Near-Dry Machining Cuts the Heat

Systems for supplying minimum quantities of cutting fluid are slipping into shops that use traditional flood-cooling–though slowly

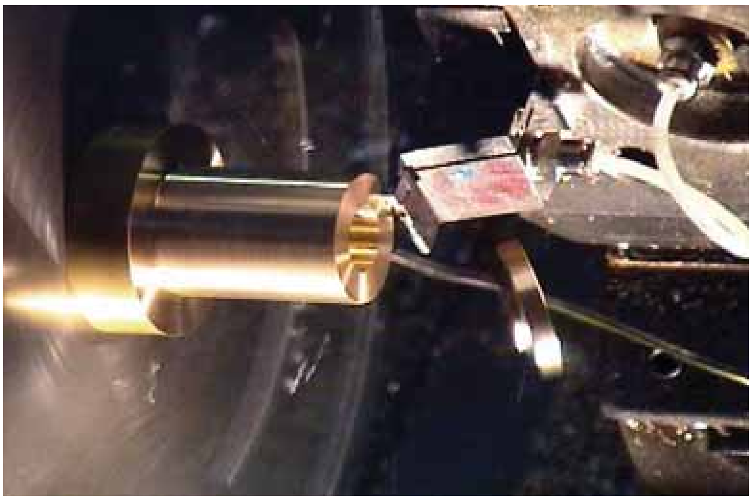

Photo courtesy Unist

Near-dry turning uses equipment that mists a minimal amount of cutting fluid at the cutting interface.

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"Metalworking fluids are not costly in themselves, but they can run up the costs of production if poorly chosen or improperly handled and controlled." This is a reasonable observation for today, even though this statement appeared nearly 60 years ago in a booklet on cutting fluids from Standard Oil. The emphasis on fluid handling and control shows how conscious people were, even then, of the real costs of fluid use, and explains why they started developing the earliest methods for minimizing cutting-fluid use. The concept of near-dry machining—or more broadly, minimum quantity lubrication (MQL)—certainly isn't new.

In operations that use traditional flood-cooling methods, coolant handling creates more costs than the cost of the fluid itself. For the wet machining of aluminum castings, for example, coolant-related costs are 10–20% of total machining costs—roughly twice the costs of cutting tools. But of this, only 25% is for the lubricant itself; the rest goes towards coolant supply maintenance (42%) and operational energy costs (33%). These figures are based on a study from the Advanced Manufacturing Technology Development group of Ford Motor Co. (Dearborn, MI). (Ford is now a

heavy user of near-dry machining at its Livonia, MI transmission plant, ramping up in 2005 from 41 initial MQL-enabled production machining centers to around 200 machines by next year.)

Because the small amount of cutting fluid that it uses is vaporized in the cutting process, near-dry machining can make a real dent in fluid-handling costs. Some automotive and aerospace component manufacturers have adopted MQL, but it generally has been slow to catch on in operations where it makes sense, at least in North America. But why is this, given traditional flood-cooling's liabilities of coolant degradation and disposal, worker health hazards, and shop contamination?

The simplified answer may be that for jobs that require coolant, flooding the workpiece and tool with a water/oil emulsion has always been effective, and just seems to make sense. "Change comes slow, and many engineers tend to benchmark their company's past best practices. For many companies this is flood and high-pressure coolant," says Kevin Howes of Bielomatik Inc. (New Hudson, MI).

But Howes emphasizes that other practices that are now common for fluid and chip handling were not initially popular. For example, machine guarding has been switched from fence guarding to complete dry-floor guarding, and flumes have been moved from the floor to inside the machine. "The next step in cost savings and protecting the environment is eliminating coolant wherever possible," he asserts.

Photo courtesy Blaser Swisslube

Chip management with MQL requires a different approach, since there's no flood coolant to wash chips away.

Change has also been hindered by the specialized tooling and/or equipment that near-dry machining requires, says Randy Templin, vice president of Blaser Swisslube Inc. (Goshen, IN). First, a delivery system is needed that supplies a consistent, minimum quantity of lubricant at the tool/workpiece interface. MQL may require new cutting tools, spindles, and toolholders. And it typically requires new methods for handling chips and dust (even though MQL chips are free from coolant contamination). Moreover, at some companies, MQL isn't felt to be needed because their already "sound fluid-management practices utilizing high-quality flood coolants make for economical use with a limited waste stream," adds Templin.

