JULY 2008 / VOLUME 60 / ISSUE 7

cover story

By Alan Richter, Editor

Unimerco

Striving for Consistency

Ductile cast iron isn't considered a difficult-to-machine material, but drilling it predictably and productively can prove elusive without the proper tools and techniques.

Along with its machinability, damping properties and economy of production, ductile cast iron offers wear and fatigue resistance, toughness and—as the name indicates—ductility.

In addition, a type of ductile iron, austempered (ADI), is attractive to parts designers because it combines high tensile strength with light weight, according to Guhring Inc., Brookfield, Wis. Regarding automotive engine design, those material characteristics can increase engine output while maintaining engine block wall thickness. Another benefit is that current engine output can be maintained while reducing engine block wall thickness, thereby decreasing engine weight and upping energy efficiency.

Drilling ductile iron, however, poses challenges because the material can vary significantly from foundry to foundry and even from batch to batch in the same foundry. "The number one thing with ductile iron is to have a predictable drilling solution in an unpredictable material," said Curtis Cole, drilling

Learn more about holemaking

Get more information on drilling ductile cast iron by visiting Alan Richter's blog and reading the Interactive Report online at www.ctemag.com.

Striving for Consistency *(continued)*

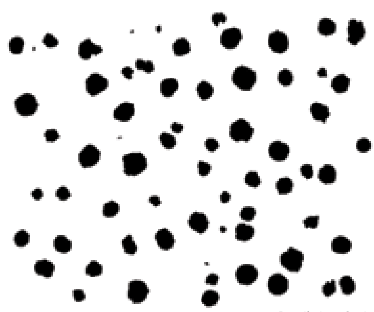
products specialist for toolmaker Sandvik Coromant Co., Fair Lawn, N.J. "From heat run to heat run, ductile cast iron can vary greatly."

Jim Wood, executive and technical director for the Ductile Iron Society, concurred. "The raw materials that go into making ductile iron can vary from foundry to foundry because you get different scrap steel in different parts of the country, and scrap steel is the major constituent in making cast iron," he said, noting that about 40 to 50 percent of the cast iron's makeup is scrap steel.

Inside the Matrix

According to the book "Ductile Iron Data for Design Engineers," offered through the Ductile Iron Society, machinability is determined by microstructure and hardness. The graphite particles in gray, malleable and ductile irons are responsible for the machinability characteristics of these materials. That's because graphite acts as a lubricant when machining cast iron and helps chips break in a controlled manner. "When you look at ductile iron under a microscope, the graphite is in the form of round nodules," Wood said.

The graphite particles influence cutting force because the lubricating graphite makes chip removal easier, and they influence surface finish because ductile cast iron with a high count of smaller graphite nodules won't cause finish problems when graphite pullout occurs during machining. But the matrix is the primary determinant of tool life, the book stated. Ferrite is the softest matrix constituent in ductile iron and as a result exhibits the best machinability. The ferrite provides enhanced machinability because of the effect of silicon, which decreases ferrite's toughness and the lubricating and chipbreaking effects of the graphite spheroids. Machinability increases with silicon content up to about 3 percent but decreases significantly with silicon content above that level.



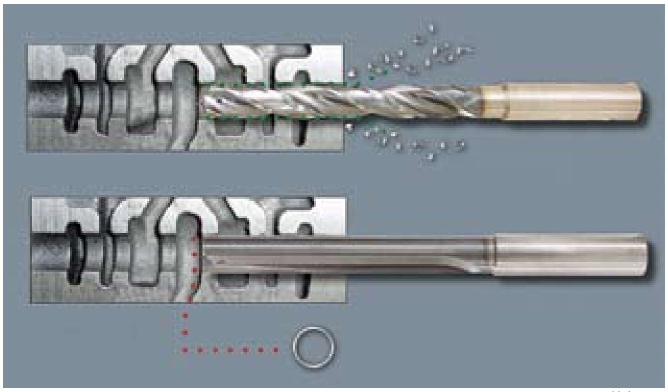
Ductile Iron Society

In unetched form, ductile iron's granular graphite nodules can be clearly seen in this micrograph at 100x magnification.

