JUNE 2007 / VOLUME 59 / NUMBER 6

➤ BY BILL KENNEDY, CONTRIBUTING EDITOR

A PCBN tool with PCBN content in the 50 to 65 percent range (pictured is the BZN HTM 2100 grade from Diamond Innovations) is appropriate for hardened steel machining applications like this turning operation.

Diamond Innovations

Apply Directly To Workpiece

A review of superabrasive tool technology and application tips to help shops beat the headaches of machining difficult-to-cut materials.

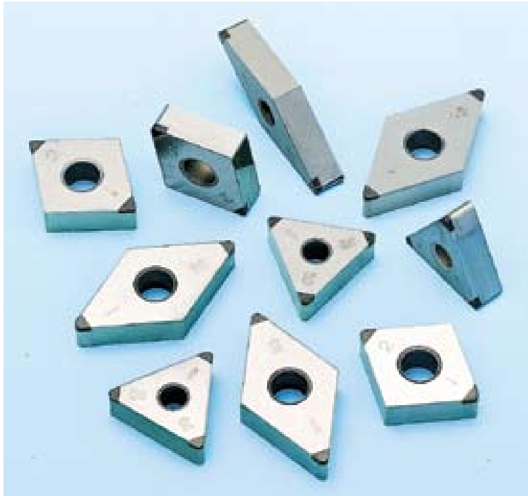
For a metalworking shop, continuous improvement can be a continuing headache. Consumers demand higher product performance and lower prices while product designers utilize lighter, stronger and harder to cut materials to meet those demands. Then, it's up to the shop to find ways to machine those workpieces with maximum efficiency and precision.

Advanced cutting tool technology helps shops keep up. To productively machine materials like high-silicon aluminums, reinforced composites and high-temperature alloys, toolmakers offer superabrasive tools composed of polycrystalline diamond (PCD) and polycrystalline cubic boron nitride (PCBN). A monocrystalline diamond has been recently developed.

Synthetic diamond is the hardest man-made material; cubic boron nitride (CBN) ranks second. However, diamond reacts chemically with the iron in ferrous materials, causing rapid wear that generally makes diamond tools unsuitable for machining ferrous workpieces. CBN has less affinity to iron and is more stable at high cutting temperatures, making it ideal for machining hardened or abrasive ferrous materials, such as hardened steels (>45 HRC) and cast irons.

Greater Variety

Jim Graham, Ph.D., machining products manager for Diamond Innovations, Worthington, Ohio, said the variety of PCBN grades available is greater than that of PCD grades



Sumitomo Electric Carbide

Finishing applications with PCBN tools usually involve multiple-tipped and ground inserts, like these from Sumitomo. The size of the brazed-in tips is sufficient to match typical DOCs when finishing with carbide inserts.

because there are fewer variables in the makeup of PCD tools. PCD grades are differentiated by diamond grain size; tools made with coarse grains are tougher, while finer grain tools impart finer surface finishes (more detail on PCD tools later). "Basically, you are manipulating only one variable," Graham said.

Grain size is also a variable in PCBN tool synthesis; sizes range from 8 microns in coarse-grain tools to submicron size in fine-grain examples. In general, the stability and quality of the cutting edge improves as grain size decreases. However, the performance of PCBN tools can also be manipulated by changing the percentage of the tool's PCBN content relative to that of its metal or ceramic binder.

Thermal conductivity—a tool's ability to carry away heat—increases in line with PCBN content and plays a key role in the performance of PCBN turning tools. In tough applications, such as heavy roughing of cast iron, high PCBN content (about 70 percent or greater) enables a tool to diffuse heat generated in cutting and maintain the toughness and wear resistance required for these severe cutting processes.

Finishing operations, however, do not generate as much heat as heavy cuts. In these cases, low-content PCBN tools allow heat to remain in the workpiece, softening the workpiece at the entry point and reducing the amount of energy needed to make the cut. Low-content PCBN tools are generally recommended for finishing hard ferrous materials, such as hardened steels.