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Boeing might serve as an example of a company that is reducing its fluid use without completely adopting MQL. Boeing has reportedly approved a number of Blaser metalworking fluids that are compatible for stain-free machining of aircraft aluminum and titanium. Yet, Templin is not aware that Boeing is practicing anything more extreme than minimum quantity coolant (MQC) machining with water-miscible fluids, rather than MQL with straight oil. "MQC spray mist applications are common for face-milling long wing spars," says Templin.

But some companies have found adequate reasons for completely switching to near-dry machining, says Jeff Coffey, product engineer at Unist Inc. (Grand Rapids, MI). Justifiable cost savings is typically the first thing they seek; other issues usually have to do with improving employee safety and creating a cleaner environmental footprint. "Flood coolant is basically a mixture of water and oil. At the end of its life, it's not something you can just throw out in the backyard, any more than you can throw out an oil change in your backyard when you change the oil in your car."

The most straightforward approach to MQL is to use an external nozzle that delivers an air/oil mist to the tool/workpiece interface. Along with reducing costs, this reduces operators' exposure to flood-coolant ingredients that can cause skin dermatitis and breathing problems, adds Coffey. And even though some argue that flood cooling controls metal dust most effectively, he says flood cooling creates overall dirtier air than MQL systems that spray a mist of oil. "Most people assume it's the other way around," he observes, "but most studies show that the near-dry machining has better air quality."

Moreover, MQL systems usually use safer, vegetable-based oils. Although these fluids are up to 10 times more expensive per volume than petroleum-based oils, they're used in much lower volumes. Vegetable oils such as Blaser Swisslube's Vascomill product are well suited for MQL, says Randy Templin. "The polar molecule of a vegetable-derived ester oil lubricates better than mineral [nonpolar] oil."

Vegetable oils optimize MQL in milling, boring, drilling, turning, reaming, sawing, and tapping. Benefits are measurable for a recent project Templin points to: aluminum wheel machining (because this project is still in an evaluation stage, the manufacturer did not want to be identified). Here, switching from mineral oil to vegetable oil for MQL has reportedly lengthened tool life from 60 wheels per insert edge to 230 wheels (saving several minutes each shift in tool changeover time), and it reduced smoke by 50%.

Applying mists of vegetable oils in machining also is said to provide better surface finishes. This, along with MQL's "low mess factor," is a reason MQL is drawing interest from the aerospace industry, says Jeff Coffey of Unist. Only a small amount of oil is needed to reduce friction in machining, and friction is the source of heat and the reason that water in flood cooling is typically used. Says Coffey, "[MQL] focuses on preventing friction from happening in the first place."

This "no friction, no heat" concept is one that new users of MQL need to learn; the other lesson is about how little oil is really needed for cool machining. "With MQL, if you can see what's coming out of the nozzle, you're generally using too much," Coffey insists.

In the hard-milling of molds, MQL is an alternative to flood cooling and provides up to 80% longer tool life, according to the Accu-Lube division of ITW Rocol North America (Glenview, IL). The company's oil-applicator systems and Loc-Line nozzles were reportedly adopted in 2006 by Creative Evolution (Schaumburg, IL), which wanted to optimize its CNC milling machines for hard milling. Depth of cut is limited when hard-milling dry, and the MQL solution is said to have worked well for deep, complex cuts in molds.

Photo courtesy Unist-Haas

MQL is used when reaming components at Swift-Cor Aerospace in Gardena, CA.

However, MQL with external nozzles requires perfect execution for getting the right amount of fluid to the cutting point, says Robert Myers of Accu-Lube. "The difference between 'dry' and 'near-dry' is determined by the aim of the nozzle, and if that is off by a measurement equal to the radius of the tool, you are cutting dry and not near-dry."

MQL for Grinding?

A "near-dry" approach may have some benefits for grinding as well. Here, the term "reduced-flowrate lubrication" may be more accurate, given grinding's relatively heavy need for coolant—in the neighborhood of 4 L/min per millimeter of grind width.

The environmental-related cost savings from dramatically reduced fluid use may be enough to trump any losses in material-removal rate, says John Webster, president of Cool-Grind Technologies LLC (Storrs, CT) and chair of SME's Abrasive Cutting Processes Tech Group in its Machining and Material Removal Community.

Even if MQL systems reduce productivity by 50%, the economic and environmental benefits of minimizing the coolant system may still offset the disadvantages, because of lower pumping energy, lower chilling energy, reduced coolant disposal, and easier fluid management. To understand the potential savings in grinding, "a complete economic analysis of conventional coolant application versus MQL would have to be made," says Webster.

