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SPECIAL FOCUS: PCBN TOOLS

BY BILL KENNEDY, CONTRIBUTING EDITOR

# Making the Grade

**Application-specific PCBN grades enhance metalcutting operations.**

The evolution of workpiece materials and manufacturing processes drives cutting tool development. A good example is the growing use and specialization of tools composed of polycrystalline cubic boron nitride.

Today's PCBN grades can fulfill the requirements of a wider range of applications than earlier grades, which were hard but lacked sufficient toughness. Advanced manufacturing methods enable toolmakers to develop grades that optimize performance on specific workpiece materials and in specialized processes, such as hard and interrupted turning.

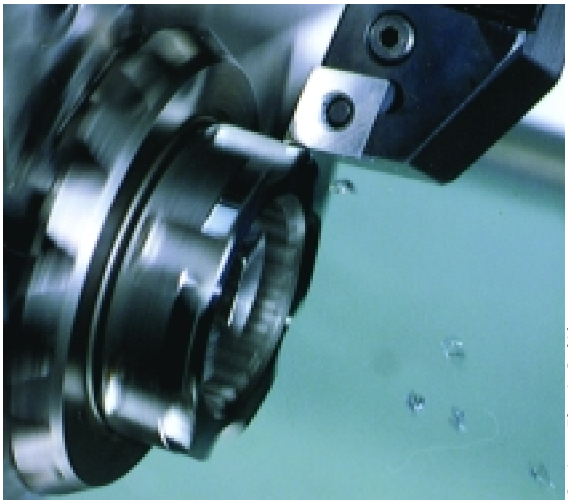
This broader applicability has spurred the growth of PCBN tools. Industry sources say usage has doubled during the past 5 years.

## Customizing Compositions

First synthesized in the late 1950s, cubic boron nitride is made from hexagonal boron nitride via a high-pressure, high-temperature process. The only known material harder than CBN is diamond.

Tools for cutting metal are made of polycrystalline cubic boron nitride, a composite formed by sintering CBN particles with a metallic or ceramic binder, such as aluminum, aluminum oxide, titanium carbide or titanium nitride. Among the variables that can influence a PCBN grade's performance are the percentage of CBN particles and grain size (Figure 1). In general, a high concentration of particles increases a tool's resistance to abrasion and results in greater compressive strength.

DeBeers Industrial Diamonds, Shannon, Ireland, says the CBN content of its grades ranges from 45 to 90 percent, by volume. Grain sizes run from 8µm, for coarse-grain tools, to submicron size, for fine-grain tools. The stability and quality of the cutting edge tends to improve as grain size decreases.



*Sumitomo Electric Carbide*

**Toolmakers have developed PCBN grades tough enough to handle interrupted turning.**

Good thermal conductivity is one characteristic of CBN, and a tool's ability to remove heat from the cutting zone increases as CBN content rises. This thermal conductivity is one reason PCBN tools perform well in hard-turning operations.

In heavy-roughing applications, the heat generated in the cut softens the superficial layer of the workpiece, making it easier to machine. The toughness and wear-resistance of tools with a high-CBN content are well suited for this severe environment. However, such a grade is not generally recommended for finishing. The lighter depths of cut employed do not allow enough heat to be generated to soften the workpiece surface.

Low-content-CBN tools, on the other hand, are less thermally conductive. They permit an adequate amount of heat to remain in the workpiece. The heat softens the workpiece at the point of cut, reducing the energy needed to part the metal. (DeBeers calls the process "self-induced hot cutting.") Tools containing lower amounts of CBN are generally recommended for finishing hard ferrous materials.

The temperatures and "hits" that a PCBN tool will experience during machining determines the composition of its binder. For example, the components of an aluminum binder can help the tool resist high temperatures.

However, those same components may increase the tool's brittleness, making it inappropriate for interrupted cuts. A TiN binder, conversely, gives a tool the compressive strength needed for interrupted cutting.

