Converting from Steel to Ductile Iron Yields

More Parts for Less Cost

In today's competitive market, hydraulic component manufacturers are constantly faced with the task of making parts better, faster, and cheaper. Converting from carbon steel to continuous cast ductile iron from Dura-Bar can help manufacturers accomplish that goal. Moreover, the ready availability can be an important factor for metals buyers struggling with a tight market for certain steel bar stock.

In the past, hydraulic part manufacturers looked for ways to reduce their machining costs by turning to ductile iron castings in near-net shapes. Cast iron is well known for its free machining properties. Graphite contained in iron's ferrous metal matrix acts as a chip-breaker, dissipating heat and reducing tool-wearing friction between the work piece and the insert.

Use of near-net shapes in ductile iron castings can mean less machining, but that advantage is often offset by the defects associated with the traditional sand casting methods. As a result, manufacturers have sacrificed the machining advantages of ductile iron castings for steel bar stock. But steel, too, can have defects that prove costly during the machining process.

Continuous cast ductile iron bar stock allows manufacturers to realize the benefits of ductile iron's superior machinability without the defects associated with sand castings or steel bar stock. These parts can be machined much faster than with free machining steels. This gives hydraulic part manufacturers an opportunity to dramatically increase throughput, lower machining costs, and improve profitability.

Reduce Cycle Time with Longer Tool Life

Using continuous cast ductile iron bar stock in lieu of free machining steels typically reduces cycle times by 25-50% over steel while extending tool life. Dura-Bar's advantage over steel is particularly significant where sophisticated CNC equipment is used for parts requiring multiple operations. A basic description of grades of ductile iron and the steels they are designed to replace are outlined in Fig. 1.

Many hydraulic manufacturers have benefited from using continuous cast ductile iron bar stock such as Hydro/Power, Inc., a custom hydraulic cylinder manufacturer located in Birmingham, Alabama. "The machinability is a real plus for us," Jerry McVay, Hydro/Power's president, said. "In fact, we've been able to get our speeds and feeds up to a point where we're getting some dramatic improvements in cycle times," McVay added.

McVay's comments were echoed by John Robertson, Hydro/Power's vice president of manufacturing. "One of the glands that we manufacture requires a lot of profiling, grooving, and threading," Robertson said. "By using continuous cast ductile iron bar stock and making a few minor adjustments in our machining process, we've managed to reduce the cycle time for one part from 14-1/2 minutes down to six minutes," he added. "Needless to say, that's resulted in some significant cost savings for both us and our customer."

Fig. 1. Most Machinable Ductile Iron Grades

Material*	Hardness Rating	Characteristics	Steel It Replaces
65-45-12 Plus	143-207 BHN	A ferritic matrix structure with small amounts of pearlite. Very similar to low-carbon steel grades. An excellent replacement for low-carbon leaded steels as well as rephosphorized & resulfurized free machining grades.	1010 1018 1020 12L14 1212 1215
80-55-06 Plus	187-255 BHN	Contains approximately 50% ferrite & 50% pearlite. Slightly less machinable than 65-45-12. Used as a replacement for medium carbon steels when better wear resistance and higher strengths are required.	1040 1060 1045 1141 1144

*Dura-Bar grade designations are in the form xx-yy-zz where xx = tensile strength in ksi, yy = yield strength in ksi, and zz = elongation in percent.

Using continuous cast ductile iron bar stock also has helped eliminate the need for additional operations. “Because Dura-Bar wears so well, we can use it on pistons and glands without having to undercut and add wear rings or brass inserts,“ Robertson said. “In essence, we’re leaving out a machining step, and that saves us even more money.”

In addition to superior machinability, another key advantage for Hydro/Power is the reliability of the product. “We’ve been using it for 20 years, and we’ve never run into a single piece that was bad,” McVay said. “Our scrap factor has been absolutely zero.”

Machining

Ductile Iron vs. Steel

Despite the advantages of continuous cast ductile iron bar stock over many free machining steels, machinists’ handbooks typically do not list machinability ratings for ductile iron bar stock—mainly because most experts do not compare steel bar stock to ductile iron castings. However, a recent eight-year study by the University of Alabama Birmingham (UAB) and the Department of Energy was able to measure the rate of insert wear for ductile and gray irons.