Typical PCBN binders include aluminum, aluminum oxide, titanium carbide and titanium nitride. Varying the composition of the binder to minimize chemical interaction with a specific workpiece material is another way to fine-tune tool performance.

Often, the application determines tool composition. Sumitomo Electric Carbide Inc., Mount Prospect, Ill., is expanding application of its PCBN tools in P/M and high-temperature alloys, such as Inconel. According to Hiroshi Muraki, engineering product manager, Sumitomo frequently tests both a high-content BN700 grade and a lower-content BNX20 grade and determines which is best for a specific application. While the higher-content grade provides good wear resistance and toughness at high cutting speeds—1,100 to 1,400 sfm in Inconel depending on the application, for example—the lower-content grade will occasionally be the better choice when chipping resistance is crucial.

According to Muraki, turning speeds when cutting Inconel with PCBN can be five to 10 times higher than those achieved with solid-carbide tools, reducing cycle times. Feed rates are basically the same or slightly lower. For example, if carbide tools are feeding at 0.006 ipr, the PCBN can be fed at 0.006 or 0.004 ipr.

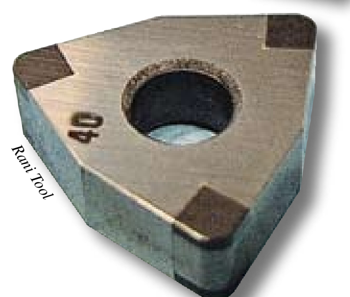
Paul Ratzki, marketing supervisor for Sumitomo, said finishing applications involve multiple-tipped, ground inserts. "Where a customer may be using solid-carbide, we can match their finishing DOC, which might be 0.020" or 0.010"," he said. Muraki added that PCBN tool life under these conditions can be five times that of carbide.

Avoiding 'Sticker Shock'

Initial price is a traditional drawback to applying superabrasive tools, with users experiencing "sticker shock" compared with conventional tools. Manufacturing techniques, though, are helping to reduce tool costs.

Daniel Cossarin, marketing manager for Rani Tool, Newington, Conn., gave the example of technology that enables the pressing of a "sandwich" consisting of carbide surrounded by PCBN. The layered material can be brazed into the corner of an insert in a single operation. Eliminating the second operation (for each insert corner) reduces manufacturing costs. The result is a less-expensive tool that, in negative geometries, can be flipped to permit machining with both sides of the insert.

PCBN tool development is often driven directly by market forces. Diamond Innovation's Graham presented the case of growing demand for tools that can more productively machine recently cast irons. Apparently, tools



Pressed PCBN/carbide/PCBN "sandwiches" (top photo) can be brazed into insert corners (above) in a single operation, reducing tool manufacturing costs. The resulting inserts, like these from Rani Tool, are less expensive, and inserts with negative geometries can be flipped to permit machining with both sides of the tool.

last longer when machining iron that has aged 4 or 5 days after casting. Graham said the reason isn't totally clear, but nitrogen absorption over that time may change the iron's surface microstructure and make the material break down more easily. However, just-in-time manufacturing and limited availability of cast iron have led to many cast-iron parts, such as brake disks, being machined only 1 or 2 days after they are cast. Tool life has suffered and "the end-user community is pushing back on us to make better products so they can get their tool life back to where they need it," Graham said.

Diamond Cutters

PCD tools begin as a mixture of diamond particles and catalyst. Intergrowth occurs between the diamond grains during the synthesis process. The larger the grains, the greater the intergrowth between them and the more wear resistant the tool.

PCD tools are generally characterized according to grain size. Depending on the manufacturer, fine, medium and coarse grades correspond to grain sizes of 2, 10 and 25 microns. Although coarse-grain PCDs are stronger and more wear resistant than finer-grain grades, the coarser grains have rougher cutting edges. A coarse-grain grade will offer excellent tool life in roughing but generally produces a lower quality surface finish. A fine-grain material will impart a finer surface finish with somewhat reduced tool life.