One grade developed for interrupted cuts is DeBeers' low-content (45 per-

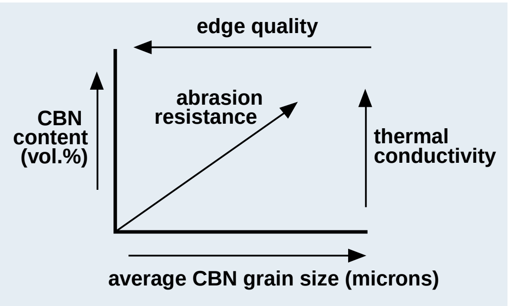



**Figure 1: A high concentration of CBN particles increases a tool's resistance to abrasion, while cutting-edge quality improves as grain size decreases.**

cent, by volume) DBN45 grade. Its submicron particles preserve edge quality while its TiN binder provides compressive strength. DeBeers tailored the grade for finishing operations on hardened steel. The grade can be run at 394 sfm, a 0.04-ipr feed and a 0.08" DOC when finish machining 60 HRC, cold-worked D-3 tool steel.

Dr. Gabriel Dontu, technical support manager for Diamond Abrasives Corp., New York, said two major PCBN trends are occurring. One is the development of grades specifically targeted at a narrow range of workpiece materials and applications. This has led to productivity benefits, Dontu said, but "the drawbacks are increased manufacturing and tool costs, as well as the addition of a new variable to an already complex process."

The other trend is the development of "more forgiving" grades that can cut a wider range of materials and be applied in more applications. These tools will simplify the manufacturing process for toolmakers and make it easier for users to select the best PCBN tool for their application.

"The downside is that we are not there yet," Dontu said of the second trend.

### Go Configure

PCBN materials are available in a variety of configurations, including solid inserts; carbide-backed, full-face inserts; and carbide inserts with large or small PCBN tips (Figure 2). Solid inserts offer edge security (they're less likely to fail than other styles), shock resistance and multiple cutting edges. But they are expensive and may not fit all tool bodies.

Full-face PCBN inserts backed with tungsten carbide are more adaptable to standard tool bodies. Carbide inserts with brazed PCBN tips offer economy and feature single or multiple tips per insert. Recently, "mini-tip" inserts have been introduced; they're inexpensive enough to be considered throwaway tools.

However, tools with smaller tips can't be run with as big a DOC as larger-tip tools. While a standard-tip insert may be capable of a 0.060" DOC, a mini-tip is often limited to 0.015".

As with any brazed tool, edge security becomes a concern when the tip's DOC capacity is exceeded. Excessive heat can weaken the braze, compromising the integrity of the tool.

Rizwan Hasan, engineering supervisor at Sumitomo Electric Carbide Inc., Mount Prospect, Ill., said the company's new BNX25 grade for interrupted cuts represents a step toward resolving concerns about tipped-insert edge security. Its PCBN tips are brazed directly onto a carbide insert rather than to a carbide shim, as is the case with other PCBN-tipped tools.

### Edge Preparation

The hard, relatively brittle cutting edges of PCBN tools are subject to chipping, so up-sharp inserts are rarely produced. Instead, various edge preparations are applied to help extend tool life and improve part quality.

The basic choices include hones, T-

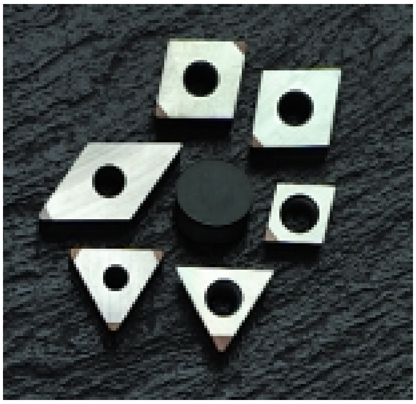



**Figure 2: A variety of PCBN tools are available, including carbide inserts with large or small PCBN tips, solid-PCBN inserts and carbide-backed, full-face inserts.**

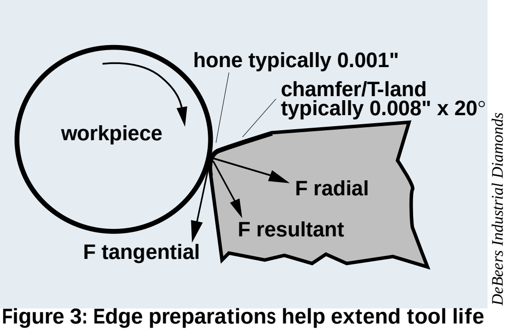



**Figure 3: Edge preparations help extend tool life and improve part quality. The basic preparations include hones, T-lands or chamfers, or a combination chamfer and hone. (F = force.)**

