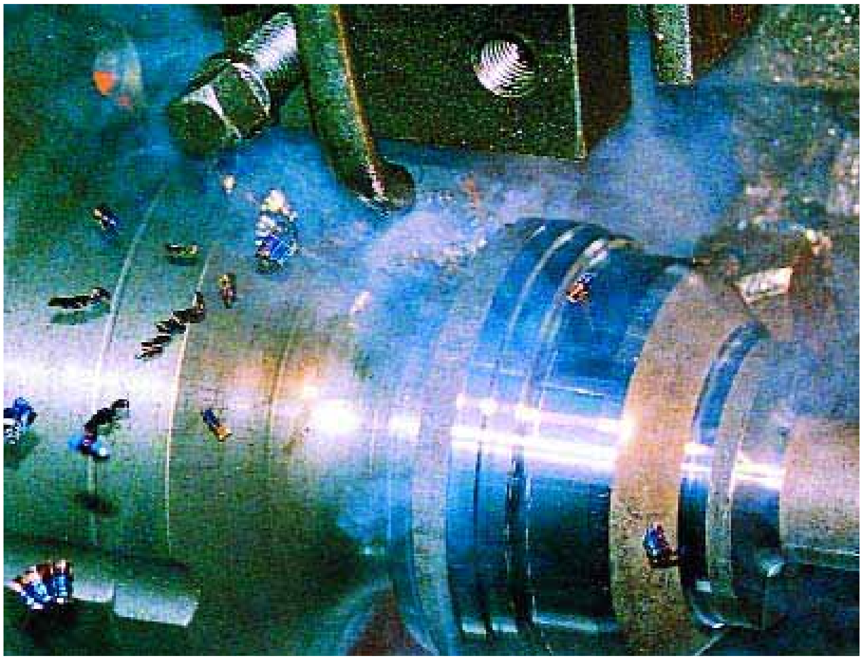
Factors to consider when dry or near-dry machining.

▶ BY GREG LANDGRAF, ASSOCIATE EDITOR

Metalworking fluids are a double-edged sword. They can be effective for lubricating and cooling the tool/workpiece interface and flushing chips, but maintenance, safety, fluid disposal and air quality can create pricey headaches.

As a result, a growing number of U.S. manufacturers are turning to dry or near-dry machining, seeking benefits ranging from coolant cost savings to improved tool life to higher value for recycled chips without having to buy fluid-extraction equipment.

"In our studies, about 15 percent of the operation costs are attributable to the use of coolants—three to four times the cutting tool costs," said Mark Ostraff, sales and marketing manager for Horkos Products, Marubeni America Corp., New York. (Horkos is a Japanese machine tool builder; Marubeni is its North American importer and distributor.)



Sandvik Coromant

New tool substrates and coatings have been developed that perform better dry than wet.

In addition to the coolant itself, these costs include disposal, containment, maintenance and labor. There is also the health factor. "How many times has a guy slipped in a pool of coolant? How many dollars are spent cleaning [up] messy pools?" Ostraff asked.

Dry Benefits

Dry machining refers to machining with no fluids whatsoever. Near-dry machining, or minimum-quantity lubrication (MQL), uses a tiny amount of fluid applied to the cutting edge, either through the tool or externally. With near-dry machining, the fluid vaporizes during the process, leaving dry chips.

Wally Boelkins, president of Unist Inc., Grand Rapids, Mich., said one of his customers receives 20 cents per pound more when recycling dry chips than wet chips. With 50 machines each producing 1 ton of chips weekly, the company picks up an extra $1 million per year from the recycled chips.

Bill Tisdall, product manager for turning at Sandvik Coromant Co., Fair Lawn, N.J., said recent developments have improved the performance of many tools when cutting dry. "Before, you could run tools dry, but they would work better with coolant," he said. "Now, we're getting better tool life running dry."

He added that in one test, the company's 4005-grade insert produced 750 parts when run wet vs. 1,200 parts when run dry.

