"The Best of"
The Ductile Iron News

For many years previous to our presence on the World Wide Web, "Ductile Iron News" appeared in print with a limited mailing list. Therefore, our global audience has never had access to some of the articles which we rate as our "Best Contributions." In this issue we are reprinting a few that we know you will find informative.

Designing with Ductile Iron
Cincinnati Milacron of Cincinnati, Ohio is an acknowledged world leader in advanced manufacturing technologies for the metalworking and plastics processing industries, with expertise in a variety of fields, including machinery, computer controls, software, cells and systems, metrology, inspection and robotics.

The Advantages of Investment Casting Technology and the Benefits of Ductile Iron
The ductile iron family offers the design engineer a unique combination of strength, wear resistance, fatigue resistance, and toughness, as well as excellent ductility characteristics. In all its grades, ductile iron exhibits mechanical properties that make it an ideal alloy for investment casting.

DIS Member
Charles W. Mooney, Jr. Dies

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FEATUERS
- Notice: AFS/SAE 2002 Meeting (Not a reprint)
- Ductile Iron Answers the Pipe Maker's Dream
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- The Advantages of Investment Casting Technology
- Use of Bismuth in Ductile Iron
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- Venting - "The Lost Art"
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AFS to Coordinate SAE 2002 Casting Papers/Presentations

DES PLAINES, ILL. – The AFS Marketing Div., working in conjunction with the AFS Technical Dept., has assumed the responsibility for gathering, reviewing and scheduling metalcast-related papers for presentation at the 2002 Society of Automotive Engineers (SAE) World Congress & Expo. This effort is being initiated to continue a focused representation of metalcasting at the event, as well as the continued publication of casting-related papers into the permanent SAE record. Focused sessions on metalcasting have existed for two years now (previously coordinated by Edward Vinarcik of Bosch Airflow Systems). 50,000 engineers and industry decisionmakers attend this event.

Papers and presentations for next year’s event (March 4-7, 2002 in Detroit, Michigan) should be directly applicable to design engineers working in the transportation industries. Appropriate technical subjects may include:

- unique/innovative transportation applications of cast metal components;
- design validation techniques;
- case studies showing reduced cost or added value through casting utilization;
- variability reduction and performance improvements;
- environmental considerations and recyclability of castings;
- design/material property data;
- new and/emerging technologies related to the design and prototype of metal castings.

The deadline for paper offers is June 1. The paper offer should include a 200-300-word description that includes a tentative title and full author/company information (including mailing address, telephone, fax and email). Draft manuscripts are due August 31, with final papers due to SAE by December 17. Papers and presentations will be reviewed per SAE requirements and audience scope.

Send abstracts to SAEcongress@afsinc.org or mail to SAE 2002 Congress, c/o AFS, 505 State Street, Des Plaines, IL 60016.
In the forty some years since the invention of Ductile Iron, virtually every manufacturer of pressure pipe has switched from gray iron to this superior metal. Why? Because Ductile Iron's exceptional characteristics enabled improved performance with a reduction in thickness and weight.

Widespread evaluation of Ductile Iron in the 1950s demonstrated its superior strength and impact toughness, prompting more producers to switch from gray iron. By the mid 1970s, all major producers of iron water main pipe had converted entirely to Ductile Iron.

The United States currently sees approximately 1 1/4 million tons of Ductile Iron pipe produced annually. And an estimated 1 1/2 million miles of pipe have already been installed to distribute the several hundred gallons of water used each day by every family.

History of Pipe Materials

Water has always been a precious commodity, and its transmission has facilitated the advancement civilization enabled the comforts of our modern living standard.

While the Romans were acclaimed for their transmission of water, their aqueducts provided only downhill passage, by gravity flow. Complete distribution required pressurization in pipe. Earliest pipe materials were predominantly bored logs, with some use of lead pipe and brittle baked clay pipe.

Iron pipes were first used in the 15th century in Germany and France. The most notable installation as the Palace of Versailles built by King Louis XIV in 1664. These cast iron pipes are still in use today, over 300 years later. Gray cast iron pipe progressively became the preferred material for water.

