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B. Kennedy

Low-carbon steels are easy to work with in many respects and are a cost-effective match for many applications. However, the continuous chips the alloys generate during operations such as turning and boring can grow into unmanageable rat's nests. This photo shows continuous chips from a turning operation in a Kennametal lab.

Chips Happen

Strategies for single-point boring of long-chipping, low-carbon steels.

By Bill Kennedy, Contributing Editor

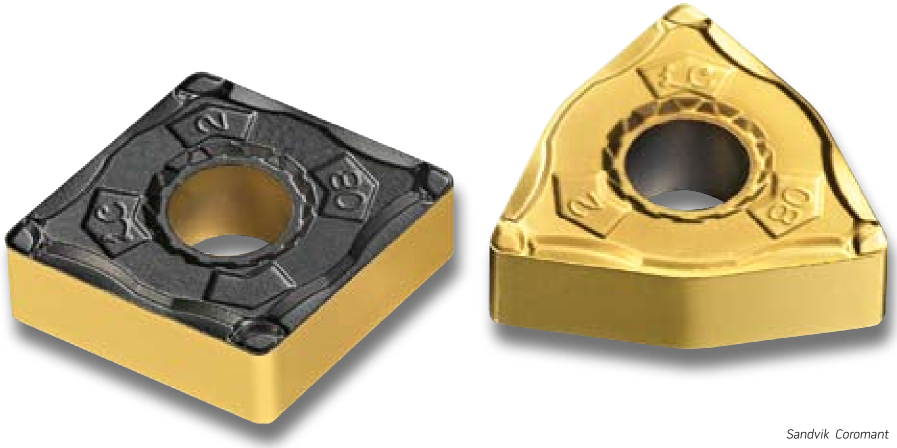
Machinists know that steel is never simply steel. Steelmakers manipulate combinations of iron, carbon and other elements to produce alloys with specific hardness, strength, malleability and wear and corrosion resistance for applications as diverse as surgical instruments, axles and steel wool.

Generally, additional carbon makes steel harder and stronger. At one end of the scale, AISI 1005 to 1020 low-carbon steels (about 0.05 to 0.2 percent carbon by weight) are inexpensive, easily formed and sufficiently strong for applications such as auto bodies, axle tubes and shafts, appliance components, wire and some machine parts.

The relative softness of low-carbon steels makes them easy to work in some respects, but more difficult in others. In machining, continuous chips of low-carbon steel can grow into unmanageable rat's nests. The steel tends to cause built-up edge on the cutting tool, ruining the workpiece's surface finish and causing premature tool failure. When OD turning, uncontrolled chips are a safety risk for the operator, can jam chip-removal systems and may damage the workpiece. The problems multiply when machining internal bores with a single-point cutting tool because unbroken chips can plug the bore and be recut, damaging the part and the cutting tool.

Bend and Break

The malleability that enables low-carbon steels to bend without breaking—a valuable characteristic in many applications—becomes a problem when chips remain unbroken. A simple solution is shaping a cutting tool's rake face to bend the chip enough to break it. Brent Godfrey, product specialist in the rotating tooling department of Sandvik Coromant Co., Fair Lawn, N.J., said thinner chips magnify the problem. "When finishing a bore, you can't use an extremely high DOC. If you are taking a low DOC, you frequently need a tight chipbreaker where you try to curl the chip and break it." Sandvik Coromant developed its LC insert geometry specifically for turning and boring low-carbon steels. The geometry is offered in both standard and wiper designs to control chips when cutting unalloyed steel to make automotive transmissions.



Sandvik Coromant

In many cases, insert geometries can bend low-carbon steel chips sufficiently to break them. Sandvik Coromant developed its LC geometry for turning and boring low-carbon steels and offers it in both standard and wiper designs to provide chip control in unalloyed steel.

Tightly bending the chip does, however, increase cutting forces, so the boring setup must be rigid. By nature, the single-point boring process locates the cutting edge at the end of a bar extending some distance into a bore. A longer bar multiplies machining forces and increases the chances that those forces will push the cutting edge off course, causing chatter and poor tool life.

