JUNE 2003 / VOLUME 55 / NUMBER 6

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cover story

More for Less

PCD costs drop as tool styles proliferate.

Ingersoll Cutting Tools

Today's tougher-to-machine aluminum alloys require advanced PCD materials and tools.

It's common machine shop wisdom: Polycrystalline diamond cutting tools last a long time and can be run at high metal-removal rates when machining aluminum, but they cost a lot. Although there's some truth to that, there's also more to the story.

The aluminum of today is not yesterday's aluminum. Newly developed alloys, especially high-silicon composites, require careful selection of the tool grade and geometry to maximize productivity and part quality.

Another change involves costs. Competitive pressures and process improvements have cut the price of PCD tools by half, or more.

The upshot is that more PCD tools for machining aluminum are available than ever, and they're available for less.

PCD Basics

PCD starts as a mixture of diamond particles and a catalyst. Subjected to high pressure and temperature, the mixture becomes an extremely hard composite with unique properties.

According to Dr. Gabriel Dontu, technical support manager at Diamond Abrasives

Corp., New York, diamond-grain intergrowth occurs in the synthesis process. "Bridges" develop between individual diamond grains, he explained. The result is an almost solid diamond material with islands of catalyst.

"It's not like with PCBN (polycrystalline cubic boron nitride), where you don't have an actual bond between the CBN particles," he said. "In PCD, there is intergrowth; you have coherent crystalline lattice bridges connecting the diamond grains."

Industry classifies PCD tools by grain size. Depending on the manufacturer, fine, medium and coarse grades roughly correspond to grain sizes of 2µm, 10µm and 25µm, respectively.

Coarse-grain PCDs are stronger and more wear-resistant than fine-grain grades, and they offer excellent tool life when roughing. But, coarser grains also result in tools whose cutting edges cannot impart finishes as smooth as those achievable with fine-grain tools. A fine-grain tool provides a better surface finish but wears more quickly.

ClappDiCO

ClappDiCO's new line of milling cutters are fitted with throwaway PCD inserts.

Price Pressure

Historically, sticker shock has been the major impediment to widespread acceptance of PCD tools. Things have changed over the past 2 years, though. During that time, industry sources estimate that PCD tool prices have dropped 40 to 60 percent. Basic economics explains part of the price plunge: Supply exceeds demand.

PCD first began to significantly outperform carbide in the early 1990s, and demand for PCD tools grew throughout that decade. Lately, however, as the technology has matured, the growth in sales has slowed. The current manufacturing economy also has dampened sales. And, industry sources say, new competitors have shaken the price structure for PCD tools.

Tommy Corcoran, president of American Superabrasives Corp., Red Bank, N.J., credited lower processing costs and better fabrication techniques for part of the price reduction. He pointed out that EDM technology, used to rough out diamond blanks, improves continually. And for finishing the cutting edges, "the diamond wheels of today are much better and less expensive than those of 10 years ago," he said.

Automakers Drive Change

U.S. consumers like their vehicles big. This, combined with economic pressures and CAFE (Corporate Average Fuel Economy) standards, forces automakers to search continually for greater fuel efficiency. Aerospace manufacturers face similar pressures. The result is a growing number of applications for lighter manufacturing materials, such as plastics, composites and aluminum.

If light is good, lighter and stronger are even better. Silicon is a major alloying element in the newer aluminums. Materials made with it weigh the same, or less, while exhibiting increased hardness, strength and wear-resistance, along with better thermal-expansion characteristics.

The percentage of silicon in aluminum determines both its performance and machinability. Alloys with silicon concentrations at the full saturation point are called eutectic. In hypereutectic alloys—above 12.6 percent silicon concentration—the silicon precipitates out of the aluminum matrix in the form of solid particles.

Below about 12 percent, the alloys are called "hypoeutectic" and the silicon is mixed with the aluminum so there are no precipitates. Hypereutectic aluminum alloys have the greatest wear-resistance, rigidity and fatigue strength. But, as is usually the case in metalcutting, improved material properties means poorer machinability.

John Erb, chief engineer at United Engine & Machine Co., Carson City, Nev., pointed out the difficulties of machining hypereutectic aluminum alloys, especially the T-6, heat-treated 390 alloys used to make the company's KB pistons.

Erb said aluminum itself is not difficult to machine, but nothing short of diamond can cut the silicon particulates in the hypereutectic types. He referred to the particulates as "rocks," and emphasized the necessity of sharp PCD tools.