Since being introduced in the mid-1970s, PCD tools have gradually evolved, according to Stuart Robertson, product engineer for cutting tools at CITCO Diamond and CBN Products, Chardon, Ohio. Two newer PCD technologies—submicron-grain tools and "intermodal" grades featuring two or more different grain size distributions—can produce better finishes and increase tool wear resistance, said Robertson. Manufacturing these grades is possible because "the raw material suppliers have improved their capabilities with presses and production processes for submicron grades," he said.

The submicron-grain tools have dense diamond intergrowth, reducing the amount of matrix between the grains. The result is good abrasive wear resistance and enhanced toughness, as well as the ability to sustain cutting edges that can impart fine finishes.

At IMTS 2006, CITCO exhibited its new Dipax D4 submicron PCD grade, recommended for milling and roughing aluminums that require tools with high abrasion resistance. "We found it good for fine finishes on aluminum wheels and some milling applications," Robertson said.

The grade has a price premium (about 15 percent on standard tools), a result of higher costs for the fine-grain raw materials and advanced grinding techniques to generate the cutting edges, but that premium is offset by the tools' ability to increase productivity by 20 to 30 percent, according to CITCO.

The following companies contributed to this report:

CITCO Diamond and CBN Products
www.citcodiamond.com
(440) 285-9181

Kennametal ClappDiCO
(800) 537-6445
www.clappdico.com

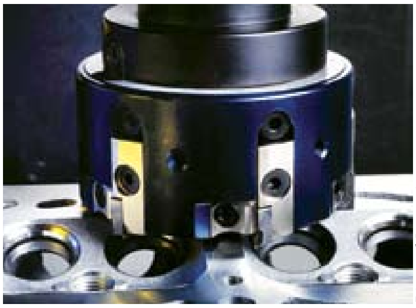
Conicity Technologies
(877) 752-6132
www.conicity.com

Diamond Innovations
(800) 443-1955
www.abrasivesnet.com

Rani Tool Corp.
(888) 554-RANI
www.ranitool.com

sp3 Cutting Tools Inc.
(888) 547-4156
www.sp3inc.com

Sumitomo Electric Carbide Inc.
(800) 950-5202
www.sumicarbide.com


Diamond Innovations

Intermodal PCD grades, such as the Diamond Innovations Compax 1800 inserts in this cutter, combine the ability to produce good surface finishes with the toughness required to withstand the interrupted cutting experienced in this milling operation on an aluminum cylinder head.

Robertson said intermodal grades combine the performance characteristics of finer-grain and coarse-grain tools. CITCO's intermodal D3 grade contains coarse, medium and fine diamond grains. The grade's composition provides impact strength and high resistance to abrasion, while producing good surface finishes and extending tool life, Robertson said. The combination can boost throughput when milling highly abrasive workpieces, such as composites.

Recent advances in round-tool PCD production techniques, specifically grinding, have boosted hole finishing accuracy, according to Jerry Natter, engineering manager at Kennametal ClappDiCO, Whitehouse, Ohio. Previously, he said, reamers featuring a single, adjustable PCD blade were "the only way to get a really true hole." The ability of toolmakers to produce accurate cutting edges and finish grind them has advanced to the point where "we are controlling size very accurately on multiple-flute tools so there is no field setup needed." He added that the tools can hold tolerances of ±2μm in aluminum and other nonferrous materials.

Kennametal ClappDiCO makes the tools as specials, in diameters from 6mm to 100mm, with most ordered by automotive industry companies. Natter added that a shop can gain maximum benefits from special tooling by grouping two or three operations into one tool design. "That's where it really pays off; shops can get the precision hole with more features," he said.