The first iron pipe in the United States was imported from England and used by the city of Philadelphia in 1804. Early iron in the United States was made in charcoal furnaces, which were concentrated mostly in the New Jersey area. Some of the earliest pipe foundries were also located there.

With the use of coke in blast furnaces, then cupolas, foundry growth expanded westward into Pennsylvania and Ohio, then southward toward the Birmingham area, where all the materials for iron were available. Soon, various accessories such as fittings, valves and fire hydrants joined with pipe as parts of the total industry, and were cast in many foundries.

Sanitary or soil pipe also grew into a considerable industry, but distinct from pressure pipe with less demanding iron specifications, shorter lengths and thinner walls.

Since 1913, Alabama has been the leading state, and Birmingham the leading city, for iron pipe production.
The first iron pipes were cast statically in horizontal modules in lengths limited
to three to six feet because of suspension of the massive center cores. Many
of the early foundries produced pipe along with many other types of casting.
As demand for pipe increased, the casting equipment became more
specialized, casting vertically in pits with lengths increased first to 12 feet,
then 16 feet.

In 1918, a Brazilian, DeLavaud, presented a centrifugal casting process which
revolutionized pipe production. The use of the centrifugal force of a rotating
mold eliminated need for the center core. And the water-cooled metal mold
permitted repetitive casting at high production rates. Long heat treating ovens
were necessary to anneal some chill obtained against the metal mold.

A centrifugal process using sand rammed molds was developed to avoid the
chilled structure and necessity for annealing. Later, a resin bonded thin sand
process was invented by ACIPCO and used by a few plants for several
years.

With increase labor cost and the advent of Ductile Iron, which required
annealing on all processes, sand lined processes have been abandoned. All
pressure pipe is now cast in water cooled metal molds using highly
specialized equipment with automation and computerized controls.

**Gray Iron Pipe Quality Advances**

With advances in metallurgy and melting controls, and through the use of
chemical, and spectrometer laboratories, gray iron pipe progressively
improved and its strength increased. Quality was closely controlled to
specified levels of strength, and the moduli of rupture and modulus of
elasticity determined on test specimens from the wall of the pipe. Each pipe
was hydrostatically tested to 500 psi.

Guided by a strong
pipe association,
thickness
classifications were
established for
various operating
pressures and
depths of cover with
allowances for
pressure surges
from valve closing
and from super
imposed truck
loads.

**Ductile Iron
Evaluated and
Adopted**

When the discovery
of Ductile Iron was announced, some pipe producers saw no need for it,
since gray iron had served well and was stronger that other competitive pipe
materials, primarily plastic in small diameters and reinforced concrete in large
diameters. But others recognized the potential for Ductile Iron in pressure
pipe service. Several companies experimented with Ductile Iron, and some
trial orders were produced for special applications and evaluation.
Performance tests and experiences were very favorable.

Again, the pipe association guided evaluation of Ductile Iron on test pipe of
various thicknesses, outfitted with strain gages, installed in various type
trenches and depths of cover and subjected to various pressures and external
loads simulating passage of trucks.

These tests verified the superior properties of Ductile Iron, which permitted
reduction in thickness. The established thickness reductions more than
compensated for the increased cost of Ductile Iron and actually reduced the
pipe cost per foot.

Through a period of transition, most companies produced both gray iron and
Ductile Iron pipe to suit customer preference. But with good experience from
Ductile Pipe in service, preference for Ductile Iron progressively increased. In
the mid seventies, all major producers went totally to Ductile Iron and abandoned gray iron pipe. Those producers who resisted Ductile Iron were eventually closed or purchased.

**Processes and Properties**

With conversion to Ductile Iron, pressure pipe production became an even more specialized process.

Pipe producers generally melt in large water-cooled cupolas with the latest accessory equipment. Some producers duplex in electric furnaces for more positive supply and control. In the early years, some used a basic slag to obtain low sulfur from the cupola. In recent years, general practice has been to melt with an acid to neutral slag and desulfurize externally using on of several available agitation methods. Low sulfur iron is then treated with magnesium by several of the available treatment processes.

Magnesium treated iron with closely controlled chemistry and temperature is poured at a controlled rate into molds rotation at proper centrifugal speed with post inoculant added in the stream and mold.

