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▶ BY TECHNICAL EDITOR CHARLES BOYLES, CPE

Enhanced Performance

Benefits and machining characteristics of compacted graphite iron.

If you've been machining cast iron parts on a regular basis and you've noticed a change in tool life after switching to a new workpiece material, you may now be working with compacted graphite iron.

CG iron is a relatively new material that has some properties that make it superior to gray (cast) iron, which contains a large percentage of carbon in the form of flake graphite. CG iron is especially attractive for automotive applications that require large castings, such as engine blocks, cylinder heads and bed plates for diesel engines. So, what is driving the change to CG iron? A number of things.

Why the Change

Design engineers serving the automotive industry continually seek ways to enhance the performance of existing engines. They look for the "marginal capacity" of the design while keeping the basic design the same. The marginal capacity refers to the ability and suitability of a design to meet additional needs. Making incremental improvements is good up until the point where the basic building block—the engine casting in this case—must be redesigned to perform at a higher level.

But, should a design engineer find a material with superior attributes—say, a higher compressive strength, greater ability to withstand thermal stress or the ability to withstand higher operating pressures—the engineer can increase the functional performance levels of an existing design. Then, that design is said to have an increased marginal capacity.

Typically, more capacity means a larger, heavier casting, which usually involves redesigning the existing casting and designing and building new molds. When the product is large, like an engine block, the cost of building new molds can be staggering.

According to the folks at La Grange (Mo.) Foundry Inc., though, CG iron is similar enough to gray iron that they can use the same molds. Using the same molds for different alloys represents a significant cost savings over having to design and build new ones.

Comparing gray, ductile and CG irons

Gray cast iron, which is sometimes referred to as flake graphite iron, has graphite flakes distributed in an iron matrix. Generally, it is easy to machine because most of the carbon is in the free state. Also, even in high-strength parts, gray (cast) iron has been considered a highly desirable material since parts can be cast close to their finished dimensions, minimizing the amount of machining required.

Compacted graphite iron is an intermediate-grade iron that falls between gray and ductile iron. In CG iron, 80 percent of the graphite is compacted and 20 percent is spheroidal. There is no flake graphite. With a high tensile-strength-to-hardness ratio and a grain structure that is primarily pearlite, CG iron has higher tensile strength than gray iron at an equivalent carbon content. CG iron also is easier to machine than ductile (nodular) iron.

—C. Boyles

Iron Classifications by Free Carbon Configuration

Gray (Cast) Iron	Flake Graphite	FG Iron
Ductile (Nodular) Iron	Spheroidal Graphite	SG Iron
Unclassified	Compacted Graphite	CG Iron

CG iron can also boost the performance of the end product. By manufacturing cylinder heads from CG iron instead of gray iron, for example, some manufacturers have been able to increase engine output by 50 percent. Also, the operating temperatures for modern engine manifolds are in the neighborhood of 930° F (500° C). Under these conditions, gray iron manifolds tend to crack. CG iron parts accommodate these temperatures, increasing wear life and reducing warping and oxidation.

CG iron's enhanced heat-handling characteristics are especially important in the small or thin sections of a casting, which are more susceptible to failure.

CG iron offers obvious benefits, but users must be willing to make a tradeoff: The new material is harder to machine than gray iron.

DIAMETER	DEPTH	TOOL	SPEED	FEED
1.375"	2.0"	Carbide-Insert Drill	690 rpm	3.45 ipm
47/64"	3.0"	Twist Drill	410 rpm	1.6 ipm
1.75"	1.625"	Carbide Spade Drill	170 rpm	2.5 ipm
1.25"	9.0"	Carbide Spade Drill	220 rpm	2.1 ipm

Cooper Energy Service's speed and feed chart for CG iron shows conservative speeds and feeds for drilling smooth and straight holes into a cylinder head with a maximum hardness of 187 BHN. The minimum tensile strength is 43,540 psi and the minimum yield strength is 32,650 psi.

Mishap leads to development of CG iron

BY THOMAS JOHNSON

Compacted graphite iron, which has been produced since 1976, was born out of a metallurgical mistake. But thanks to an interesting combination of properties (see table), it has found a place in industry.

CG iron was discovered as an off-spec melt of ductile iron. When ductile iron is poured, a ladle of magnesium-bearing material is added to produce graphite in nodular, or round, form. If this melting process is compromised, the graphite assumes either a blunt, or worm-like, form, or it takes on the flake graphite shape of gray (cast) iron.

The main advantage of gray iron is its relatively low cost. But as designs are pushed to handle higher loads and design margins are reduced, there comes a point where gray iron becomes inadequate. Also, when impact or fatigue loads become more significant, a decision must be made to step up to ductile iron. The step up usually means new tooling and an average cost increase of 30 percent.

