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BY ALAN RICHTER, EDITOR

A coated PCBN insert is able to handle the continuous and interrupted cuts required for machining this cast iron spline.

Carboloy

Cast Cutting

Considerations when machining gray and ductile cast iron with carbide, PCBN and PCD cutting tools.

Cast iron is defined as "a cast ferrous alloy containing carbon in excess of solubility in austenite that exists in the alloy at the eutectic temperature." How the material is made, though, is usually described in less technical terms.

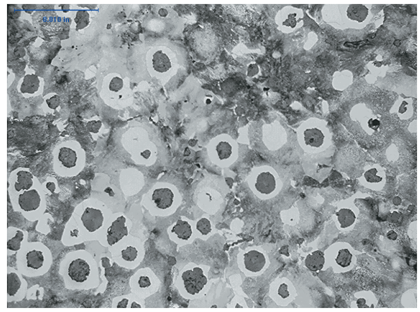
"Iron is typically made by taking a lot of junk, a lot of scrap and reclaim, and just throwing it in this big pot and melting it," said Don Graham, manager of turning products for Carboloy Inc., a Seco Tools Co., Warren, Mich. "Of course, the foundry person would be offended by how simple I'm making it sound because the chemistry certainly is a bit complicated. But because there is a wide variety of material going in, you get a wide variety of material coming out—wider than what you'd really like."

The resulting metal, however, is ideal for making large volumes of parts economically—such as automotive parts.

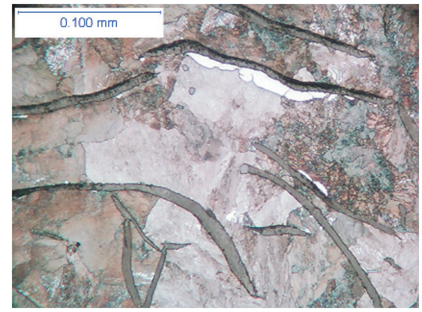
Numerous types of cast iron are available, including malleable, white, gray and ductile (or nodular). This article focuses on machining gray and ductile iron with carbide, PCBN and, when the application permits, PCD cutting tools.

Carbide Cutters

Gray iron is the dominant material



Ductile, or nodular, cast iron contains graphite spheres surrounded by ferritic and pearlitic iron phases.



Gray cast iron's flaky layers of graphite and pearlitic microstructure.

Iron Casting Research Institute

used to make an array of automotive parts, such as engine blocks, brake drums and cylinder heads. Although a third as much ductile iron is used for auto parts, roughly the same number of carbide inserts are consumed when machining ductile iron. "In other words," Graham said, "it takes about three times as many inserts to machine ductile iron as it does gray."

That's because ductile iron contains more silicon, which increases the material's abrasiveness, and some of its alloying elements contain difficult-to-machine hard particles. In addition, while gray iron consists of flaky, relatively easy-to-cut layers of graphite, the graphite in ductile iron is formed into spheres, or balls. "Around every one of those nodules, or balls, of graphite in the ductile iron there is a silicon-carbide 'eggshell,'" explained Graham. "That silicon carbide makes it quite abrasive."

Although easier to cut, gray iron also presents challenges. One is the considerable amount of heat generated in the cut. Therefore, a fairly thick, multilayer tool coating—about 20μm—incorporating a layer of aluminum oxide is recommended. An Al_2O_3 coating tolerates the high cutting speeds of 1,700 to 2,000 sfm that carbide cutters typically run at when machining gray iron.

"The thick Al_2O_3 coating does two things," Graham said. "First, it acts like an insulating tile on the Space Shuttle does, keeping heat out of the tool and rendering it harder and less prone to deformation. Second, the Al_2O_3 is chemically very stable, so it won't react with the gray iron and cause cratering."

He noted that when machining ductile iron with carbide, which is done at lower cutting speeds of 600 to 1,100 sfm, a more abrasion-resistant coating is needed. This is achieved by combining Al_2O_3 with thick layers of titanium carbonitride.

Of course, the carbide grade's substrate is also important. In addition to a fine grain structure, a modest cobalt-enriched zone helps when machining ductile iron. The reason is because as the insert begins to wear, microchipping of the coating occurs. "If that progresses, microscopic chips appear in the substrate," Graham said. "With more cobalt right under the coating, that substrate microchippage is prevented."