After stripping, the pipes are fully annealed through long annealing furnaces, some as long as 240 feet. As-cast pipe has a slight depth of chilled iron which requires some time in a 1700°F zone. Due to the late post inoculation, the carbides break down fast to fine nodular graphite with a high nodule count. Then a lower temperature zone breaks down pearlite to a ferritic matrix for highest ductility and impact toughness.

Guided by tests the pipe association, specifications established by A.N.S.I. and A.W.W.A require tensile tests from the wall of the pipe to meet 60,000 psi tensile, 42,000 psi yield, and 10 percent elongation. Impact strength is specified both at room temperature and at -40°F on a modified Charpy-V specimen testing the full wall of the pipe.

**Conclusion**

The pressure pipe industry has taken advantage of the superior properties of Ductile Iron, totally converting all iron pipe to Ductile Iron.

Ductile Iron pipe has established an outstanding performance record against increasing stresses, superimposed loads and earthquakes. Ductile Iron has also enhanced the reliability of water transmission, thereby providing comfort and sanitation and contributing to our high standard of living.
Designing With Ductile Iron

Cincinnati Milacron of Cincinnati, Ohio is an acknowledged world leader in advanced manufacturing technologies for the metalworking and plastics processing industries, with expertise in a variety of fields, including machinery, computer controls, software, cells and systems, metrology, inspection and robotics. The company recently redesigned its entire line of injection molding machines utilizing Ductile Iron. The resulting machines were not only simpler in design, with fewer parts, but also highest quality, lower in cost and capable of superior performance.

The company’s previous line of injection molding machines had platens made from AISI 1020 plate steel. These steel plates ranged in size from 5 inches thick by approximately 40 inches wide and 40 inches long for smaller machines to over 20 inches thick by 100 inches wide and 100 inches long for large 3,000-ton machines. Because the plates required a large amount of machining time for cleanup and lost a large amount of material due to machining chips, it was decided that Ductile Iron castings should be used for the platens, and several other parts, in the new design. This decision was made for several reasons; first, the properties of Ductile Iron are similar to the properties of the AISI 1020 steel that had previously been used; second the use of castings would allow the company to consolidate several parts into one; and third, the use of Ductile Iron would substantially reduce machining costs.

Most of the parts for which the design team at Cincinnati Milacron was considering Ductile Iron castings were subject to high cycle fatigue. Therefore, the mechanical properties of the Ductile Iron to be used had to be comparable to the properties of the plate steel. It was decided that grade 60-45-15 ferritic Ductile Iron was a suitable match for these critical parts. Table 1 below lists the typical mechanical properties of the AISI 1020 steel plate and the properties of the gide 60-45-15 Ductile Iron that the company specified as a replacement for the majority of the cast parts in the new design. In addition to the typical mechanical properties listed, Ductile Iron has fatigue and fracture toughness properties that allow it to be used in fatigue applications.

The design team for the castings included people from several different groups, including design engineers, manufacturing engineers, purchasing personnel and representatives from Cast-Fab Technologies, a foundry. Working together from the start of the project, the team designed the parts with a collective eye not only toward surpassing strength and fatigue requirements, but also toward improving both castability and machinability.

One of the goals for the redesign of these complicated machines was a simplification of the existing design through a consolidation of parts. Toward
Designing with Ductile Iron

These platens, made of ANSI 1020 steel plate, were used in Cincinnati Milacron's previous line of injection molding machines.

Cincinnati Milacron's newly designed line of injection molding machines uses Ductile Iron castings for several parts, including platens.

Critically stressed parts were designed using finite elements analysis to determine stress levels in all areas of the casting.

This design technique gave the design engineers the ability to design highly reliable parts with stress levels well within the fatigue limit values and to remove any material that does not contribute to the strength of the casting, thereby reducing weight. An example of an FEA is shown at right. Each of the colored areas represents a stress level. FEA can also be used to determine part deflection in various areas of the casting when rigidity is an important factor.

Foundry that input in the early stages of the redesign project proved to be very important because it averted several potential casting problems. By showing the foundry high stressed areas of the casting, they were able to design the pattern and gating and risering systems to assure sound metal in these areas. They were also able to suggest design changes that improved castability and prevented designed-in casting problems. Machining stock was adjusted to the proper thickness to avoid having casting defects, dross, slag or sand on machined surfaces, highly stressed areas or areas that have hydraulic sealing surfaces. Casting dimensional tolerances were determined to avoid interference between castings at assembly and assure that core tolerances and machining stock could be adjusted so that core holes would clean up without excessive machining.