Controlling tool deflection is crucial. Outlining steps to enhance boring system rigidity, Jim Kasperik, global manager of the Kennametal Knowledge Center, Latrobe, Pa., suggested first applying the largest diameter bar possible because, for example, a 1½"-dia. bar is five times more rigid than a 1"-dia. bar. According to Kasperik, this is calculated using the moment of inertia formula for a round bar: $I = (1 \div 4\pi)r^4$. I is 0.005 for a 1"-dia. bar and 0.025 for a 1.5"-dia. bar. After determining the bar length required to achieve a specific bore depth, minimizing bar length also helps maintain rigidity. For example, a bar with a 3" overhang is twice as stiff as one that overhangs 4".

As the bore's length-to-diameter ratio grows, more rigid boring bars may be needed. Antichatter boring bar technology proceeds from plain-steel bars to heavy-metal (tungsten with a nickel-copper-iron matrix) and solid-carbide bars to antivibration bars and special bars that can be tuned to resist vibration at application-specific frequencies. In addition, Kasperik recommended

Sandvik Coromant

Through-bar coolant helps to both cool chips (increasing their tendency to break) and evacuate them from the bore being machined.

holding any bar in a collet or split bushing, not a solid sleeve with setscrews in which the bar is held at just two points.

Once rigidity is maximized, machining parameters can be adjusted to facilitate chipbreaking. "One of the things we suggest is that operators increase feed rate and cut back on rpm," said Don Graham, manager of turning products for Seco Tools Inc., Warren, Mich. "As long as we are talking steels [superalloys would be something different], the higher the rpm, the hotter the chip gets, and the hotter the chip, the softer the chip. A soft chip is a difficult chip to break. If you can slow the rpm, you cool the chip and make it more brittle. You want to cool that chip as much as possible." Graham also recommended through-bar coolant as a way to cool chips and help evacuate them from the bore.

Graham noted that increasing the feed rate to break the chip has a downside, as does reducing rpm. "If you drop rpm, you lose cycle time. When you increase your feed rate, you are increasing the force of the cut and can generate chatter and lose surface finish," he said, reiterating the need for a rigid boring setup.

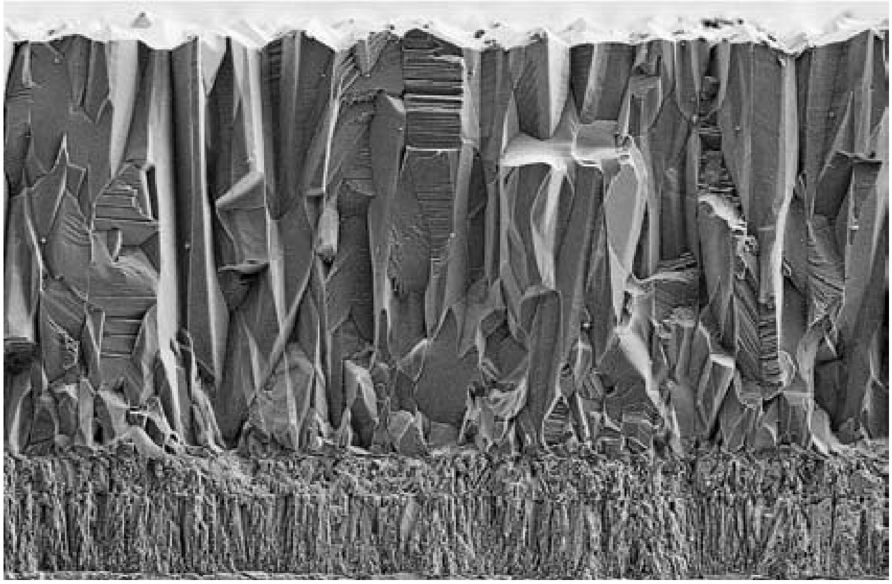
Godfrey agreed. "If you can get your feed rate high enough, you can always get the chip to break," he said, noting that a key issue when boring long-chipping materials can be the machine tool's power capacity. "I've visited a few customers cutting low-carbon materials where the main problem was the machine was not strong enough. It didn't have enough horsepower to push the tool at the feed rate we needed to break chips."