In many situations, dry or near-dry machining also allows faster cutting. Neil Mantle, engineering director at Warren, Mich.-based Cincinnati Lamb's

Mildenhall (U.K.) operations, reported that in one job producing crankshafts using solid-carbide gundrills, removal rates were boosted from 180 mm/min. to 660 mm/min. by switching from flood coolant to MQL.

Making the switch, however, is a bit more complicated than just turning off the coolant. Several things need to be considered.

Keep It Clean

One of the biggest challenges when dry or near-dry machining is chip removal.

"In milling, the biggest problem is getting rid of chips," said Dennis McNamara, product manager (milling) for Carboloy Inc., Warren, Mich. If the chips aren't evacuated, "the cutter can recut the chips and press them into the workpiece, hurting the finish."

"Chip evacuation remains the biggest challenge," agreed Rob Myers, business unit manager for Accu-Lube, a natural-based lubricant manufactured by ITW Rocol North America, Glenview, Ill. "And it needs to be handled in the machine tool design."

Simple machine layout can help. "The single most effective thing you can do is have a through-the-bed opening directly underneath [the workpiece]," said Ostraff. The opening in the machine bed leads to a conveyor, which carries chips to a collector.

Slanted surfaces at the base of the fixturing area and on a deflector shield help direct chips downward as well. Ostraff said 50° inclines are effective, and that stainless steel surfaces reduce friction. Minimizing obstructions, in general, also helps. "If you've got ledges and such, chips can build up," Ostraff said.

For many applications, dry and near-dry machining has one significant chip-evacuation advantage over using flood coolant. "The wetness of the chips is what makes them stick," said Unist's Boelkins. "When they're dry, they're easy to move."

Dry Drilling

Holemaking, however, is an exception. In traditional machining, the fluid that cools and lubricates the cut also helps remove chips from the hole, workpiece and fixture. When cutting near-dry, only the spindle's motion can work to evacuate chips.

"In tough applications, polished flutes are advisable to aid chip removal," said Jim Strolberg, vice president of technology, Walter Waukesha (Wis.) Inc.

Ostraff described several options for clearing chips when dry drilling:

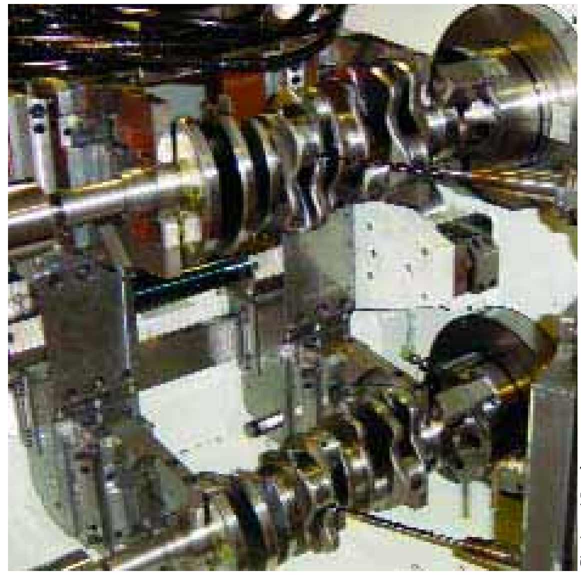
■ **Compressed air.** "After unloading a part, we use air blow-off to remove chips from the locating surfaces," he said. This ensures accurate positioning of the next part.

■ **Trunnion, or tilt, table.** The operator loads a workpiece facing up, as if for vertical machining. The trunnion table then tilts the workpiece 90° into a horizontal position. Horizontal machining helps evacuate chips, because once they clear the part, they're free to fall away.

■ **Vertical inversion fixture.** This device allows the operator to load a part on one station while the machine cuts a second part at another station. In between, the pallet flips end-over-end, which helps clear out chips. When a workpiece is being cut, it is held from above, so no chips will fall onto the workholder. Although effective, this approach is more expensive than a trunnion system.