Pearlite, which consists of a mixture of soft ferrite and hard lamellar iron carbide, is a common matrix component in all intermediate-strength ductile iron grades. Machinability increases with increasing pearlite content, and pearlitic irons are considered to have the best combination of machinability and wear resistance.

Martensite is an extremely hard matrix phase produced by quenching ductile iron. It is too hard and brittle to be machined as quenched, but after tempering, martensite is more machinable than pearlite of similar hardness.

Carbides are the hardest constituents in ductile iron and have the poorest machinability. When present as thin



Unimerco

When performing interrupted rough drilling or reaming through ductile iron valve body spool bores, a tool enters a void at the end of each land and the last piece of workpiece material—in the shape of a ring—can get pushed into the void or slip off the reamer as it retracts (bottom). Unimerco offers ring-free core drills that shred ductile iron into chips that are easily evacuated.

lamellae in pearlite, they are easily sheared and are in their most machinable form.

"Severe undercooling can create primary carbides," Wood said, "and that's what you don't want when it comes to machining." He added that primary carbides are caused by high-alloy carbide formers, such as chrome in scrap steel.

Drilling Challenges

End users also don't want to create rings, or "wedding bands," when performing interrupted rough drilling or reaming through ductile iron valve body spool bores, according to Jim Stead, director of technical applications for Unimerco Inc., Saline, Mich. In these applications, a tool enters a void at the end of each land and the last piece of workpiece material—in the shape of a ring—can get pushed into the void or slip off the reamer as it retracts. The probability of this happening increases as the tool dulls.

Many valve body manufacturers manually inspect parts to find any debris, according to Stead. "Sometimes they perform 100 percent inspection with a flashlight and bore gage to make sure there are no chips or wedding bands hung up in the voids," he said. If one is found, tweezers are used to remove it.

Unimerco's approach to preventings these rings from forming and eliminating the time and expense associated with final inspection is to employ multistepped tools. Unimerco offers ring-free core drills that shred ductile iron into chips that are easily evacuated from the bores through voids. Additionally, compared with applying conventional drills, the tools allow a manufacturer to increase drilling speed from 250 mm/min. to 600 to 700 mm/min. and typically decrease the overall cycle time by 50 to 75 percent when machining spool bores, Stead said. "As a general rule, we can take a five-pass operation down to three in ductile iron," he said, which includes passes with a pilot drill, a core drill and a finish reamer.

Core Shifting

In addition, the ring-free core drills can effectively remove more stock from one side of the bore than the other when a bore has uneven stock distribution. "Our process is robust when faced with in-process variations such as core shift," Stead said.

Because the centerline in a cast bore can shift depending on the bore's accuracy, Jim Porter, application engineering supervisor for toolmaker Allied Machine & Engineering Corp., Dover, Ohio, said it is usually more cost effective to drill from solid with an included angle drill. "If the hole isn't precisely located where you want that centerline to be, the tool is going to want to follow the hole's existing centerline," he said. "Our preference is to drill from solid."

Porter added that the downside of drilling from solid is that a ductile iron workpiece cast without cored holes costs more because it contains more material. However, more operations are required to straighten cored holes. "It's a catch-22 situation," he said.

The included angle varies for tools that are appropriate for drilling ductile iron. Traditional twist drills have a 118° included angle, for Allied Machine's T-A spade drills it's 132°, and the company's GEN3SYS replaceable-tip drills have a 140° included angle. "It's more product dependent than anything," Porter said.

The geometry is also important for the cutting edge when drilling ductile iron. A more neutral geometry is more appropriate for the relatively abrasive material, according to Bob Jennings, product manager for Ingersoll Cutting Tools, Rockford, Ill. "[It should be] more toward the negative side than the positive side but almost neutral," he said, adding that a hone or other edge prep is required.

To prevent a drill's corners from breaking when machining the abrasive ductile material, Guhring introduced the RT 100 R Ratio solid-carbide drill with a patented full radius point grind.

Starting-point speed and feed recommendations for drilling ductile cast iron.