## PCBN, diamond exhibit different wear patterns

Diamond tools are unsuitable for machining ferrous workpieces because the carbon in diamond reacts chemically with iron. Rapid flank and crater wear result. CBN does not share diamond's affinity for iron, so PCBN tools are ideal for use on hardened or abrasive ferrous materials.

However, CBN does react with some workpiece materials at high cutting temperatures, meaning PCBN tools can experience chemical wear.

Diamond Abrasives Corp.'s Dr. Gabriel Dontu said CBN reacts with certain elements and phases. "You need to know the chemical and phase composition of the material you're machining, then choose the appropriate grade of PCBN in order to minimize the chemical interaction and maximize the mechanical performance of the tool," he said. "For example, when machining a material with a high content of free ferrite, the ferrite is going to react with the CBN, reducing the tool's life."

Dontu added, "The higher the percentage of a phase that's going to react with CBN, the lower the content of CBN you want in your tool."

—B. Kennedy

lands or chamfers, or a combination chamfer and hone (Figure 3). A hone—typically about 0.001" wide—rounds the edge and offsets its tendency to chip, but it doesn't increase edge strength to the same degree as a chamfer. Hones are effective for low-DOC, low-feed finishing operations.

A T-land or chamfer is a flat area applied at an angle to the cutting edge. Chamfers typically range from 0.004" to 0.008" in width and are applied at angles of 15° to 25°. A chamfer directs the tangential and radial forces generated during turning into the insert's body. The wider the chamfer and/or the greater its angle, the stronger the edge will be.

A chamfer combined with a hone maximizes edge protection and can be beneficial when rough turning. There is a tradeoff, though. Cutting forces increase because the modified cutting edge pushes the workpiece material instead of shearing it. Consequently, toolmakers recommend using a minimal edge prep—just enough to protect the cutting edge.

In addition, some toolmakers offer wiper-style PCBN inserts. They feature a flat edge behind the insert nose that wipes, or smoothes, the part surface. A wiper insert imparts surface finishes that are twice as fine as a standard insert, when run at the recommended feed. When the feed rate is doubled, the wiper insert will leave a finish equal to what a standard insert imparts at the recommended feed.

Insert shape also has a bearing on performance. For example, tip angle significantly influences heat management in the cutting zone. "The smaller the angle, the smaller the volume of the tool, and the smaller the [amount of heat] transmitted from the cutting area," Dontu said. That can be beneficial when machining materials that rely on putting heat into the part to soften it and, thereby, expedite the cutting action.

On other materials, though, such as nickel-base alloys, too much heat can warp the part. Dontu recently made recommendations for the machining of Rene, a tough nickel-base alloy. "You would think you would need a very tough tool, one with a large hone, a T-land and a tough edge. Actually,

## Shop turns away from grinding

Reliance Tool and Manufacturing Co., Elgin, Ill., makes mold and die components from stainless and tool steels, ranging in hardness from 52 to 64 HRC. Tolerances typically are 0.0005", with some jobs requiring 0.0003". Many of the mold components and draw punches for dies feature intricate angles and radiuses around 0.005".

Until 5 or 6 years ago, Reliance would rough the parts to size, heat-treat them and then grind the final contours and tolerances. To achieve tight radiuses, Reliance used a profile dresser to make custom grinding wheels. Making the wheels and performing the grinding was very time-consuming.

Mold shop supervisor Jeff Staes said, "We kept looking at this and saying, 'This is ridiculous to take 3 or 4 hours just to set up and dress a wheel.' "

So Reliance began to experiment with hard turning. That effort has evolved into purchasing custom PCBN inserts designed to reach the tiny part features.

"We actually have had PCBN inserts made with a 0.005" nose radius," Staes said, noting that a human hair is about 0.003" to 0.004" in diameter.