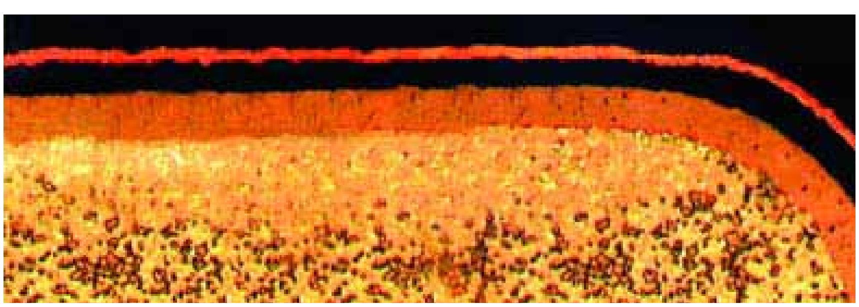
■ **Liquid flush at the end of a drilling cycle.** This is the most efficient and reliable approach, according to Ostraff. After a cycle, fluid briefly flushes the machining area to remove chips. In addition, this approach minimizes environmental impact. "The liquid is basically water with rust inhibitors—it's not cutting fluid," Ostraff noted. He added that the liquid is recirculated through the machining system and reused.

■ **Vacuum system.** A vacuum shroud surrounds a tool and suctions out chips from the machining area. Ostraff said this approach collects about 95 percent of the chips. A vacuum shroud is dedicated to each tool and travels with it to and from the toolchanger.



Cincinnati Lamb

One crankshaft machining operation was able to more than triple metal removal rates by switching from flood coolant to MQL.



Sandvik Coromant

A magnified cross-section of a tool for dry turning that shows the substrate, TiCN abrasion-resistant layer, Al_2O_3 heat-protection layer and TiN wear indicator. Total coating thickness is 15µm to 18µm.

A Thicker (Tool) Skin

Advanced coating technology is one factor that allows tools to stand up to the rigors of dry machining. "We're able to apply thicker coatings, which provides more protection," said Sandvik's Tisdall.

Tisdall said the newest turning grades

feature coatings 15μm to 18μm thick; 5 years ago, 11μm to 14μm was the standard. “The thicker coatings may not be a big change, but it’s definitely making a difference,” he added.

Thicker coatings are now possible because of the development of multilayer coatings. Past a certain thickness, monolayer coatings don’t adhere well and flake off. Multiple-layer coatings solve that problem.

Sandvik deposits a layer of titanium carbonitride, which resists abrasion and improves a coating’s adhesion to carbide, followed by an aluminum-oxide layer, which protects the tool against heat, and finally a 0.5μm titanium nitride layer, which indicates wear when its gold color wears off.

Tools with thick coatings are suitable for roughing and medium machining, but less appropriate for finishing. “Below a certain DOC you get built-up edge,” Tisdall said. He added that finishing requires a high, up-sharp edge to break the chip. Thick coatings don’t adhere as well to a sharp edge because there is less surface area for them to stick to. For dry finishing, he recommends a cermet tool or a tool grade with slightly thinner coatings.

Don Graham, product manager (turning) for Carboloy, added that thicker TiCN coatings also help protect against heat.

Workpiece Materials

Graham said cast iron is the easiest of the ferrous materials to machine dry; the graphite content makes the chips easier to break. Steel is only slightly more difficult, although he advised minimizing the tool contact time to eliminate heat issues. “If the time in the cut is lengthy, the part heats and expands,” he said. “Then the part cools and it is undersize.”

Stainless steel is more difficult, because of both heat buildup and difficulties in chip breaking. Graham noted that most stainless steel applications require near-dry, rather than totally dry, machining.

Walter Waukesha’s Strolberg said that machining aluminum can pose a special challenge when machining near-dry. “As the temperature increases, aluminum becomes a liquid. The failure mode is BUE.” He advised using a smooth cutting edge and boosting the speed so the aluminum does not stick.