For medium- and high-carbon steels and OD machining, Kennametal's Kasperik agrees with the concept of breaking chips via higher feed. "For typical OD cuts on 4130 and 4340, I would never tell you that speed had anything to do with chip control," he said. "I would say change the feed and DOC."

However, when boring low-carbon steel, "crank that speed up as much as possible," Kasperik said. "In the case of boring low-carbon steel, I would not increase the feed first because of the possibility of deflection and BUE."

High cutting speeds "create chaos in the system," which is a good thing, Kasperik said. "You're going so fast you've created acceleration, you've created velocity. As the chip starts to curl, it starts to hit things. It might hit the workpiece. It might hit the bar, thus tricking it into thinking it wants to break." Higher speed doesn't increase bar deflection and may even lower cutting forces. "Speed is where it's at when you talk about low-carbon steel," he said.

Kasperik pointed out that tool breakage in soft materials like low-carbon steels is typically caused by BUE, not lack of tool toughness. BUE blocks the chip, makes chipbreaker geometries ineffective and increases cutting pressures, causing the tool to break. Higher cutting speeds combined with the proper coating reduce BUE, Kasperik said. "The faster you go, the more the chips tend to flow across the cutting



Seco Tools

This micrograph of Seco's Duratomic coating shows crystals in the aluminum-oxide top layer (about 75 percent of the image) that are oriented to present a hard, tough and smooth crystal facet into the cut. A smooth insert surface enhances chip flow and helps prevent BUE. Layers below the alumina are a fine grained nucleation layer, about 5 to 10 percent as thick as the oxide; a titanium carbonitride layer that is columnar in structure; and the coarse-grained substrate.

edge instead of grabbing."

Regarding coatings formulated to help minimize BUE, Seco's Graham cited the company's CVD Duratomic coating. He said the process to produce the coating results in a smooth surface that enhances chip flow; the key is controlling the direction the crystals grow in the coating's aluminum-oxide outer layer. Noting that most crystals have different properties depending on their orientation—a diamond can be easily cleaved from one direction but stoutly resists fracture from other directions—he said Al_2O_3 crystals follow the same rule.

"We learned how to tilt the crystals a little bit [instead of making them completely vertical], to bring a harder, tougher direction into the cut," said Graham. "When we tilt these crystals, the part of the crystal that is parallel to the surface of the cutting tool is actually a flat facet. Apart from increased tool life and speed capability, the surface is a little smoother and resists BUE. That can be beneficial when you are boring because as soon as you get BUE, you increase the cutting force."

Shape and Sharpness

The gummy nature of low-carbon steels, as well as the tendency for a boring tool to deflect in the cut, influences the choice of insert shape and sharpness. Kasperik said 0° relief (straight-sided) inserts are recommended in most machining operations because they present a strong edge to the part and can be flipped to utilize both sides for cutting. In boring, however, if a bar tooled with a 0° relief insert deflects, the insert flank will heel against the bore. At the very least, heeling degrades the surface finish, and, at worst, can break the tool. A positive insert (in which the flank beneath the cutting edge tilts away from the workpiece) provides clearance to minimize the effect of deflection. Common ANSI relief angles for turning are from 7° to 11°.

The gummy nature of low-carbon steels, as well as the tendency for a boring tool to deflect in the cut, influences the choice of insert shape and sharpness.

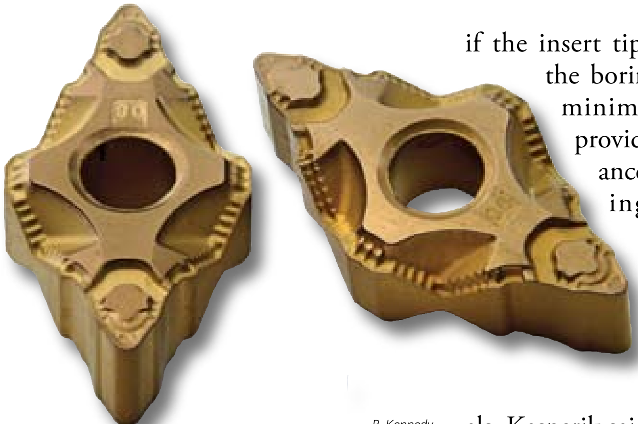
"We are much more apt to use positive inserts when boring gummy steels," Kasperik said. He added that 0° relief inserts are typically molded to shape and feature larger hones and corner radii than positive inserts, which generally are ground to shape and have sharp edges with minimal or no hone. In softer and gummier materials, the sharp edge is desirable because it tends to shear the workpiece material rather than plow through it.