The inserts have to be applied carefully, but on some parts "there are areas you literally can't get to and grind," he said. "We developed these inserts to take care of the situation."

Machining parameters are light—about 0.002" maximum DOC and a 0.0005" feed. Staes said, "The trick is, the smaller and more fragile the insert, the lighter the depth of cut or feed. It has to be a relationship."

Edge preparation is key to the performance of PCBN inserts. An up-sharp cutting edge chips easily. A T-land or chamfer will spread forces over a larger area and increase edge strength. But reducing sharpness means the edge will push more than cut, boosting cutting forces.

To balance edge integrity and cutting forces, Reliance applies the most delicate of edge preparations to its small-nose radius inserts. Staes uses diamond polishing disks, run under a stereomicroscope, to apply hones by hand. "I give them just a light edge hone so they're not dead sharp," he said. Previously, he had the fabricator that created the custom inserts apply a hone, but they went too far. "Too big a hone creates too much pressure and the tip breaks off," Staes said.

Reliance always uses both a roughing and finishing insert when hard turning. "If you're trying to hold five-tenths or less, you don't want one tool doing all the work," Staes said. "We rough it and leave three-thousandths for a finish pass. It's enough so that the edge gets in and bites into the material, but not so much that it creates excess tool pressure or wears out the tool."

The roughing tool has to be well-maintained so that the finishing tool always cuts the same amount of stock. "If the roughing tool starts to wear," he said, "all of a sudden you're up to five-thousandths finish material, and you're going to get different tool pressures and your size is going to be gone."

For cost efficiency, Staes said he often uses a ceramic insert for roughing, usually a TiC/alumina-coated X-11 grade from Toshiba Tungaloy. He applies Toshiba's PCBN grades for finishing.

Staes said Reliance has developed its own hard-machining parameters. "Often, the supplier gives you a general area to start in and, for whatever reason, those parameters don't work. You have to analyze what is happening to the tool and adjust it."

He called interrupted cuts, which occur frequently, "a whole other ballgame … a science in itself." The key to handling interruptions, Staes said, is not to slow down the operation, but increase the speed. It's like trying to shove a straw into a potato. If done slowly, the straw crumbles. But if done quite fast, penetration is achieved. Interrupted cutting is on the same order.

"You have to develop enough speed to actually enhance the cutting ability. If you're too slow, it destroys the tool," he said.

—B. Kennedy

*For more information about* Reliance Tool and Manufacturing*, call (847) 695-1234 or visit www.reliancetool.com.*

though, it is kind of sticky and has a high tendency to strain-harden. We used a sharp edge to take forces out of the surface and not strain-harden it."

Dontu added that when applying PCBN, "the tool must be customized to the application."

Consideration also must be given to how the insert wears. Excessive wearing of the insert flank causes loss of size control. Sumitomo's engineering manager, Tom Jensby, said a hard, heat-resistant coating makes a PCBN insert more abrasion-resistant. This slows flank wear, which helps the tool to maintain size longer.

A coating can also minimize notch wear, which is caused by lack of toughness. It ensures that the insert imparts the required surface finish for a longer period of time.

Jensby said Sumitomo offers coated PCBN tools that target the problems of flank and notch wear. The TiAlN coating on the company's multitipped BNC200 grade is engineered to help control flank wear, while the BNC80 grade comes with a TiN coating engineered to resist notch wear.

### Machining Faster

Chad Hefflinger, field sales representative for ClappDico Corp., Whitehouse, Ohio, stressed the technical complexity of PCBN-tool applications. That complexity contributes to the tools' relatively high expense.

In many cases it can be difficult to justify the higher costs of PCBN unless a multiplicity of factors, including tool composition and edge prep and speed and feed, are adjusted to the specific workpiece material. When that is achieved, said Hefflinger, the savings "can be huge, especially if you're displacing grinding" with hard machining.

Industry sources report that machining-time reductions of 60 percent or more are common when hard turning replaces grinding.

And, oftentimes, Hefflinger said, hard turning can impart finishes equivalent to grinding. "Many operations employing grinding specify a 16 rms, or better, finish, and that's not difficult to achieve with PCBN. We can come in under 16 rms without trying very hard, and there are things that can be done with combinations of speed, feed and wiper inserts that can drive the finish into the 8- to 12-rms range."