ITW Rocol

For MQL applications, fluid tubes should be free of bends and the fluid should be applied in a heavy pattern.

The Heat Is On

A near-dry enterprise

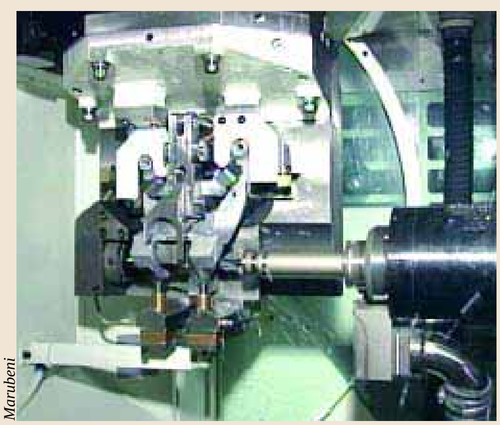
Enterprise Automotive Services (EAS) is one of a growing number of U.S. companies exploring the possibilities of near-dry machining.

The Warren, Mich., automotive component manufacturer began machining near-dry in 2001. “It’s all been positive,” said Lamar Pitts, the company’s manufacturing project engineer. “The part quality is very good and we had cost savings right off the bat.”

The company has a Horkos horizontal machining center specially designed for near-dry machining. EAS applies Accu-Lube LB-6000 lubricant from ITW Rocol when machining parts on the HMC.

Pitts said that ramping up the near-dry production was not difficult. The machining center came with the program for the part. The company only had to build a foundation for the machine and tweak the manufacturing process for about 2 days. “We did some research in-house beforehand to optimize the feeds and speeds and the quantity of the lubricant,” Pitts added.

EAS manufactured an aluminum strut bracket as its first MQL part. Now, it uses the Horkos for making cast iron engine mounting brackets, a part that requires extensive drilling and milling. An inverted table and chip-conveyor system collects the chips, although the aluminum part was machined using vacuum shrouds for chip collection. Pitts said the new part’s shape makes it impossible to use vacuum shrouds, because it does not provide enough clearance for them.



Marubeni

EAS produced an aluminum strut bracket in an inverted postition to aid chip removal when machining near-dry.

The company manufactures only one part with MQL because it has only one machine optimized for the process. Nevertheless, Pitts said the project has been an unqualified success. Air quality, though good to begin with, has improved, and the company has reduced coolant expenses and improved tool life. The bottom line, Pitts said, is that “we’ve proven that it saves money in the long run.”

— *G. Landgraf*

The tool's substrate also matters when dry or near-dry machining. "Thermal deformation is a frequent failure mode," said Doug Ewald, Latrobe, Pa.-based Kennametal Inc.'s global key accounts manager for General Motors. "Substrate developments help to counter it."

Among those developments, Ewald said, are alloys that resist thermal deformation better, tool substrates with reduced binder content and substrates with cobalt enrichment in certain places to improve localized toughness.

Tisdall agreed that substrates with a cobalt-enriched zone are tougher along the edge line and useful for dry machining. "The gradient sintering process hardens the tool throughout and on the edge lines," he explained. "Just behind the edge lines, there's a softer area made of tungsten carbide and cobalt, but with the harder cubic carbides, like titanium carbide and niobium carbide, depleted. It gives the tool extra edge toughness."

Ewald noted that ceramic is another good substrate for cutting dry. "By nature, it has lower thermal shock resistance, so it is suited to dry machining," he said. He added that ceramic tools are commonly used for cast iron machining.

For stainless steel, on the other hand, better results can be obtained with a micrograin-carbide substrate. "If you have two substrates of comparable toughness, you'll have better deformation resistance in micrograin, which will give better tool life," Carboloy's Graham explained.

Walter Waukesha

Milling is the most common application for dry machining.