Dry Running

Whether gray or ductile, machining cast iron is a dirty business. That's because the graphite in the material basically shatters during machining. The result is a lot of dust and dirt around the machine tool, which shops often try to control by applying flood coolant. However, machining dry increases tool life and performance, Graham said.

Using coolant can cause thermal cracking in the tool because of temperature fluctuations. Getting coolant to where it's needed most—at the tool/workpiece interface—is difficult. The result is extreme differences in temperature between areas of the insert coolant reaches and those portions of the tool in the cutting zone.

The second reason concerns the coating. "These coatings are ceramic and ceramic is brittle," Graham said. "If you can get that coating hot, which you will at a high cutting speed and without coolant, that coating becomes tougher. Therefore, you resist microchippage along the cutting edge."

Jim Robinson, project engineer for the MODCO Div. of Valenite LLC, Oak Park, Mich., added that applying coolant can sometimes cause recutting of chips when boring engine block cylinders. Because it's difficult to get coolant down a bore that the tool has already entered, end users often direct coolant so it enters from the bottom of the bore. "What that tends to do is hold the cast iron swarf in the coolant; it acts like a fountain," he said. "It wears the tool out prematurely because the swarf is abrasive and it stays in the cutting [zone] all the time. It can cost you 50 to 75 percent in tool life."

Running dry, however, isn't problem-free. In addition to having to find another way to deal with the dust and dirt, dry machining can cause the cast iron part to heat up and increase in size slightly. "So you cut to what you think is to size, get your tolerance, pull the part out of the machine, let it cool, it shrinks a little bit and you discover you've cut the part undersize," Graham noted.

He added that one way to overcome that dilemma is upping the feed so the cut is completed before the part heats up too much.

Cut to PCBN

PCBN is another cutting tool material suitable for cast iron, according to Henrik Sandqvist, product manager of advanced materials at Carboloy. The two primary applications are gray and white iron. "Ductile iron has a lot of ferrite, so that's a material that we can't really machine with PCBN at all," he said.

Even with gray iron, the ferrite content needs to be relatively low for PCBN tools to be effective. "The free-ferrite content, which usually is stated on the part drawing or on the casting specification, should be less than 10 percent and, preferably, less than 5 percent," Sandqvist said. "Otherwise, the free ferrite in the casting is going to dissolve the CBN grains, resulting in rapid tool wear."

When the free-ferrite content is less than 5 percent, PCBN can be applied at significantly higher cutting rates, especially speed, than carbide (see Figure 1).

How much ferrite is present can depend on the season. "We see problems in the differences between winter castings and summer castings, because of the cooling rate they have at the foundry," Sandqvist said. "That influences how much free ferrite there is." He added that either season can cause the cooling rate to be outside the proper range—possibly too low of a rate in the summer and too high in the winter.

Brett Young, sales and applications manager for Kirkland, Ill.-based Shape-Master Tool Co., said that PCBN tools can be applied to ductile iron, but indicated that it's tougher to justify their use economically. Where PCBN might make sense is when the tolerance or surface-finish specification cannot be achieved with coated carbide tools, or when the user wants to replace grinding with a cutting operation.

When machining gray or ductile iron with PCBN, Young recommends a starting-point feed rate of no less than 0.003 ipr and a DOC of 0.003" to 0.125". "Increase the feed rate as much as the surface finish will allow for both productivity and tool life gains," he said. The difference is in cutting speed, where ductile should be machined at 500 to 1,000 sfm vs. gray at 2,000 to 5,000 sfm.

Young added that full-top PCBN inserts are generally required for heavy roughing and are more economical in terms of cost per cutting edge. For finishing with a DOC of 0.025" or less, multiple-tipped throwaway tools are the norm. "I have seen situations where PCBN is very cost-effective for roughing a gray iron casting—at a higher feed and DOC—but isn't cost-effective for the light cutting conditions needed to hold dimensional and surface-finish requirements," he said.

Another issue is the spacing of graphite particles. In ductile iron, the graphite forms into nodules, which are farther apart than the graphite particles in gray iron. This creates longer chips, as well as decreases the thermal conductivity of ductile iron relative to gray iron. These combined effects increase both the time and temperature conditions, which can result in chemically accelerated tool-wear rates when machining ductile iron, Young said.