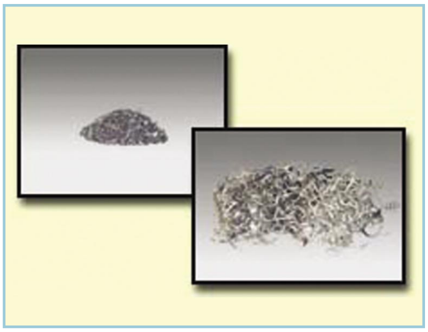
Because of the consistency and quality of the product, continuous cast ductile iron bar stock was selected as the baseline material for the machinability study. Lab tests conducted by Dr. Charles Bates, UAB research professor, examined tool wear rates at different machining speeds to determine a critical turning speed – i.e., the maximum speed that can be achieved before tool failure.

In the study, 3.250˝-diameter pieces of continuous cast ductile iron bar stock were turned on a lathe to remove a specific amount of material. The insert edge was then examined microscopically to determine the amount of wear that occurred during machining. The test was repeated at various speeds to determine the maximum speed at which rapid tool failure would occur.

Building upon the results of Dr. Bates’ study, Dura-Bar engineers conducted tests of their own to determine the machinability of its products compared to several grades of steel bar stock. Specifically, machinability ratings for Dura-Bar were determined by machining 2.375″ bars of Dura-Bar grades 65-45-12 and 80-55-06 down to 1.125″ in five passes (removing 0.250″ per pass, or 0.125” depth of cut).

Machining was done at 450 surface feet per minute using a feed rate of 0.010″ per revolution. Sandvik Coromant coated carbide inserts, style CNMA in grade GC3015, were used for all tests. *(Editor’s note: The current recommendation for tooling would now be CNMA style in New Grade GC3205—one of the recently released new series of cast iron turning grades from Sandvik Coromant.)*

Above: Savings with continuous cast ductile iron bar stock are usually greatest in hydraulic components that require multiple machining operations.



Above: Graphite contained in iron’s ferrous metal matrix acts as a chip-breaker which dissipates heat and reduces tool wear.

The number of parts per insert was determined when either the load meter reading exceeded 60% on two consecutive passes or the surface finish on the part exceeded 80 RMS after any one of the passes.

For comparison purposes, steel bar stock grades 1212, 1144, 4140, and 8620 were machined under identical conditions. A comparison of all grades tested is presented in Fig. 2.

In the biggest differential, the tests revealed that Dura-Bar 65-45-12 machined 70% better than 1212 steel – i.e., 340 pieces machined per insert edge for Dura-Bar vs. 200 for steel. The performance of Dura-Bar 80-55-06 was closer to that of 1212 steel (190 vs. 200 pieces per insert edge). However, the test did not take into account the ability to run Dura-Bar at higher speeds and feed rates that would yield more pieces per insert edge than with the 1212 steel.

The ability to run continuous cast ductile iron bar stock materials at higher speeds also was confirmed by Sandvik Coromant, a leading manufacture of machine tooling. "Where these materials replace steel components the advantage is increased speeds and feeds due to greatly improved machinability," Roger Grey, grade development specialist at Sandvik Coromant, said. "We tell our customers to automatically increase the machining speeds specified in our catalog by 20% when they're running continuous cast ductile iron bar stock compared to other irons."

He added that even higher speeds can easily be achieved due to the "excellent structural consistency" of the material. "The structural integrity is just so good, that the 'normal' data associated with machining comparative irons made by other casting processes just doesn't apply," Grey said. "Also, Dura-Bar's excellent surface finish and lack of porosity make it especially well-suited for hydraulic applications."