Tool geometry needs are difficult to generalize. Strolberg said users must pick the geometry that's right for the specific application, whether running wet or dry. Often, no tool geometry change is needed when switching from wet to dry machining. In some cases, however, to ensure that heat flows into the chips, users may need a more aggressive cutting geometry and run the tool at higher speeds.

Graham said that when machining most ferrous alloys, as the chip heats it becomes more ductile and harder to break. In such instances, he suggested a finishing chipbreaker.

Even though chips can carry away much of the heat generated in dry or near-dry machining, Ewald said workpieces still can reach elevated temperatures. Obviously, this makes part handling difficult. Also, "operators may need heat compensation for gaging parts," he noted.

Focus on MQL

While dry machining is primarily for milling, near-dry machining, or MQL, is more common for other applications. "Dry machining doesn't work well with holemaking," Marubeni's Ostraff explained. "It's limitations led to the near-dry concept."

As the name implies, near-dry machining involves application of a small quantity of fluid, precisely applied, to lubricate or cool. The amount varies by application and by the type of fluid used, but ranges from about 2 fluid oz. to 2 gal. per 8-hour shift.

"You can't use a flood coolant for near-dry applications and expect it to work right," said ITW's Myers. The reason is that a coolant for flood applications is lubricant suspended in water and is not concentrated enough for MQL applications, Myers said.

Unist's Boelkins, however, said that either water-based fluids or neat oils can be used. "If the application is primarily cooling, then use a water-based fluid, because water evaporation removes heat," he explained.

Water-based fluids can cause steel to rust, Boelkins acknowledged, and about 10 times as much volume is needed than when using neat oils. The volume, however, is still paltry compared to flooding a workpiece with coolant.

Myers recommends vegetable oils for MQL applications. "Vegetable oils are safer for workers [than mineral oils] and very polar, which makes them less likely to mist than mineral oils."

Ostraff noted that when choosing an oil for MQL, users should keep issues of susceptibility to bacteria propaga-

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tion, odor generation and evaporation properties in mind.

Because near-dry machining uses so little fluid, proper delivery becomes more important. "The challenge has always been lubricating the exact cutting edge," rather than the general area, said Myers.

Because the fluid is atomized, handling the fluid as it makes its way to the cutting edge can be tricky. "The tubing needs to be straight or lubricant collects in the corners," Myers noted.

"If you have too sharp a corner, the mist might not make it around," Walter Waukesha's Strolberg agreed. He recommends 3mm- to 6mm-dia. tubes for fluid delivery. "Start with as big and smooth a path as you can, and end with as small a path as possible to increase velocity."

Cincinnati Lamb's Mantle said research indicates the quantity of air mixed with the lubricant is an important factor. "As we reduced air pressure, we got drill breakage," he said.

Myers, however, noted that "a fine aerosol spray is not always the best. A heavy, spitty pattern, especially on a rotating tool, [lessens the tendency of the lubricant] to go into the air."

Unist's Boelkins agreed that fluid particles should be large for ideal lubrication. "The way to reduce friction is to get the fluid between the tool and the workpiece that are rubbing against each other. The tinier the particles are, the less likely that is," he said.

Marubeni's Ostraff identified three basic approaches to fluid mixing and delivery: Mixing fluid with air and applying externally, mixing outside the spindle and applying through the spindle, and mixing and applying through the spindle. He said the external approach is the least expensive and most easily retrofittable but is generally most effective when drilling shallow holes. "The most efficient, in our opinion, is to pump oil and air separately into the spindle and mix them just prior to discharge through the tip," he said. "It has been effective at up to 30,000 rpm."

While many issues need to be taken into account to successfully incorporate dry or near-dry machining, the benefits can be dramatic. As a result, a growing number of companies are taking advantage. As Ostraff said, "It's growing and growing, and becoming more accepted. The challenge is getting customers to try it when they're unfamiliar with it."