Unlike machining gray iron at cutting speeds as high as 6,000 to 7,000 sfm, "with ductile iron, typically, as you go faster, at least with regard to surface footage, more heat is generated and the worse the machinability becomes," Young said.

Hot Hardness

Like carbide, machining dry is recommended for PCBN, especially when

Turn down the heat

Heller Machine Tools LP built a transfer-line machine for the production of an automotive differential case made of ASTM A-536 100-70-03 ductile cast iron, consisting of more than 5 percent ferrite, but experienced a problem. Tool life wasn't acceptable for the finishing operation that generated the case's internal sphere.

"We were taking off less than 0.010", but we were only making about 15 to 20 parts per carbide cutting edge before we had to index the insert," said Bruce Chapin, tooling engineer for the Troy, Mich., machine tool builder. "We tested five different grades of coated carbide and still could not get more than 15 to 20 parts per edge."

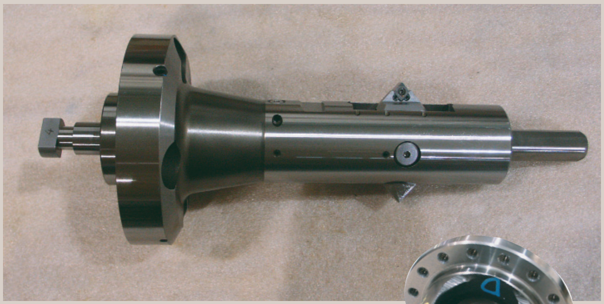
With cutting edges that lasted only a half hour, the parts producer couldn't be expected to shut down the line that frequently to index the tool and still make a profit.

Dan Diskin, vice president of tool supplier Silver Hawk Precision, elaborated that, in addition to the carbide grades, Heller also tried several PCBN and ceramic grades. Those tools also experienced rapid, catastrophic failure. "We pulled out every trick in the book."

Eventually, a new grade of PCD from Element Six was tested. "We stuck PCD in there and we didn't change any speeds or feeds and it lasted about 280 parts, which is a phenomenal difference," Chapin said.

Diskin explained that the Mapal CPGW 32.51 insert has a neutral rake, a positive cutting clearance and is ground upsharp. It's run at low machining rates with both flood and through-tool coolant to keep as much heat off the cutting edge as possible to avoid graphitization of the diamond.

Because it's a transfer line, where the longest operation determines cycle time, the relatively low speeds and feeds for



A. Richter

The Mapal drawbar-actuated tool, with PCD insert, feeds out into the ductile iron casting and finishes the four internal spherical surfaces of the differential case (inset).

the PCD tool didn't have a negative impact on cycle time. "Other stations take more time," said Jochen Dessbesell, project manager/proposals for Heller. "If this was the longest cutting time, then we'd be looking at speeding it up, but we don't want to sacrifice tool life."

To enhance tool life, Heller selected the biggest insert that the drawbar-actuated tool body would accept. "The larger the insert, the thicker the insert, the stronger the insert," said Chapin.

Part of the difficulty in machining the material is that it has a high tensile strength—70,000 psi. "To do what the part is required to do, it needs to have a high graphite density and a high tensile strength," said Dessbesell. "The required chemical composition to achieve that makes it tougher to machine."

And if the PCD didn't do the trick? "We would have kept trying more carbide grades. I'm sure we would have come up with something," Chapin predicted. *—A. Richter* milling, in order to avoid thermally shocking the tool. Sandqvist added that heat toughens the hard PCBN material, but a little goes a long way. "You don't want too much heat to stay in the insert," he said, "because even a hard material like PCBN can soften somewhat at elevated temperatures."

He explained that hot hardness indicates how much heat can enter the insert and still have it maintain a high level of material hardness. For PCBN, it's from 1,700° to 1,900° F, which is higher than the hot hardness of carbide.

Because PCBN is such a hard and wear-resistant material, coating it wouldn't prolong tool life much. Nonetheless, a coating, such as titanium nitride, is helpful. "PCBN is black and the flank wear is going to be black and the operator doesn't see that," Sandqvist said. "Having a yellow or gold coating on the insert helps the operator see when it's time to change the insert."