				Feed: ipr or *mm/rev.*								
				Nominal hole diameter								
Ductile cast irons	Hardness HB	Condition	Speed fpm *m/min.*	1/16" *1.5mm*	1/8" *3mm*	1/4" *6mm*	1/2" *12mm*	3/4" *18mm*	1" *25mm*	1½" *35mm*	2" *50mm*	Tool material grade AISI or C ISO
Ferritic ASTM A536: grades 60-40-18[1] and 65-45-12[2] SAE J434c: grades D4018[1] and D4512[2]	140 to 190	Annealed	85[1] 115[2] *26*[1] *35*[2]	0.001 --- *0.025* ---	0.003 *0.075*	0.006 *0.15*	0.010 *0.25*	0.013 *0.33*	0.016 *0.40*	0.021 *0.055*	0.025 *0.065*	M-10, M-7, M-1 S-2, S-3
Ferritic-pearlitic ASTM A536: grade 80-55-06 SAE J434c: grade D5506	190 to 225	As cast	70 *21*	0.001 *0.025*	0.003 *0.075*	0.006 *0.15*	0.010 *0.25*	0.013 *0.33*	0.016 *0.40*	0.021 *0.055*	0.025 *0.065*	M-10, M-7, M-1 S-2, S-3
" "	225 to 260	As cast	50 *15*	0.001 *0.025*	0.002 *0.050*	0.004 *0.102*	0.007 *0.18*	0.010 *0.25*	0.012 *0.30*	0.015 *0.40*	0.017 *0.45*	T-15, M-42* S-9, S-11*
Pearlitic-martensitic ASTM A536: grade 100-70-03 SAE J434c: grade D7003	240 to 300	Normalized and tempered	45 *14*	0.001 *0.025*	0.002 *0.050*	0.004 *0.102*	0.007 *0.18*	0.008 *0.20*	0.010 *0.25*	0.013 *0.33*	0.015 *0.40*	T-15, M-42* S-9, S-11*
Martensitic ASTM A536: grade 120-90-02 SAE J434c: grade DQ&T	270 to 330	Quenched and tempered	30 *9*	--- ---	0.001 *0.025*	0.002 *0.050*	0.004 *0.102*	0.005 *0.13*	0.006 *0.15*	0.007 *0.18*	0.008 *0.20*	T-15, M-42* S-9, S-11
" "	330 to 400	Quenched and tempered	20 *6*	--- ---	0.001 *0.025*	0.002 *0.050*	0.004 *0.102*	0.005 *0.13*	0.006 *0.15*	0.007 *0.18*	0.009 *0.20*	T-15, M-42* S-9, S-11*
Austenitic (Ni-resist) ASTM A439: types D-2, D-2C, D-3A, D-5 ASTM A571: type D-2M	120 to 200	Annealed	35 *11*	0.001 *0.025*	0.002 *0.050*	0.005 *0.13*	0.007 *0.18*	0.010 *0.25*	0.012 *0.30*	0.015 *0.40*	0.018 *0.45*	T-15, M-42* S-9, S-11*
Austenitic (Ni-resist ductile) ASTM A439: types D-2B, D-3, D-4, D-5B	140 to 275	Annealed	25 *8*	0.001 *0.025*	0.002 *0.050*	0.005 *0.13*	0.007 *0.18*	0.010 *0.25*	0.012 *0.30*	0.015 *0.40*	0.018 *0.45*	T-15, M-42* S-9, S-11*

* Reference
Source: "Ductile Iron Data for Design Engineers"

"It's similar to the Racon point for HSS and cobalt drills," said Bob Hellinger, the toolmaker's national sales manager for standards. (A Racon point has a rounded, or curving, point to minimize stress and reduce corner wear or breakage because a rounded cutting edge—similar to a corner radius on a cutting edge—is less prone to breaking when cutting an abrasive material than one that comes to a sharp corner.) "The full radius point is almost like a ballnose endmill's rather than the sharp corners on regular drills."

Guhring

To prevent a drill's corners from breaking when machining the abrasive ductile cast iron material, Guhring introduced the RT 100 R Ratio solid-carbide drill with a patented full radius point grind.