Manufacturing engineering was also involved at this early stage, designing castings both for ease of machining and fixturing and for reduced tooling costs. The use of Ductile Iron reduced machine costs since it machines more like gray iron than steel. It also permitted an increase in rough machining feeds and speeds, thus reducing machine time as compared to steel. In addition, tool life increased due to the fact that the graphite in Ductile Iron reduces wear. And deburring was also reduced because the size of the burr was reduced or eliminated.

The design advantages described above were only realized thanks to the superior capabilities of Ductile Iron. With mechanical properties similar to steel and castability and machinability similar to gray iron, Ductile Iron enabled Cincinnati Milacron to optimize the design of its new line of injection molding machines, making them more reliable at lower cost.

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The Advantages of Investment Casting Technology
and the Benefits of Ductile Iron

Since ductile iron was developed in the 1940’s, this remarkable metal has proven its value in tens of thousands of engineering and casting applications. Ductile iron is created by an alloying process which converts the crack-promoting graphite flakes of gray iron into nodules. With this microstructural transformation, the metal acquires superior ductility, elongation characteristics, and machinability. The ductile iron family offers the design engineer a unique combination of strength, wear resistance, fatigue resistance, and toughness, as well as excellent ductility characteristics. In all its grades, ductile iron exhibits mechanical properties that make it an ideal alloy for investment casting.

Ductile iron represents the fastest growing segment of the iron market. It is a cost-effective substitute for carbon and low alloy steels, and in some applications, ductile iron can even outperform steel. By applying the two-stage heat treatment process known as austempering, the metal acquires even more advantageous properties, challenging the performance of medium grades of steel.

The qualities of ductile iron make it an ideal metal for the design freedom and precision available through investment casting. The metal and the process have the potential to provide complex parts with high dimensional accuracy, exceptional detail, and excellent economics.

Achieving the full potential of ductile iron requires superior metallurgical process control, as well as the highest levels of skill in part design, ceramics, and metal pouring to realize the joint benefits of ductile iron and investment casting.

Precision Metalsmiths, Inc. was one of the first investment foundries in the world to pour ductile iron as well as a pioneer in offering castings with austempered ductile iron (ADI). We maintain the demanding controls of chemistry, process procedures, timing, and temperature required to retain our certification by the Ductile Iron Society. In more than two decades of work with ductile iron alloys, proprietary processes and equipment which been developed enable us to provide castings that take full advantage of this metal’s properties. Our ongoing research and development efforts ensure that our castings reflect the latest advancements in foundry technology.

Engineering for Maximum Cost Savings

The ductile iron family includes grades that offer specific mechanical properties required for various applications.

Metallurgists will help you select the best alloy for your use while our engineers will carefully assess the part design for compatibility with investment casting. In addition to modifications that optimize cost efficiency, we can often suggest changes that improve the effectiveness of the finished part. If required, a process can economically provide accurate metal prototypes for testing.

Technicians machine the precision tools needed to form patterns in wax formulation. Your ductile castings are manufactured with the Shellvest® process.
A wide range of after-casting processes including austempering, heat treating, and other finishing services, can also be provided.  

The Benefits of Ductile Iron:

- Less brittle than most types of iron.
- Lower cost than carbon and low alloy steels.
- Less gating required, lowering unit cost for both materials and labor.
- Excellent castability/high yield rate.
- Four times stronger than cast iron.
- 0% lighter in weight than steel.
- Highly machinable.
- Superior wear-resistance.
- Available in grades that offer a range of desirable properties.
- Most grades can be used in the as-cast condition without additional heat treatments.
- Offers an average 25% cost savings over forgings or steel castings.

The Benefits of Austempered Ductile Iron (ADI):

- 100% recyclable.
- Twice as strong as untreated ductile iron.
- Fracture, fatigue, and toughness properties comparable to forged or cast steels.
- Increased toughness under abrasive conditions.
- Crack resistance that exceeds untreated ductile grades.
- Available in a wide range of mechanical properties.