"The sharp edge of the tool actually cuts the rocks and makes a nice finish," Erb said. "If the tool is dull, it won't cut the rocks. It will rip them out of the matrix, leaving a rough finish."

Softer aluminum alloys aren't necessarily easier to machine, especially when fine finishes are required. There are challenges to cutting them, too.

Dr. Bert Erdel, president of the Innotool division of Ingersoll Cutting Tools, Rockford, Ill., said problems with low-silicon aluminum include poor chip formation and built-up edge. “It can be much easier, depending on what cutting geometry you offer, to finish a part that is a little harder,” he said. “A gummy aluminum—below 9 percent silicon—can be very difficult to cut. With a harder [aluminum workpiece] surface, you can get a better finish.”

Aluminum metal-matrix composites can be thought of as extensions of hypereutectic aluminum alloys. MMCs combine ceramic fibers, or particulates, with a metal alloy base. The reinforcing fibers offer improved mechanical and physical properties while the composite, overall, retains aluminum’s favorable characteristics.

Aluminum MMCs are strong and light and offer good thermal stability and conductivity. Conversely, their excellent wear- and abrasion-resistance is gained at the expense of machinability.

Right Tool for the Job

Tom Drury, general manager of J&M Diamond Tool Inc., East Providence, R.I., said that when machining aluminum, a carbide tool’s wear life is about 5 percent of a PCD tool’s. “And, you rough with carbide at 400 sfm while with PCD you rough at 1,200 sfm—even in the high-silicon aluminums,” he said.

The following companies contributed to this report:

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Ingersoll Cutting Tools
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J&M Diamond Tool Inc.
(800) 777-6813
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Mastertech Diamond Products Co.
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www.mastertechdiamond.com

United Engine & Machine Co.
(800) 560-4814
www.kb-silvolite.com

Drury recommends fine- or medium-grain PCD grades for machining no-silicon and low-silicon aluminums, and coarse-grain grades for alloys with a higher silicon content.

Ed Mohrbach, vice president of sales and marketing for ClappDiCO Corp., Whitehouse, Ohio, agreed that high-silicon alloys should be machined with a coarse-grain PCD. If surface finish is a problem when milling, he added, “use a wiper insert with a smaller grain size to sweep the surface; it will give you a good finish.”

Correct application is a must, according to Drury. “Users never forget a bad tool. There’s a reason for any tool failure, and usually it’s because it’s been misapplied.”

He said he wouldn’t sell a tool he knew would be applied incorrectly. “When someone calls, I always look for the details of the application. They may say, ‘I want diamond because it’s hard.’ But diamond doesn’t work well just because it’s hard. It has to be used in the right applications.”

He recalled an example of a misapplication. A customer turning stainless steel asked for diamond because his carbide tools were failing quickly. Drury pointed out that diamond tools wear rapidly when machining ferrous workpieces because the diamond combines chemically with the carbon in the steel. The right choice for hardened steels is PCBN, he said.

Generally, PCD tools with positive geometries should be applied. They reduce cutting forces and minimize BUE. However, when machining a high-silicon alloy, it may be appropriate to modify the positive geometry, especially when switching from carbide to PCD. “If you’re replacing carbide tooling with a 25° flank on it, you may want to look at reducing it slightly,” said Drury. Reducing the angle will prevent exposing the diamond edge to “a real mean material.”

Tom Frakes, president of Mastertech Diamond Products Co., Mentor, Ohio, said too much positive rake can be a problem, because the greater a tool’s positive rake, the weaker the edge. Put another way, the less clearance angle on a PCD edge, the stronger the edge.

To provide as much edge strength as possible but still maintain a positive geometry, Frakes has pocketed a negative-rake CNMX insert and brazed in a PCD tip at a positive cutting angle. The negative rake on the insert provided a stronger edge, “but you could still shave with it.”

As for edge preparation, Drury said, “we don’t do a lot with diamond. If we do anything at all, we apply a very light hone.” A light hone is appropriate for milling applications, where, Drury said, “putting in some axial rake can also help get better performance.”

Success with PCD inserts sometimes depends on more than proper geometry and application parameters. (Feed rates with PCD tools typically range from 0.005 ipr for finish turning to 0.015 ipr for roughing.) Drury cited one such instance.