Also regarding insert configurations for boring, Seco's Graham said, "We like to use very small nose radii." Cutting forces act on a large nose radius as they do on a round insert, pushing the tool radially out of the cut. At the opposite extreme, with a sharp 90° corner forced directly into the bore, "essentially you are plunging, and forces are all directed back into the toolholder, with no radial force at all. The larger the insert nose radius, the bigger the radial force and the greater the tendency to chatter," Graham said. "So we prefer a light nose radius for boring."

By the same reasoning, insert lead angle (ANSI) should be kept as close to 0° as possible (90° approach angle from an ISO point of view) to minimize off-axis forces on the cutting tool.

An insert's shape has significant effect on chip clearance. The more acute (less than 90°) the insert's nose angle, the greater the available chip clearance. However, Kasperik pointed out that a compromise may be necessary when choosing the insert shape. A narrow-angle (35° nose angle) DNMG insert provides better chip clearance than a CNMG style (80° nose angle), but the narrower insert concentrates cutting forces farther from the bar axis and increases torsional force on the bar, which can produce chatter.

To assure sufficient chip clearance, toolmakers provide minimum bore diameters for various bar/insert shape combinations. Minimum bore diameters are calculated by doubling the distance of the cutting tool point from the boring bar's centerline. For example, if the insert tip extends 0.125" from the boring bar's centerline, the minimum bore diameter to provide adequate chip clearance is about 0.250". Boring diameters smaller than the recommended minimum are possible on short-chipping materials, such as cast irons, but not for long-chipping materials, Kasperik said.



B. Kennedy

Pull, or back, boring can expedite boring of low-carbon steels. Instead of boring from the mouth of the hole towards the bottom, the tool is moved into the bore without contacting the workpiece, then positioned to cut as it is pulled out. The operation requires inserts that cut in multiple directions, such as these CT (copy turning) geometry inserts from Kennametal. They cut effectively moving forward, but a section of the tool behind the normal cutting edge is designed to cut and control chips when pull boring.

Backboring Solution

Kasperik described back boring, or pull boring, as a combination of technique and insert design that can expedite boring of low-carbon steels. Instead of boring from the mouth of the hole towards the back, the operation uses a bar that fits in that hole without cutting. "You lower the bar and cut on your way out," he said.

Kasperik said efficient back boring requires appropriate tooling. "Most tools are not designed to cut backwards. You can't take too heavy of a DOC, and chip control may suffer as well." As a

Boring small details

WHILE MACHINING BORES in long-chipping material is a challenge, machining smaller bores represents a more difficult task.

"When you get into very small bores [less than ½" in diameter], you have to be careful," said Don Halas, Seco Tools Inc. product manager for threading, grooving and multidirectional turning. "In standard turning, we have a variety of chipbreakers whose purpose is to break the chips, but they also increase cutting forces." High cutting forces can fracture the necessarily thin boring bars used to machine small bores.

Halas said Seco's Mini-Shaft tooling system provides a reliable way to machine small bores. The system's screw-on inserts do not feature chip control grooves. "They are basically flat-topped but are raked to funnel the chip away from the cut and out of the bore," he said. In addition, a port in the bar immediately adjacent to the insert provides coolant flow to flush the chips. "We are not trying to break the chip as much as we are trying to control it," Halas said.

The tools come in two sizes: one that can handle bore diameters as small as 8mm and a larger size for bores as small as 11mm in diameter. Halas said customers have been more interested in the smaller tools. The system can be used on machining centers as well as lathes and for operations including grooving, profiling, backfacing and threading, in addition to boring.

The Mini-Shaft tooling system includes both solid-carbide and steel boring bars. "You would think a solid-carbide bar would always be your first choice for rigidity," Halas said. "But we found out that our steel bars are being applied regularly because if chip jamming does occur, a carbide bar will snap while a steel bar will hold up a lot better due to its flexibility."