Fig. 2. Machinability Ratings for Ductile Iron & Steel Bar Stock

Material Grade	No. Pieces Machined Per Insert Edge	Machinability Rating (1212 = 100%)	Comments
Ductile Iron			
Dura-Bar Plus 65-45-12	340	170%	Most machinable grade. High ferrite content promotes free machining properties, and the graphite nodules act as chip breakers. Using standard coated carbide flat-top inserts, 65-45-12 can machine better than 12L14, especially at high machining speeds.
Dura-Bar Plus 80-55-06	190	95%	Most commonly specified grade because of the balance between wear and strength and machinability. Similar to 1212 at low speeds, easily out-performs 1212 at higher machining speeds.
100-70-02	85	43%	Rarely used except to eliminate heat-treat process in applications where the as-cast hardness is sufficient.
Steel AISI Designations			
1212	200	100%	Phosphorus and sulfur are added to promote solid phosphides and sulfides that act as chip breakers.
1144	165	83%	Resulfurized to promote sulfides, slightly more machinable than plain carbon steel, grades 1040 and 1045.
4140	130	65%	Used primarily for its fatigue strength and ability to through-harden. Chrome and molybdenum additions result in decreased machinability.
8620	120	60%	Used primarily for applications requiring high wear resistance but must be carburized prior to hardening. Machinability is similar to 4140, slightly reduced because of higher alloy additions.

Fig. 3. Typical Machining Speeds & Feed Rates for Dura-Bar

Ductile Iron Bar Stock*

Machining Operation	Machining Speed (sfm)	Feed (inch per revolution)	Depth of Cut (inches)
Rough Turning (O.D. and I.D.)	800 – 1,200	0.014″ – 0.028″	.100″ - .175″
Finish Turning (O.D. and I.D.)	1,600 – 2,000	0.004″ – 0.020″	
Drilling (with insert)	475 – 825	0.004″ – 0.015″	
Drilling	320 – 400	0.003″ – 0.012″	
Grooving (O.D. and I.D.)	900 – 1,500	0.002″ – 0.007″	

*65-45-12 Dura-Bar Plus

Ductile Iron Bar Stock*

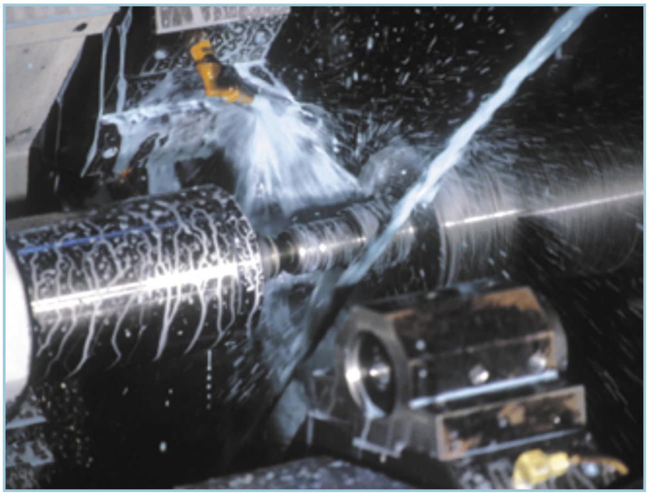
Machining Operation	Machining Speed (sfm)	Feed (inch per revolution)	Depth of Cut (inches)
Rough Turning (O.D. and I.D.)	700 – 900	0.008″ – 0.024″	.100″ - .175″
Finish Turning (O.D. and I.D.)	1,000 – 1,500	0.004″ – 0.020″	
Drilling (with insert)	410 - 650	0.004″ – 0.015″	
Drilling	270 - 350	0.003″ – 0.012″	
Grooving (O.D. and I.D.)	500 - 900	0.002″ – 0.007″	

*80-55-06 Dura-Bar Plus

As a starting point for hydraulic component manufacturers, technical experts have developed some recommended minimum speeds and feed rates for machining. These recommendations are contained in the chart in Fig. 3. *(Editor's Note: The recommended speeds and feeds listed in the chart should be used on Dura-Bar Plus ductile iron grades only. These grades are specially produced to maximize speeds and feeds. Carbides, inclusions, and other processing variables that have not been properly controlled to standards will not allow all ductile irons to be machined at the above speeds, and serious damage may occur to machine tools.)*

Better Machinability Yields Significant Cost Savings

Machinability studies comparing ductile iron and steel make it possible to craft some typical cost comparisons. For example, suppose a part made from 1212 steel bar stock is turning at 650 surface feet per minute.



Above: Using continuous cast ductile iron in lieu of some free machining steels can save money by reducing machining cycle times by 25-50%.