Although gray iron is a relatively soft material with a hardness of 240 HB or so, it is quite abrasive, although not as abrasive as ductile iron. With that in mind, an abrasion-resistant grade of PCBN is required. That generally means applying a high PCBN-content grade, one consisting of about 90 percent CBN. The remaining 10 percent is a ceramic binder.

When it comes to edge preparation, Sandqvist said a small chamfer, from 0.004" to 0.008" (0.1mm to 0.2mm), protects the edge from breakage. "There are occasions, though, when you machine a thin-wall product or when you don't want too much deflection," he added. "Then you can use a sharp or almost-sharp edge."

One such application is boring. "Too much tool pressure may deflect the boring bar enough to create taper or an out-of-roundness condition. Tools are available that are sharp, with a light hone only, or with a reduced chamfer angle to counteract those problems," Young said.

That's certainly the case when boring a gray iron liner pressed into the cylinder bore of an aluminum engine block. "You want to use a freer cutting geometry to reduce distortion," said

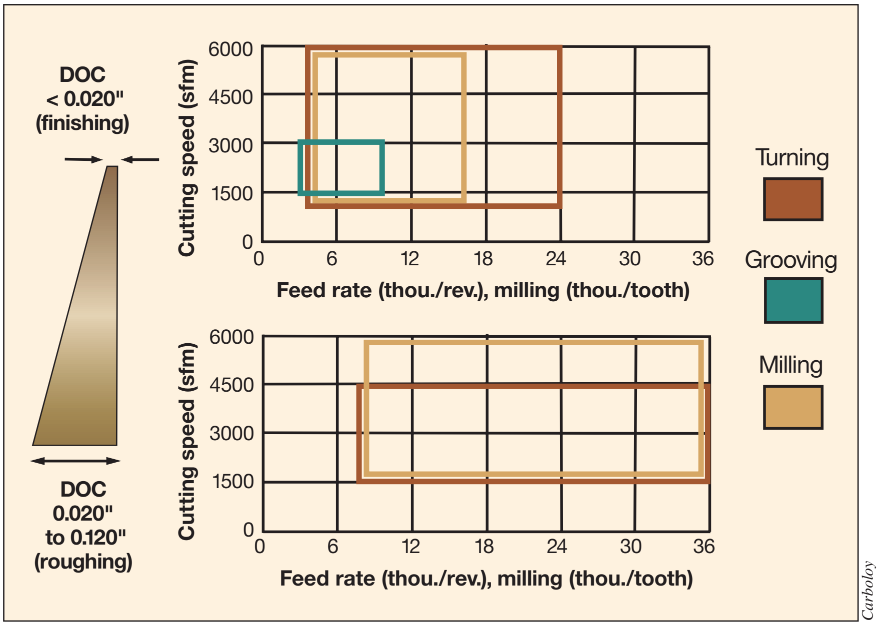


Figure 1: Parameters when machining gray iron with PCBN.

MODCO's Robinson. "Keep a sharper edge. Unlike a lot of PCBN applications, I do not recommend T-lands." Instead, he recommends an A-hone, which is a light hone.

"Generally, on an aluminum block you have an aluminum wall of about 0.060" to 0.070" and then a 0.060" to 0.070" wall in cast iron left," he added.

Typically, semifinishing and finishing is performed at the same workstation, Robinson said. Semifinishing is done on the way down the bore at a DOC of 0.014" per side and finishing is done on the way out at a DOC of 0.001". Cutting speed is from 3,400 to 3,700 sfm.

Robinson noted that when boring cylinders, a common error is running the tool too slow. "If you want to error, error at a higher feed rate because tool life, in general, will be better," he said. "That breaks down at a certain point, but, for instance, if you're running at 0.003 to 0.005 ipr, tool life will probably be much better at 0.010 ipr if the part geometry and finish requirement will accept that feed rate."

Carbide vs. PCBN

A number of issues exist when deciding whether to apply carbide or PCBN tools to cast iron. One is volume. "The larger the batch size, the larger the volume, the more you gain from using PCBN," said Carboloy's Sandqvist. "Compared to carbide or ceramics, you can machine at two, three, maybe four times the speed. Also, tool life might be three, four or five times longer, and you can usually take a pretty heavy DOC as well. With PCBN, productivity increases five to 10 times."