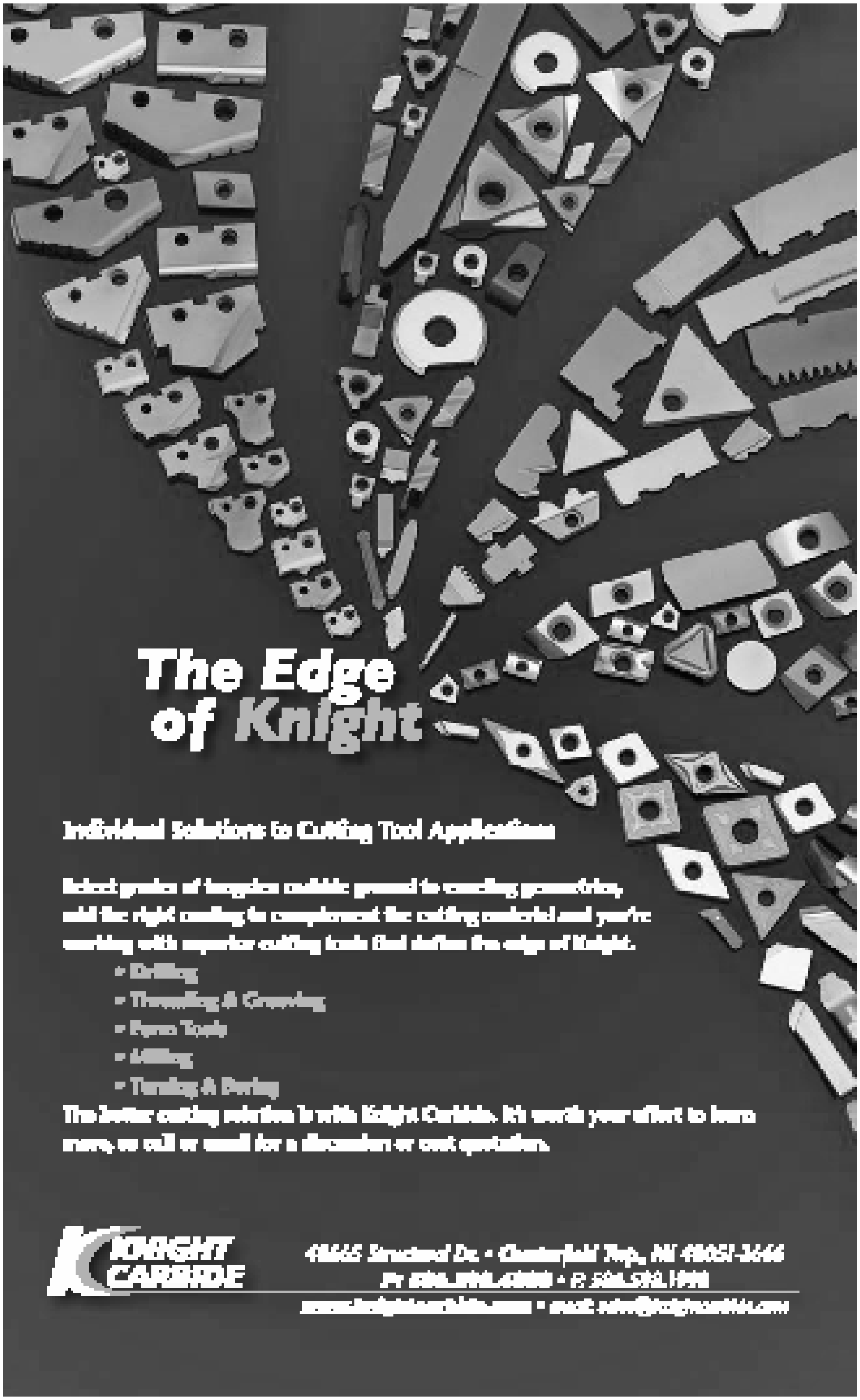
The system was developed for machining small medical and aerospace parts, but other applications have materialized. "I thought the highest growth area for this product would be medical parts, but it actually is in small parts for automotive, in high-volume items at Tier 2 and Tier 3 suppliers where low-cost, low-carbon steels are in wide use," he said.