Converting the part to Dura-Bar 65-45-12 ductile iron bar stock and increasing the turning speed to 1200 surface feet will result in an 85% increase in machining speed.

1200 – 650 = 550

550 ÷ 650 = 0.85 (85%)

Not all of the increase in turning speed will apply directly to the time savings for a machined part. Other variables—such as loading and unloading the machine and tool changes—always will be part of the total cycle time. Using 75% of the increased turning speed should give a good estimate of the cycle time reduction to be achieved. Given the above example, the expected new cycle time would be 64% of the original time (0.85 x 0.75 = 0.6375, or approximately 64%).

Assuming that 12 minutes is the total time required to produce a finish machined part with 1212 steel, the cycle time would be only 7.65 minutes (12 x 0.6375 = 7.65). Therefore, for a machine shop having an overhead burden of $65 per hour, the cost savings would be as follows:

Using 1212 steel:

12 minutes/part
= 5 parts per hour (60 ÷ 12 = 5)
$65 per hour ÷ 5 parts per hour
= $13 per part fixed cost

Using Dura-Bar 65-45-12:

7.65 minutes/part
= 7.84 parts per hour
(60 ÷ 7.65 = 7.84)
$65 per hour ÷ 7.84 parts per hour
= $8.29 per part fixed cost

Total savings: $4.70 per part

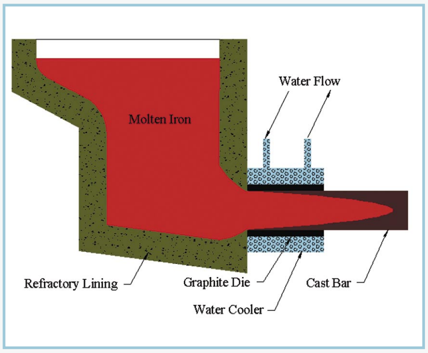
Converting from carbon steel to ductile iron does not necessarily require a tooling change. However, additional improvements in cycle time can be gained when using inserts made especially for ductile iron.

Specifically, inserts without chip-breakers are recommended. The graphite nodules present in ductile iron—although microscopic in size—are still large enough and well-dispersed enough to eliminate the need for the chip-breakers that are typically used when machining steel bar stock. Inserts with chip breakers have a very thin edge on the interface between the work piece and the cutting tool. That edge can overheat and cause premature chipping when running at the faster speeds possible with Dura-Bar. A flat-topped insert will perform better because the heat caused by frictional forces during machining will dissipate easier across the top of the insert. FPJ

The Continuous Casting Process

Continuous casting of gray and ductile iron was pioneered in the U.S. by Wells Manufacturing Company in 1961 as an alternative to sand castings and steel bar stock. Wells' widespread success of its continuous cast products led to the establishment of the company's Dura-Bar division in 1974.

The casting process involves moving molten iron through a water-cooled graphite die in a bar machine designed to pressurize the metal as it enters the die. As the molten iron moves through the die, a solid skin begins to form in the shape of the outer surface of the bar. The bar is cast through the die in a series of strokes, each one about 2″ long, until the solidified rim is just thick enough to support the head pressure created in the bar machine.



Above: Continuous Cast Bar Machine – Cross Section

When the bar exits the graphite die, the surface temperature is just below the solidification point of the iron, and the rim is about 0.250″ thick. The core – or "bulls eye" – of the bar contains molten iron, and the entire bar is solidified and cooled in ambient air to produce a homogenized cast iron cross section.

The bar machine crucible acts as an oversized "riser" preventing solidification shrinkage. Impurities such as slag and dross float to the top of the molten iron, well away from the entrance end of the die. The crucible is specially designed to prevent turbulence during iron delivery and to keep uniform iron temperatures throughout the production run.

The resulting bar stock is free from gas, tool-wearing inclusions, and other defects and has a very fine-grain structure that allows for excellent surface finishes on a machined part. The graphite die and the ability to control uniform solidification in the rim during casting are the only limitations to the possibilities for sizes and shapes that can be produced using the continuous casting process.

More information on Dura-Bar continuous cast iron is available from Dura-Bar at 800-227-6455 or on the web at www.steelalternative.com.