But MQL may not be applicable for all grinding. Rather than substituting MQL in high-flowrate grinding (analogous to substituting it in flood-coolant machining), MQL might be more appropriate to use with high-efficiency deep grinding (HEDG) regimes where most of the grinding energy goes into the chip produced. In HEDG, at high wheel and table speeds, lubricating for abrasive wear can be more important than cooling; this allows lower flowrates.

Overall, MQL in grinding is harder to justify in comparison with MQL in standard machining, where chip sizes are larger, specific cutting energy is low, and workpiece surface temperatures are lower. "The challenge of grinding [with small chip thickness, undefined cutting edge geometry, and high specific grinding energy] will be a significant hurdle to overcome, unless the environmental case dominates in the future," Webster concludes.■

Through-the-tool MQL systems help ensure that cutting oil always gets to the right place. This concept delivers an oil/air mixture to the cutting point through passages in the spindle, toolholder, and cutting tool. Given the complicated fluid mechanics involved, this approach may work best for operations that have the engineering talent to develop the tools and integrate the equipment with automated machine tools.

Photo courtesy Blaser Swisslube

Flood-coolant machining effectively washes chips out of the machine, but fluid-handling creates additional costs overall.

Large-scale use of through-the-tool MQL is illustrated at Ford's Livonia Transmission Plant. Livonia's MQL machining line for aluminum transmission cases and valve bodies required years of development, says Alexander Stoll, lead MQL engineer in Ford Powertrain's Advanced Manufacturing Technology Development. Since deploying MQL machining centers in 2005, the company has estimated a per-piece savings of up to 17% in life-cycle costs calculated over a 10-year period, compared with the flood-cooling alternative approach. Moreover, the floors and aisles between the machining centers are oil-free.

Ford uses a "two-channel" MQL system, which means that oil and air are sent through separate passages through the spindle and toolholder until they are dynamically mixed at the cutting tool. ("One-channel" systems mix air and oil before sending the mixture through the tool spindle.) Stoll says the cutting tool design is critical for metering a well-distributed pattern of lubrication through holes in the spinning tool. "Basically you have to focus on the 'water-hose effect' and make sure that not all the oil or all the minimum quantity lube comes out of one hole."

Ford worked with Bielomatik on integrating MQL systems with each machining center. "The Ford example is one of the most impressive because of the quantity of systems being used, the many various machining processes being performed, and the production volumes and tolerance requirements," says Kevin Howes. Speed is key for the high-productivity machining centers, which require a 0.1–0.2-sec lubrication response from the MQL system. "Ford is using linear motor machine technology with very fast acceleration and deceleration, and a very fast toolchanger providing multiple tool changes." This combination, along with speeds of 24,000 rpm, required the use of a two-channel system.

One-channel systems have slightly lower hardware costs. They are reasonable choices for aerospace manufacturers, adds Howes, "because the production is not as high as automotive, and tool-change speeds are not as demanding." One-channel systems are limited to approximately 16,000 rpm because of the centrifugal forces that tend to break down air/oil aerosol flowing through the spindle. "However, some customers in the aerospace segment are interested in two-channel MQL because of the ability to optimize oil usage," Howes states.

Several benefits have contributed to cost effectiveness at Ford, including the dry chips that the process produces, which are removed with a vacuum system in each machine. The chips don't require a centrifuge or filter media for removing coolant, and they can be recycled directly. Stoll says future efforts will focus on improving the flexibility and standardization of MQL, "to respond to potentially changing customer demands on short notice, and also to ensure and support manufacturing with as few machine tools as possible."

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High-speed and fully dry machining operations can also benefit from adopting MQL. And difficult ferrous applications, such as deep-drilling of oil holes in crankshafts (another application developed at Ford Livonia), can be done with MQL rather than flood cooling.

Admittedly, aluminum applications are the most notable MQL applications, for basic reasons. The near-net shape of a cast-aluminum workpiece means the MQL setup doesn't have as many dry chips to handle. And cutting aluminum usually requires significant lubrication, resulting in dramatic savings when MQL eliminates flood coolant. "When cutting aluminum there tends to be adhesion between the aluminum and the tools, and the small layer of lubrication provided by MQL reduces or eliminates this condition," says Howes. "This problem is not as prevalent in steel machining." He adds that Bielomatik has supplied for MQL applications for cutting stainless steel, cast iron, powder metal, and titanium.

Near-dry machining of these harder metals cuts friction and tool wear. "Especially in the operations that are typically done dry, adding a little bit of lubricant to that same operation often increases tool life by significant amounts," says Unist's Coffey. "And it's important to use vegetable oil, because vegetable oil alleviates thermal shock that you would normally see with a water-based coolant."■

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