Properties	Gray Iron	CG Iron	Ductile Iron
Graphite Shape	Flake	Blunt (worm-like)	Nodular (spheroidal)
Tensile Strength	20 - 60 ksi	38 - 65 ksi	60 - 120 ksi
Yield Strength	None	30 - 50 ksi	40 - 90 ksi
Elongation	None	1 - 6 percent	3 - 18 percent
Hardness	156-302 BHN	137-255 BHN	143-302 BHN

However, a manufacturer in need of increased strength and some ductility could choose CG iron. And since the same tooling usually can be used when switching from gray iron to CG iron, the cost increase is only about 15 percent.

Also, the machinability of CG iron is closer to gray iron than ductile iron. While a change to ductile iron may require new machines, CG iron generally does not. Thus, CG iron can be a compromise that may meet the design parameters and constraints while minimizing costs.

About the Author

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Drilling CG Iron

When drilling, as with any machining operation, the nature of the material dictates the speed and feed. In addition to the material, the number and size of holes to be drilled per unit of time determines the tooling. Many shops apply M-7 or M-1 HSS or cobalt-HSS cutting tools to drill gray iron.

Mary Joe Hanlon, an applications engineer at Allied Machine & Engineering Corp., Dover, Ohio, said that a spade drill with indexable inserts is suitable for drilling holes from 1" to 6" diameter in iron materials, including CG iron. She also noted that the particular drills for cast irons have a greater rake angle and, as such, have a modified geometry. They tend to have a more fragile edge as well. Spade drills for gray iron typically have C-3 inserts.

However, Hanlon said a tool change would be needed if a shop began drilling the same part made of CG iron. She recommends TiN-coated carbide inserts because they have a greater abrasion resistance than C-3 inserts. TiN-coated inserts also tend to produce chips that resemble "dust." Hanlon also recommends through-coolant tools when possible to flush the cutting edges and evacuate the dust-like chips.

Conversely, Jim Geske, an applications engineer at Precision Twist Drill Co., Crystal Lake, Ill., said machine shops can use the same tools to drill CG iron and gray iron. However, they might experience greater tool wear when drilling CG iron.

"It's advisable to decrease the feed rate—perhaps 0.001" to 0.002"—when drilling holes ¼" and larger," noted

Geske. He recommends a cobalt-HSS tool for CG iron, but, ultimately, the choice is up to the engineer on the line.

Who's Drilling It?

One manufacturer of large engines, Cooper Energy Services, is making a concerted effort to improve its product and exceed the expectations of customers. It manufactures engines up to 3,200 hp and 16' long for gas compressors. The Springfield, Ohio, company also produces CG iron cylinder head sections that attach to the engine blocks.

The cylinder head is a triple-deck casting that measures approximately 18"×12"×10". When a CG iron cylinder head arrives from the foundry, it goes to the plant's machining area. There, holes are created for valves, head bolts and a number of ancillary engine components. The valve holes are bored; finish is a critical element for proper sealing. Then, six bolt holes are drilled with a HSS spade drill for the 1¼"-dia. head bolts that will be torqued down during engine assembly. In addition, there are other holes measuring from ⅜" to ½" that must be drilled and tapped for components, such as pumps.

The majority of the drilling is done on machining centers. However, backup drill presses are used to ensure production requirements are always met.

Cooper's experience is that the same cutting tools can be applied to both CG iron and gray iron engine components. The CG iron cylinder head has a hardness of about 163 BHN. Cooper uses carbide through-coolant twist drills and a semisynthetic coolant in this application.

In another application, a Midwestern pump manufacturer incorporates CG iron castings for a line of pumps that are designed for highly acidic service. The manufacturing process includes drilling hundreds of holes per day on four machining centers. In drilling ⅞"- to 1"-dia. holes, the process calls for a speed of 900 to 1,000 rpm and a feed rate of 4 ipm. These cutting parameters result in a good finish in one pass while generating a powdery chip. The company uses a coolant to keep the machining dust to a minimum.

At another large Midwestern foundry and machining operation, CG iron was evaluated as a candidate for engine components to extract more performance from existing designs. Although the material properties and machinability proved to be superior to gray iron, the price point for CG iron was deemed too high.

The size and depth of the hole ultimately dictates the type of drill that should be used. The material hardness and, to some extent, the grain structure of the material dictates cutting edge composition. Speeds and feeds can then be chosen from tabled values based on this information.

In essence, feed rates depend on the size of the drill and the material properties and should be consistent with the tool manufacturer's recommendations. And here we affirm the old adage: One test is worth a thousand expert opinions.