From Coatings to Thick Film

In the 1990s, diamond coatings created via chemical vapor deposition became a viable alternative to PCD tools. The coatings enabled diamond technology to be applied where use of PCD was difficult or impossible, such as on complex insert geometries and round tools. Where applicable, diamond coatings also were more economical than PCD tools.

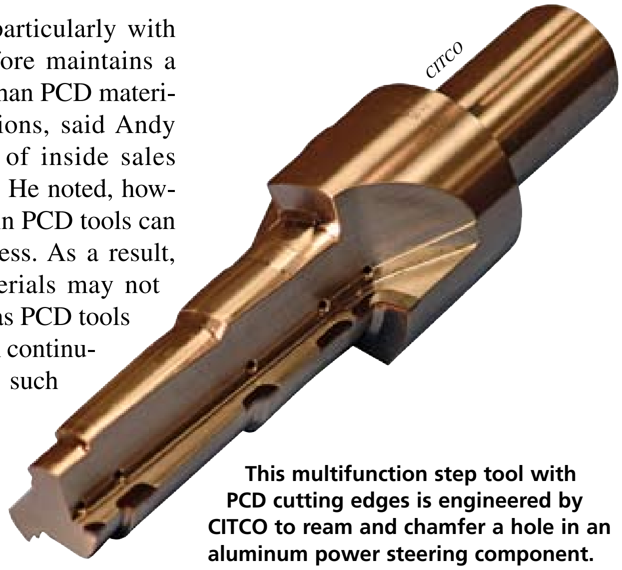
In the early 2000s, tool manufacturers began using the CVD process to produce sheets of "thick film" diamond (typically 500μm thick) that was laser-cut into tool tips and fabricated into tools much like PCD. In some applications, CVD diamond tools have demonstrated tool life two to three times that of PCD tools.

sp3 Cutting Tools Inc., Decatur, Ind., calls its thick-film tools TFd. Because the thick film material has no binder, it is less likely to break down during machining—particularly with coolants—and therefore maintains a sharper cutting edge than PCD materials in some applications, said Andy Schneider, manager of inside sales and customer service. He noted, however, that the binders in PCD tools can increase their toughness. As a result, some thick-film materials may not be as shock-resistant as PCD tools and are best applied in continuous cutting situations, such as grooving.

Chipbreaking PCD

A longtime characteristic of PCD tool application has been the difficulty of creating inserts with precision chipbreakers, either by forming the chipbreakers during synthesis or grinding the hard diamond thereafter.

Rani Tool technical and sales support representative Scott von Richter said Becker Diamond of Germany (whose tooling Rani distributes in the U.S.) has developed a process whereby a chipbreaker can be burned via laser into the PCD tool tip after the tip is brazed to the insert body. The process creates precise and complex chipbreakers, he said.



This multifunction step tool with PCD cutting edges is engineered by CITCO to ream and chamfer a hole in an aluminum power steering component.

The tools are being applied in

Cutting edge hints

Superabrasive tools can require special attention to tool geometry and cutting edge preparation. Tool providers contacted for this article provided a variety of edge-prep hints and opinions.

■ Hiroshi Muraki of Sumitomo Electric Carbide Inc. said when machining high-temperature alloys with PCBN tools, edge preparation depends on the application. "In some cases we need to add some small edge treatment, but basically small or no edge treatment is better." Sumitomo's Paul Ratzki added that if the edge preparation is too large, there is a risk of built-up edge.

■ According to edge preparation specialist Conicity Technologies, Cresco, Pa., the traditional T-land edge prep on a PCBN tool creates an unnecessarily exaggerated negative geometry that increases tool pressures and can cause failure. William Shaffer, vice president, said a properly shaped edge preparation (not simply a radius) will reduce tool pressure by as much as 40 percent while reducing tool flank wear and thereby increasing tool life. Chipping, common in PCBN tools, can be reduced or eliminated. The right edge preparation shape can increase tool life as much as 300 percent in many hard-turning applications. "The key is maintaining a precise shape on the edge prep, not just rounding the edge," Shaffer said.