Hellinger added that the full radius point can help reduce burr formation when the tool exits a through-hole and also reduces tool wear. The radius point design creates a smoother transition at the corner edge and reduces the amount of material displaced upon exiting a hole, which in turn reduces the exit burr size. Traditional Racon point designs have an increased tendency for drill wandering and are therefore run with the assistance of a drill bushing. The through-coolant Ratio drill's specialized web-thinned design eliminates walking by reducing the thickness of the chisel edge.

The Ratio drill's DK 255 F carbide substrate has an average grain size of 0.7 microns and 8 percent cobalt to provide a hard (1,720 HV) yet tough tool, according to Hellinger. "You need a carbide grade that's forgiving for the inconsistencies in ductile," he said.

Standard ratio drills are 3mm to 20mm in diameter and available for drilling 5 and 7 diameters deep, but Hellinger noted that the smaller diameter tools have flute lengths that allow them to drill holes deeper than 7 diameters, and specials can be ordered for making holes 10 diameters deep or more. For holes up to 5 diameters deep, he said a pilot drill is usually not needed, but he recommended creating a pilot hole about 1 to 2 diameters deep for deeper holes.

Drilling significantly deeper holes into ductile iron isn't unheard of, though. "We have a very large customer manufacturing diesel engines that does 40"-deep holes with a 1" spade drill," said Allied Machine's Porter.

Cole noted that Sandvik Coromant's solid-carbide 842 drill has a chamfered instead of radiused corner to better protect the tool when cutting ductile iron. This also reduces burr formation on tool exit. The company's indexable CoroDrill 880 tool accepts the company's GT insert, which was designed for cast iron. This tool has a reinforced edge line on the peripheral insert to enable a more secure drilling process. In addition, Cole said the GT insert is ground neutral to toughen the insert

Partnership nets big savings

MARKET FORCES LED GLOBAL manufacturer Sauer-Danfoss Co. to partner with toolmaker Unimerco Inc., Saline, Mich., on custom tooling for drilling ductile iron. The collaborative effort saved significant money for Sauer-Danfoss at one of its manufacturing facilities. The company manufactures hydraulic and electronic components for mobile off-road machinery.

A couple years ago, business was almost too good for Chip Bryant, a Sauer-Danfoss manufacturing engineer. The company's Easley, S.C., plant was struggling to keep up with demand even though its nine machines were running round-the-clock.

"On a daily basis, we had to get dispositions on parts, and our times weren't what they needed to be," Bryant said.

To meet demand, Sauer-Danfoss officials were considering outsourcing some of the Easley plant work, but Unimerco offered another solution. In 2006, employees from the two firms began to work on custom tools at the Sauer-Danfoss plant in Nordborg, Denmark. In the fall of that year, Sauer-Danfoss executive Poul H. Christensen brought some of the new tools being used at the Denmark facility to the Easley plant.

Gary Mann, Unimerco tool specialist, saw the tools' advantages and knew they could be applied to the Easley facility, but Bryant wasn't sold so quickly. "I was concerned with putting all our eggs in one basket," Bryant said. "The pricing of the tool seemed excessive."

The facility had some production issues. It operated different makes and models of machinery, leading to some problems with product consistency. Delivery demands were increasing at the same time.

"We weren't standardized, and we'd had a lot of quality issues," said David Duvall, North American operations director for Sauer-Danfoss.

Bryant and Mann identified and prioritized holemaking processes that could be optimized. They developed the tooling and process optimization strategies, and tested and proved the technology. Test data was analyzed and compared with the original tooling strategies.

Unimerco

Based on initial results, Gary Mann (left), Unimerco tool specialist, knew the toolmaker's custom tools could be successfully applied at Sauer-Danfoss' Easley, S.C., plant, but Chip Bryant, a Sauer-Danfoss manufacturing engineer, wanted extensive data to confirm process optimization.

"We took our biggest quality problems and addressed them first," Bryant said. "Once we got the tools in and did a tool-by-tool comparison, the price per unit decreased. It turned into a cost savings."

Decisions on whether to implement the new tools were data-driven. Time studies were conducted on the processes being optimized. One process, which originally took 33.4 seconds, was reduced to 14.4 seconds. Another process was shortened from 30.8 seconds to 19.2 seconds.

Sauer-Danfoss officials found that after optimizing some of their Easley machines with the tools, five revamped machines saved a total of 510 production hours annually. Overall maintenance costs for running the five machines were reduced by $37,270.