The integrity of your finished parts are assured using advanced quality control methods including spectrographic analysis, carbon analysis, micro examinations, computerized measurement, and nondestructive inspections with radiographic, magnetic particle, and fluorescent penetrant technologies. And finally, each part is visually inspected by an experienced technician before delivery.

Computer-controlled coordinated measuring instruments are used to verify the dimensional accuracy of tools, patterns and parts.
Ductile Iron News The Advantages of Investment Casting Technology

This cylinder, used in manufacturing air motors for hand-operated power grinders, combines precise casting detail with the strength of ductile iron. Technicians form the ductile alloy you specify by inoculating base iron immediately before casting. We only pour virgin metal. Our scrap ductile iron is sold for recycling in other, less demanding casting applications.

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<td>60-40-18 (F32800)</td>
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<td>65-45-12 (F33100)</td>
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<tr>
<td>75-60-06 (F33800)</td>
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<td>100-70-03 (F38400)</td>
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Ductile Iron - ASTM A536

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Austempered Ductile Iron - ASTM A897

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<td>230</td>
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<td>444-555</td>
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</tr>
</tbody>
</table>

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This gripper arm, used in mail insertion machines, is shown at 1/2 actual size. 1.084 lbs.

This 100x micrograph on the left shows the brittle flake composition characteristic of most irons. on the right, the 100x micrograph of ductile iron shows the nodular graphite composition that creates the alloy's metallurgical advantages.
Complex internal detail is achievable with investment casting. In this outlet flange, used in a foam-dispensing pump, ceramic cores included in the wax pattern eliminate costly machining by allowing multiple holes running in different directions to become part of the casting process. 8.464 lbs., shown approximately 3/4 actual size.

Fine detail, accurate tolerances, and smooth finish are clearly displayed in this control rod used in panic door hardware sets. 0.161 lbs., actual size 4-3/4”.

The Benefits of Investment Casting with Ductile Iron

- Near net shape—uses metal economically and reduces after-cast machining.
- Close tolerances—casts at an average tolerance of +/- .005 inch or better which decreases the need for after-cast straightening.
- Excellent surface Finish—yields an average, as-cast microfinish of 125 RMS; lessens or eliminates after-cast finishing requirements.
- Cast-in Detail—capable of including holes and lettering, lowers the need for costly machining.
- Design Freedom—allows simple or complex design, including intricate internal configuration.
- Wide Choice—ductile iron alloys offer different characteristics depending on how the graphite nodules appear in the matrix of metal.
- Size Range—ideal for small parts with weights from fractions of an ounce to 10 pounds.
- Tooling Economy—requires lower-cost tolling to cast high-quality parts.

Please contact us to review any of our brochures:

- The Advantages of Investment Casting Technology
- The Strength of Ferrous Alloys
- The Versatility of Aluminum & Non-Ferrous Castings
- Investment Casting Systems
Alloy Selection Guide

The Benefits of Ductile Iron

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Website designed and maintained by LauraWatson.com, Inc.
Introduction

Many things have been published about the use of bismuth in ductile iron, especially in inoculants for ductile iron. The literature about this is quite confusing due to varying sampling procedures, sample castings, magnesium treatments and of course the addition of the bismuth itself.

The reported results include increase in nodule count, smaller nodules and better distribution, reduced chill, decreased magnesium recovery, and bad nodularity (exploded nodules).

This study was conducted primarily to investigate the behavior of bismuth treated iron and resulting microstructure under production conditions in a highly automated foundry.

We were looking at bismuth addition as part of our continuing efforts of creative iron improvements. The literature showed some interesting potentials of bismuth and our study confirmed all the positive effects. In the time during which bismuth was used, other improvement projects continued, and we learned that some of the effects that bismuth had on our iron can be accomplished by other operational changes. To eliminate this one extra step of adding the bismuth into the ladles, the decision was made to make operational changes other than continuing efforts on automating bismuth addition. At that point the addition of bismuth was discontinued.

Conclusion

A controlled addition of pure bismuth to ductile iron in conjunction with a magnesium treatment using MgFeSi with cerium is effective in increasing nodule count, improving nodule distribution, and eliminating carbides.