Hefflinger added that grinding still has the edge when producing tight-tolerance parts requiring less than 0.0002" variation in diameter or bore.

As for ceramic tools, which are also used for hard turning, Hefflinger thinks PCBN may be a better choice. PCBN's advantage, he said, "is in the surface finish you can achieve and the size tolerance you can hold. As the edge of the ceramic tool wears, it has to be adjusted with offsets throughout the process to maintain size. PCBN tools hold their size much longer."

Sumitomo's Hasan agreed that producing an 8-rms finish is possible with PCBN tools, but "it also depends on the workpiece clamping, the insert clamping and the machine tool itself. Tolerances of plus or minus five-tenths are achievable, especially when employing wiper inserts and appropriate edge preps."

According to Todd Callaby, director of engineering for Toshiba Tungaloy America Inc., Itasca, Ill., Europeans are more involved in high-speed hard turning than North Americans.

"Europe seems to be more progressive in its thinking," Callaby said. Toshiba has developed CBN grades specifically for high-speed hard turning, and "we're seeing better acceptance of those products in Europe than we do here."

Typically, hard turning takes place at speeds of around 300 to 400 sfm, depending on the workpiece material. There are PCBN products available, Callaby said, that enable turning speeds of 800 sfm, and higher, under ideal conditions.

He added that PCBN grades designed for higher speeds have a lower CBN content and incorporate materials such as tantalum or titanium carbide to increase chemical stability. These materials minimize chemical reactions that are accelerated by the heat of high-speed machining.

"When you run fast, you can have chemical stability problems because of the heat," Callaby said.

Toshiba's BX310 grade is an example of a new high-speed PCBN tool designed to counter these problems. Its medium-size CBN grains are sintered with a heat-resistant ceramic binder to provide wear-resistance and chemical stability when cutting hardened steels at high speeds.

Tom Corcoran, president of American Superabrasives Corp., Red Bank, N.J., said North American use of PCBN tools is finally starting to grow because users in the market are catching up with Europeans in terms of modernizing their machine tools. Older machines have a limited ability to run PCBN tools, he said.

As was the case when carbide tools began to displace HSS, users are reluctant to run the tools at speeds that make them perform as productively as possible. Corcoran said that when a shop operates a PCBN tool at the same speed as carbide and it doesn't work, "They say, 'It hardly cuts better than carbide—at five times the price.' We

**The following companies contributed to this article:**

**American Superabrasives Corp.**
(800) 487-6687
www.diamond-abrasives.com

**ClappDico Corp.**
(419) 877-5358
www.clappdico.com

**DeBeers Industrial Diamonds**
(353) 61-471655
www.debid.ie

**Diamond Abrasives Corp.**
(212) 869-5155
www.diamondabrasives.com

**Sumitomo Electric Carbide Inc.**
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**Toshiba Tungaloy America Inc.**
(800) 542-3222
www.tungaloy.com

**Wasino Corp. USA**
(847) 797-8700
www.wasino.com

tell them to triple the speed and they'll get a hundred times the output."

Machine tool builder Wasino Corp. USA, Rolling Meadows, Ill., reports that cutting forces generated during hard turning may be 1.5 to 2 times higher than during conventional turning. As a result, said Wasino Applications Manager Rich Miller, greater machine rigidity and accuracy are necessary, but high horsepower is not usually required. The reason why is because roughing cuts are typically taken before hardening, and only lighter finishing passes are made on the hardened workpiece.

"Because the cuts are finishing cuts, horsepower requirements are relatively low," he said. To maintain tolerances close to that of grinding, he recommends taking qualifying cuts before finishing with a PCBN tool. "Take a prefinishing pass to remove any abnormalities in the part," he explained. "Then, on the second pass, you'll hold the size to tolerance."

As with most metalcutting operations, there are no hard and fast rules for hard turning with PCBN tools. What's good for one workpiece or operation may prove unproductive in another. However, the expanding selection of PCBN materials is making the decision to hard-turn easier than ever.