"Our quality has greatly improved, and we increased capacity by almost 5 weeks," Bryant said. Past due shipments, scrap and cutting time were reduced.

The plant increased capacity by 22 percent, said Duvall. "As a result, we no longer needed to make a $1.2 million capital investment in two machines. Our total savings was about $2 million."

The Easley plant also reduced its overall operation time from 24-7 to 24 hours a day, 5 days per week. Seven machines running 5 days a week now have a higher capacity than nine machines running 6 days per week did previously. The facility now always meets demand.

The tools proven at Easley will be implemented at other Sauer-Danfoss manufacturing facilities around the world. "By having established the process, they know what the cost per unit is, based on the history," Mann said. "Quality and cost are controlled on a global level; they know their quality will be predictable."

While Bryant initially was leery of working with just one company on tooling solutions for the Easley machines, he believes now that a one-source approach is advantageous. "When you have one source, you get better support. You're not dealing with several people at different companies," Bryant said.

In an age when outsourcing is a fact of life for many companies, the custom tools helped keep the work in-house and make Sauer-Danfoss more competitive. Duvall said it's critical that manufacturers take advantage of all technical knowledge to keep business in North America. "We can be low-cost if we do the tooling and machining properly," he said. "A low-priced tool isn't always the low-cost solution."

—Jonathan Barnes, a freelance writer based in Pittsburgh

in the overlap area between the central and peripheral sections where notching originates, especially when drilling aggressively.

"Most ductile iron customers are just trying to drill ductile, like anything else, as fast as they can so drilling is done at elevated speeds and feeds," he said.

Cool Down

Coatings can resist the high temperatures generated when running at high drilling parameters. Titanium aluminum nitride is particularly effective. "It gives a very good resistance to the heat," Cole said.

Allied Machine coats its spade drills and replaceable-tip drills for drilling ductile iron with the company's proprietary AM200 coating, which resists heat and wear and was developed specifically for drilling, according to Porter. "It has good lubricity properties as well, so it prevents material adhesion," he said, adding that the coating's thermal characteristics allow running at spindle speeds 20 percent faster than when applying TiAlN-coated drills.

Guhring offers its PVD Firex coating on the Ratio drills, which Hellinger described as a combination of TiN and TiAlN in a multilayer structure to achieve a reference hardness of more than 90 HRC and an oxidation of the coating up to 1,470° F, which is 300° F higher than a monolayer TiN coating.

Another option is the C7 Plus nanocomposite coating that Unimerco offers. "It's like AlTiN but much harder, so it helps the tool hold up under the abrasive wear condition," said Stead. The coating's AlTiN grains are embedded in an amorphous matrix of silicon nitride. According to the company, the coating maintains stability up to 1,100° C before its grain boundaries begin to oxidize and the coating's structure decomposes. It has a hardness of 45 GPa.

Some coatings enable dry machining, but coolant is desirable when drilling ductile iron to help evacuate the material's small, curled chips. Flood coolant

Striving for Consistency *(continued)*

can be appropriate for holes less than 1.5 to 2 diameters deep, according to Ingersoll's Jennings, who noted that the toolmaker offers standard tools to drill up to 8 diameters deep. Through-coolant is recommended for deeper holes to help evacuate the chips up the flutes and out of the hole. "With any production, high-feed drilling operation, through-the-tool coolant is certainly a requirement," he said.

Jennings added that the through-coolant pressure should be at least 150 to 200 psi, but the best performances are achieved at around 1,000 psi. "If there's a knob where you could turn the coolant pressure up," he quipped, "you keep turning it until you take the bark off your hand."

"The more the merrier," Hellinger concurred, adding that high-pressure coolant improves the hole's surface finish, possibly eliminating a finishing operation. High-pressure coolant helps evacuate chips from the hole quicker and

reduces the possibility of having chips scour the ID. Additionally, the higher the coolant pressure, the less time the chip will reside in the drill flute.

To avoid chips and particles being recycled through the coolant system and clogging a drill's coolant holes, Sandvik Coromant's Cole suggests filtering particles larger than 80 microns. "Maybe even 40 microns, depending on the size of the drill," he said.