—B. Kennedy

Seco Tools

Instead of using chip control grooves, the screw-on inserts in Seco's Mini-Shaft tooling system are flat-topped and raked to funnel chips away from the cut and out of the bore. In addition, a port in the bar adjacent to the insert provides coolant flow to flush the chips.

solution, toolmakers have developed inserts that cut in multiple directions, such as Kennametal's "CT" (copy turning) geometry. The tool cuts effectively moving forward, but a section of the tool behind the normal cutting edge cuts and controls chips when moving backward, as in pull boring. "With the right cutting conditions, I'm not only making chips, I'm pulling them with me as I pull out," Kasperik said, adding that nothing is left behind and the surface finish is finer than what would be imparted if chips were jamming in the bore.



Discontinuous Chips

Craig Segerlin, national product manager for solid-carbide endmills and CF Multi-Master tools, Iscar Metals Inc., Arlington, Texas, said helical interpolation of the bore with an endmill is a way to ensure chip breakage when boring low-carbon steels. In helical interpolation, a CNC program moves the tool in a circular path in the X and Y axes while the tool simultaneously descends into the bore in the Z-axis direction. Segerlin describes the helical toolpath as a "tornado" motion.

Helical interpolation of the bore with an endmill is a way to ensure chip breakage when boring low-carbon steels.

Milling by nature is an interrupted cutting operation and thereby produces discontinuous chips. "Helical boring makes a little gnat-sized chip," Segerlin said. "No matter what the material, the chip breaks."

Segerlin said an end user typically leaves 0.010" to 0.020" in excess stock in a bore after drilling, then semifinishes the hole via helical boring with

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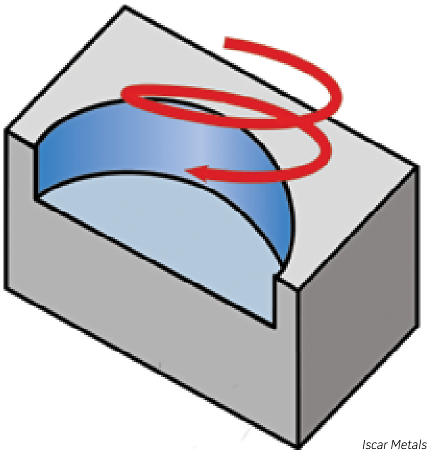
an endmill. "We are doing this more and more," he said. "Helical boring is used frequently for true position issues. After a customer drills a hole, he comes back with a multiflute endmill, helically bores to get true position and then reams or bores with a single-point, fine finishing head."

Segerlin said a way to approximate the largest-diameter endmill that can be used to helically bore a particular hole diameter is to multiply the required hole diameter by 0.769. Using that formula, a 0.385"-dia. endmill is the largest that can be used to helically interpolate a 0.50"-dia. hole (0.769 × 0.50"). On the other hand, the approximate smallest diameter hole that a specific-diameter endmill can interpolate is found by multiplying the endmill's diameter by 1.3. Segerlin said Iscar's 2-flute, 0.157"-dia. endmill, for example, can helically interpolate a hole as small as 0.204" in diameter.



Iscar Metals

One way to ensure chips break when boring low-carbon steels is to use helical interpolation with an endmill, in which a CNC program moves the tool in a circular path in the X and Y axes while the tool simultaneously descends into the bore in the Z direction.

Segerlin admitted that, all else being equal, an endmill will not produce as fine a surface finish as a single-point boring tool. "If you run at the same speed with an endmill as a single-point tool, you'll have a rougher finish with the endmill by 25 to 30 rms due to back taper on endmill," he said. The finish often can be improved by increasing cutting speed. "It depends pretty much on the application, but you can come up with a rule of thumb, such as increase the cutting speed 30 percent and back the feed down 10 to 15 percent," he said. Such an approach provides a starting point from which cutting parameters can be fine-tuned. **CTE**

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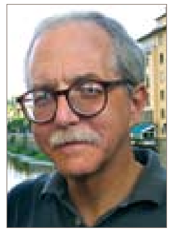

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