Shape-Master's Young noted that

The following companies contributed to this report:

Carboloy Inc., a Seco Tools Co.
(586) 497-5000
www.carboloy.com

Heller Machine Tools LP
(248) 288-5000
www.heller-machinetools.com

MODCO Div., Valenite LLC
(800) 544-3336
www.valenite.com

Shape-Master Tool Co.
(815) 522-6186
www.shapemastertool.com

Silver Hawk Precision
(248) 669-6625
www.silverhawkprecision.com

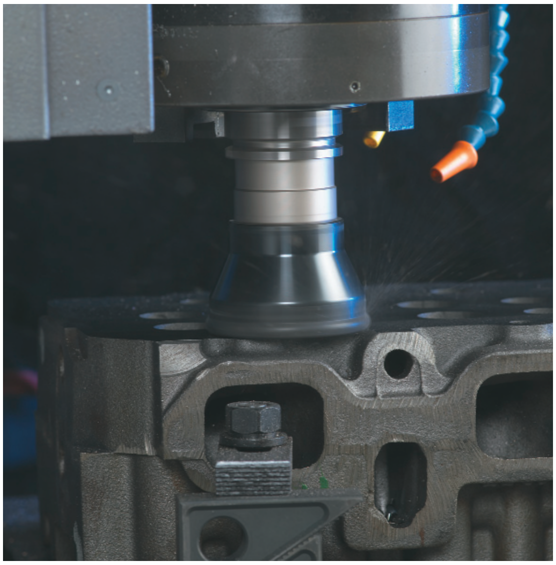
most end users select PCBN when extended tool life is critical for a successful application. “And with increased tool life, typically, you’re going to get higher part quality, less scrap, less rework and more machine uptime,” he said. “You’ll also see, in some cases, reduced breakout or graphite pullout within the casting structure because the cutting edge of the PCBN tool stays sharper.”

The higher cost of a PCBN insert compared to a carbide one may induce sticker shock in some end users, but when the application is appropriate, the price difference shouldn’t matter. Sandqvist said: “We work hard at getting people to think about cost per part. Don’t look at the purchase price of the insert. Look at how much it can produce and the insert cost per part when you can use it to make 2,000, 3,000, 4,000 parts. PCBN is definitely the most economical tool when machining gray cast iron.”

Doing Diamond

When machining ferrous materials, PCD tools are often dismissed as an option because of the high affinity the carbon in the diamond has with iron. This reaction can cause a PCD tool to fail catastrophically.

However, if the temperature at the tool/workpiece interface remains below about 700° C, there is no graphitization of the diamond nor does the carbon react with the ferrous workpiece.



Carboloy

PCBN tools are gaining favor in facemilling applications. This diesel engine cylinder head made of gray iron (GG25) is being machined at nearly 200 sfm.

Dan Diskin, vice president of Silver Hawk Precision, a Wixom, Mich., tool supplier, emphasized that 700° C is a threshold level and the temperature should stay well below that. Therefore, coolant—often flood and through-tool combined—is essential. “The heat transfer needs to be directed toward the coolant and the chip so heat traveling to the tool is minimized,” he said. “You must do everything to get the heat off the cutting edge.”

Diskin added that there are four elements to balance in making such an application successful: DOC, speed, feed and tool geometry. Although testing is needed to determine the optimal machining parameters, the tool should have a neutral rake, a 7° cutting clearance and be ground up-sharp because any hone adds friction—i.e., heat.

Young, who worked for GE Superabrasives for 9 years, provided starting-point parameters of 500 sfm, 0.005 ipr and 0.010" DOC for cutting gray iron with PCD. “If you can get PCD to work, you may try to increase speeds or feeds to get productivity up.”

He added that a couple of common applications are cam and crankshaft boring. “The bar that’s required to get through the entire block is so long that, typically, they can’t spin it at extremely high spindle speeds to get up to the speed that’s necessary to make PCBN work effectively,” Young said. “I’m aware of applications where 30,000 to 50,000 bores per tool with diamond isn’t out of the question, if they’re running it at a slow-enough material-removal rate.”

Diskin, however, cautioned against recommending parameters, other than the need to machine at low to medium rates. “Each PCD application has to be dialed in individually,” he said. “You’ll have rapid tool failure if the parameters are not optimal.”

But when they are, the results can be spectacular. “Cast iron is best machined with PCD,” Diskin said. △