Other Considerations

A rigid setup is required when applying hard and relatively brittle carbide tools to drill ductile cast iron. "You need the right holders and of course you can't have play or extra slop in the spindle," said Unimerco's Stead. He recommended hydraulic toolholders to minimize runout.

Another option is shrink-fit holders. "Collets are not preferred," Hellinger said. Guhring recommends hydraulic chucks or shrink-fit holders when possible to improve tool life and part quality. "The tool runout when measured at the point can be reduced to less than 0.005 microns, which is less than half of what can be expected of a collet chuck," he said. "By reducing tool runout, tool wear is more consistent and accuracy improves."

The severe interruptions that sometimes go hand in hand with drilling through-cavities in near-net-shape cast

contributors

Allied Machine & Engineering Corp.
(800) 321-5537
www.alliedmachine.com

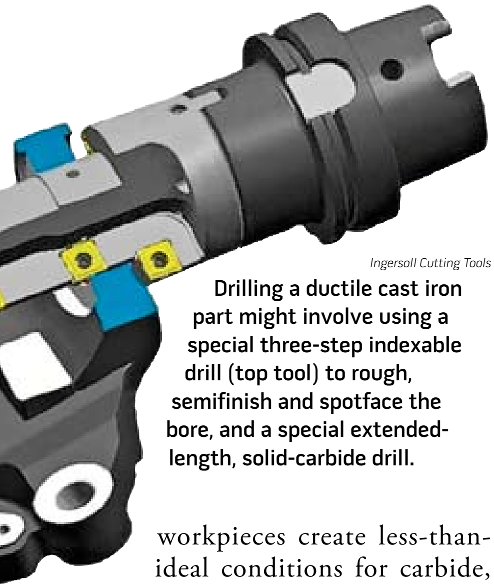
Ductile Iron Society
(440) 665-3686
www.ductile.org

Guhring Inc.
(800) 776-6170
www.guhring.com

Ingersoll Cutting Tools
(815) 387-6600
www.ingersoll-imc.com

Sandvik Coromant Co.
(800) 726-3845
www.coromant.sandvik.com/us

Unimerco Inc.
(734) 944-4433
www.unimerco.com



Ingersoll Cutting Tools

Drilling a ductile cast iron part might involve using a special three-step indexable drill (top tool) to rough, semifinish and spotface the bore, and a special extended-length, solid-carbide drill.

workpieces create less-than-ideal conditions for carbide, shortening tool life. In scenarios where lack of rigidity prevents effective application of carbide tools, a tougher HSS substrate might be the solution. “Allied has an HSS spade drill line that allows you to swap out a carbide insert for an HSS insert in the same tool body,” Porter said. He added that an HSS drill is able to cut at feed rates similar to those for carbide, but HSS won’t be able to run at the high spindle speeds appropriate for carbide because HSS cannot tolerate the same heat level.

Ductile cast iron is certainly a mature workpiece material, but it continues to replace materials for certain applications. “Ductile iron is becoming more popular,” Ductile Iron Society’s Wood said. “Gray iron is probably suffering.” That’s in part because automakers are making vehicles lighter to achieve fuel efficiency requirements and therefore castings need to be lighter and thinner. Ductile iron castings can be produced with thinner walls to reduce weight whereas gray iron can leak if the walls are too thin. “You don’t want water jackets leaking in engine blocks,” Wood said.

Wood noted that more design engineers are realizing ductile iron parts can replace weldments and forgings. “For example, where manufacturers may take some parts and weld them together, they can do that instead as an as-cast casting out of ductile iron.”

Sandvik Coromant’s Cole said the market for drills to machine ductile cast iron has slowed recently because fire hydrants, for example, are commonly made of the material and the new housing market is in a slump. However, ductile cast iron is still more common than gray iron—at least when it comes to seeking drilling assistance. “I’m seeing more ductile because it is more of a problem than gray,” Cole said. “People don’t call you when they don’t have problems.”

About the Author:
Alan Richter is editor of Cutting Tool Engineering, *having joined the publication in 2000. Contact him at (847) 714-0175 or at alanr@jwr.com.*