The correct Total Rare Earth (TRE)/Bi ratio is key to avoid degenerated graphite and will vary from one foundry to another.

Study

The main part of the study was conducted to compare results between commercially available bismuth and rare earth containing inoculant, and pure bismuth added in the form of tablets to the rare earth containing magnesium alloy used in the Tundish treatment.

During the second part of the study we experimented with different levels of pure bismuth addition and investigated the effects on the microstructure.

All experiments were carried out using a test casting with the configuration shown in Figure 1, cupola base iron treated with 5%MgFeSi (containing 1.35% Total Rate Earth) and instream inoculation (75%FeSi). Results were confirmed by looking at actual production castings.

The bismuth was added in tablet form into the Tundish ladle after adding the MgFeSi, so it was placed on top of the alloy. The bismuth tablets were about 15mm in diameter and 15mm long and weigh 18 grams. We sampled some different sizes and weights in the process of determining what addition rate to use, but concluded the above size and weight to be optimal for production.

Chill tendency was measured on chill wedges (see Figure 1), and nodule count was determined by counting in a defined field.

Results

Several trials were conducted using...
different jobs with 0.005% bismuth addition to the Tundish ladle. All showed very good nodule count, good nodularity, significant reduction of chill in the chill wedges, decrease in magnesium recovery, and no difference in mechanical properties.

Table 1 shows the results of a parallel test on both Disa 2013’s. Both Disas are supplied with the same base metal which is treated in Tundish ladles with MgFeSi alloy. To Disa II 0.0055% bismuth was added before treatment, while Disa I operated without bismuth addition. Every half hour a chill wedge that was mounted on the pattern plate was cut, polished and the section size of the wedge containing the last carbide was reported. The average depth of carbides in chill wedges without bismuth (from Disa I) was 4.5mm, compared to the average depth of carbides in chill wedges with bismuth addition of 1.9mm.

<table>
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<tr>
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When bismuth was added with the magnesium treatment alloy, the final magnesium was about 10% lower than usual. The produced castings didn’t show any effects in nodularity, and we didn’t change addition rates.

The Right Rare Earth/Bismuth Ratio
Following suggestions from the literature, the first trials in the Tundish ladles with magnesium alloy used 0.02% Bi, which resulted in a TRE/Bi ratio of 0.74 (the assumption was lower bismuth recovery, this is why the addition rate was doubled). This resulted in poor nodularity (vermicular) and very low magnesium recovery. The next test only used 0.01% bismuth, the next month we ran with 0.0055% addition, and from there the addition rate was gradually decreased to 0.002%. All samples in that range showed good results within the mentioned parameters (nodule count, chill, nodularity). See table 2 for an overview of the results.

The commercially available inoculant sampled had a range of TRE/Bi ratio from 0.3 to 0.9. It resulted in poor nodularity (vermicular), higher nodule count than pure bismuth, and higher chill tendency than with pure bismuth plus some carbides. This trial is not included in the following table due to the poor
Use of Bismuth in Ductile Iron

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tundish ladle</th>
<th>Tundish ladle</th>
<th>Tundish ladle</th>
<th>Tundish ladle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addition rate</td>
<td>0.02%</td>
<td>0.01%</td>
<td>0.0055%</td>
<td>0.002%</td>
</tr>
<tr>
<td>TRE/Bi ratio</td>
<td>0.74</td>
<td>1.49</td>
<td>2.71</td>
<td>7.45</td>
</tr>
<tr>
<td>Nodule count</td>
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<td>increased</td>
<td>increased</td>
<td>increased</td>
</tr>
<tr>
<td>Nodularity</td>
<td>poor</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Chill tendency</td>
<td>decreased</td>
<td>decreased</td>
<td>decreased</td>
<td>decreased</td>
</tr>
</tbody>
</table>

Table 2. Overview of significant experiments

Mechanical Properties

Increased attention was paid to mechanical properties of the bismuth treated iron versus iron without bismuth. Extensive testing on separately cast tensile bars as well as casting sections found no significant difference within the range of the before mentioned addition rates (except in the cases of poor nodularity, e.g. vermicular graphite present).