A large automotive shop was producing 1,500 parts per diamond insert in a grooving application, but the chips were damaging the workpiece. To create a chipbreaker, Drury said he “got really exotic” and EDMed a radial chipbreaker right into the top of the diamond. The customization (applied to a run of 50 inserts) paid off. “They went from 1,500 to 4,300 parts on the same tool,” he said.

Rigid and Fast

With diamond’s hardness comes a tradeoff: a lower degree of toughness than carbide and a much lower degree than HSS. Edge chipping is a common mode of PCD tool failure. Often it’s a result of the vibration that arises during machining. Reducing tool overhang or spindle length can help, as can assuring the rigidity of the machine itself.

A rigid machine is a must when using PCD. Drury pointed out that most shops machining high-silicon aluminums and MMCs operate up-to-date CNC equipment.

High cutting speeds also serve to protect the cutting edges of PCD tools.

American Superabrasives' Corcoran said, "If they are turning at carbide speeds, our stuff is going to fail. We know our tools will blow carbide out of the water, but if you don't turn up the speed two to three times, it won't work."

For most applications, the tool used consists of a carbide blank with a PCD tip brazed to it. The integrity of the braze plays a major role in tool life. High cutting temperature can cause braze wetting and dislodging of the PCD tip. Depth of cut exceeding 60 percent of the PCD tip's length can also negatively impact the braze. Reducing the cutting speed and/or DOC will help reduce tool tip temperatures if braze integrity becomes an issue.

When taking on an aluminum alloy with a PCD tool, Ingersoll's Erdel said that "you have to distinguish between tools that penetrate the workpiece and tools that machine the surface. When you penetrate a workpiece, you need to make sure that chips can be evacuated out of the work area."

While coolant isn't usually necessary for most surface-machining operations in aluminum, he said, it's often required to evacuate chips and cool and lubricate the cutting edges when drilling or boring.

Erdel also mentioned the importance of rigid toolholding. "Even with a beautiful tool, if you have a poor holder, you can't achieve a good finish." He recommends using HSK-style toolholders for PCD because of their rigid clamping power and ability to transmit the torque loads associated with high-speed machining.

Evolving Technology

In response to continuing demand for better tool performance, and to gain share in a tough market, toolmakers are advancing PCD technology on a number of fronts.

One involves changes in the synthesis processes. Diamond Abrasive's Dontu said promoting greater intergrowth between grains in coarse-grain tools increases wear-resistance. The company's grade CTH 025 offers a 25 to 30 percent improvement in wear-resistance over equivalent coarse-grain grades, he reported. The grade is designed for applications in which highly abrasive MMCs are cut.

Dontu also cited new grades that feature multiple distributions of grain sizes. These types of PCD are called "multimodal." They were originally developed for the mining industry, where toughness is paramount. Each grade incorporates a wide range of grain sizes.

For example, Diamond Abrasive's multimodal grade CTM 302 combines particles from 2µm to 30µm. Dontu said the combination of large and small particles provides an edge equivalent to a 10µm grade, and tool life exceeds grades made only of coarse grains.

Several years ago, Sumitomo Electric Carbide Inc., Mount Prospect, Ill., introduced a submicron (0.5µm) grade called DA2200. The company said it imparts extremely fine finishes and has nearly the same strength as carbide.

In response to recent price pressures, the company brought out a less-expensive alternative to DA2200. Sumitomo says advanced sintering processes have enabled it to produce DA2200 material that is one-third the thickness of standard PCD diamond layers, yet tools made from it have the same strength as those made from grades with thicker layers. Cost savings result because less material is used and less is removed during the grinding phase of tool-blank production.

Corcoran said there is increasing development and use of PCD-tipped multifunctional rotary tools that can drill, bore, chamfer and finish a hole in one pass. Such tooling can reduce costs for an auto manufacturer, for example, by allowing it to machine thousands of transmissions before regrinding.

ClappDiCO's new Super Speed milling cutter also eliminates PCD regrinding. It features a throwaway, mini-tip insert with a chipbreaker that contributes to efficient chip control.

Mohrbach added that the Super Speed cutter body is made of lightweight stainless steel that resists the damage often caused by abrasive aluminum chips and coolant-wash damage. The cutter also incorporates a cam-actuated, axial-adjustment device that eases insert adjustments and minimizes hardware.

Developments like these, along with more user-friendly pricing, have made PCD more attractive than ever.