■ Jerry Natter of Kennametal Clapp-DiCO said wiper geometry in PCBN tools, where the tool's nose radius is followed by a large radius or flat edge, cleans up the surface finish or permits higher feed rates while imparting the same surface finish. Wipers do increase tool pressure, but in hard-turning operations, "it's not really a factor because the parts are heavy enough and the machinery is usually designed to take it," he said.

■ Adding a light hone on the cutting edge of PCD tools "gives better tool life, and it may give better finishes than a sharp edge on startup," said Stuart Robertson of CITCO Diamond and CBN Products. "Sometimes, you'll see a finish get better after initial runs because the sharp edge will hone itself in as it produces parts. In certain applications, a hone produces finer finishes right off the bat rather than having the tool break itself in and get better finishes later on."

■ For most applications, PCD tools should feature a neutral or slightly positive rake angle (5° to 8°) with 10° to 13° flank clearance, according to Diamond Innovations. When replacing high-positive carbide tools (15° to 20° rake, 20° to 25° clearance angles), rake and clearance should be reduced to avoid edge chipping in roughing and interrupted cuts.

■ For maximum tool strength, negative geometries are recommended when machining hardened steel or cast irons with PCBN tools, according to Scott von Richter of Rani Tool Corp. However, if high tool pressures cause vibration, a slightly more positive geometry or cutting edge angle may solve the problem, as will a reduction in chamfer angle or nose radius.

—B. Kennedy

grooving operations and especially in wheel turning and aerospace applications. In an automotive wheel-turning operation on AlSi9 alloy, replacing a carbide insert with a VCGT-style PCD insert featuring a chipbreaker increased parts per edge from 250 to 2,800, according to Rani Tool. Higher cutting speeds and reduced downtime for insert changes improved productivity by 75 percent.

Tool Selection

The abrasiveness of the workpiece material is the key factor in selecting a superabrasive tool. Initially organized for internal company use, sp3 devised Material Application Code numbers to categorize tools for certain applications by giving each coating a MAC number based primarily on workpiece abrasiveness. At the bottom of the list, requiring the thinnest coatings, are less abrasive workpiece materials such as graphite, carbon and unreinforced plastics. At the high end are high-silicon aluminums and metal-matrix composites.

For example, coatings characterized as MAC 5 are 12- to 16-microns thick and are best for rough endmilling materials such as green carbide and graphite. MAC 17/18 coatings, 26- to 38-microns thick, are recommended for milling and turning carbon-fiber composites and low-silicon aluminums. Intended to handle very abrasive materials, such as carbon fiber and metal-matrix composites, MAC 20 coatings are 45- to 60-microns thick.

sp3's Schneider said because thicker coatings on small diameter (<1mm) micrograin round tools tend to peel off or delaminate, MAC coating recommendations are 30 to 50 percent thinner than those for larger diameters. "Some people think thicker is always better. The fact is the thicker you get, the duller the cutting edge," he said. "And that may affect the finish you are trying to achieve."

As sp3 added to its superabrasive product offerings, it extended the MAC system beyond coatings to insert materials. PCD is designated MAC 30, the company's TFd thick-film diamond product is MAC 40, and PCBN tools, generally for ferrous applications, are MAC 50. MAC 30 and 40 tools are typically applied in insert milling and turning highly abrasive materials, such as high-silicon aluminums.

Schneider said not every superabrasive tool application is difficult. There are many standard tools "that work extremely well right off the bat, and then we have other applications where we have to fine-tune things. We've got some low hanging fruit we can get at, then we've got challenges as well." △

sp3 Cutting Tools

CVD coating technology enables PCD to be applied on complex insert geometries and round tools. CVD reactors like this one at sp3 can apply pure diamond coatings in thicknesses from 6μm to 45μm at a rate of 0.5μm/hr.