Bismuth Carryover

We calculated bismuth recovery and theoretical buildup of bismuth in the returns. It wouldn’t pose a problem in the cupola with 50% returns in the charge. Bismuth was added to 25% of the production, that is both small Disas only, for eight months. During that time nodule count increased shop-wide suggesting that the carried over bismuth is still potent enough to help inoculation.

After the bismuth addition was stopped, it took about six months to become noticeable in the routinely measured chill wedges. This means that the nodule count decreased somewhat after the bismuth was eliminated and also the depth of the last carbides increased somewhat, but not to the same level as before. The higher level of iron quality can be accounted for by other improvements implemented during that time.
Testing Molding Sand for Compactability
By: George DiSylvestro, DiSylvestro Videography Service

Green sand molding is a process that combines the advantages of versatility, productivity and low cost for the production of quality castings of any metal that is castable. Because of the advent of high density molding, using higher pressure automated molding machines, improved casting dimensions have been obtained.

A simple test that has replaced the "hand feel test" is the compactability test. Compacted mold uniformity is a vital factor in achieving near-net-shape casting production. The test can reduce mold-wall movement that could be a prime cause of apparent shrinkage. The test is reported in percentage and establishes a relationship between molding sand compaction characteristics independent of its composition. Compactability simply indicates the degree of temper or relative wetness of the molding sand mixture. It provides a percentage number that can be related in quality control an/or computer control programs. It is recommended that the compactability test be performed at the mulling or mixing station for quick control response of the governing factors and decision making.

The compactability test determines the percentage decrease in height of a loose mass of sand under the influence of compaction. The compactability molding values are directly related to the performance of a molding sand mixture. If controlled by some of the major conditions that affect the test, the use of this could yield excellent casting finish and reduce cleaning.

THE COMPACTABILITY TEST

Under constant conditions, a riddled sample of tempered molding sand is compacted and the percentage decrease in height is determined. The test closely simulates the actual filing of a flask with molding sand and compaction by a molding machine. It is independent of the specific gravity of the sand, and is therefore superior to the bulk density test for measuring degree of temper or determining the water requirements of a sand mixture. **Figure 1** indicates the equipment required to perform the compactability test.

**DO'S AND DON'TS**

There are several guidelines to remember when testing for compactability. These should be strictly followed, as failure to do so can affect the results of the test.

- Always lubricate the specimen tube before testing.
- Be sure the strike off blade is held perpendicular to the top of the specimen tube. If not, it can pre-compact sand slightly.
- When transporting or placing the sample tube into the rammer, do not jar it as this could also pre-compact the sand.
• Lower the rammer onto the specimen tube carefully.

• When ramming the specimen do not go extremely fast or slow as this can affect the degree of ramming. A guide here is to always pause at the 4 o’clock position between rams.

• Do not use compactability specimens in other tests calling for 2” x 2” specimens.

• There are several charts and scales available from vendors which have proven a useful aid in compactability testing. Contact your supplier for information on these.

CONDITIONS THAT AFFECT COMPACTABILITY

• Moisture content

• Clay content

• Carbonaceous material

• Inert fines (water absorbing)

• Length of mulling time

Control of compactability can produce a uniformly dense mold. A firm mold can yield a near-net-shape casting with an excellent surface finish as is shown in Figure 4.

HIGH COMPACTABILITY COULD RESULT IN:

• Improved casting dimensions

• Better casting finish

• Gas-blow-pinholes

• Expansion problems

• Difficult shakeout

• Hard mold penetration

• Brittle mold surfaces
Figure 2 indicates a problem that can be encountered with high compactability molding sand. In this case the compacted sand is too dense and the result is an expansion type defect termed a scab. Another result of high compactability is shown in Figure 3. A very highly flowable sand has produced a very dense mold resulting in “hard mold penetration”.

LOW COMPACTABILITY COULD RESULT IN:

- Friable mold edges
- Crushes - inclusions
- Hard to lift pockets
- Mechanical penetration
- Apparent shrinkage
- Cuts and washes
- Cope drops
- Oversize castings
- Rough surfaces

Figure 5 shows a result of low compactability. A stiff molding sand that resisted compaction produced open voids in the mold and metal penetration occurred. Shown in Figure 6 is an example of mold dilation due to a soft mold which caused an oversized casting and metal shrinkage.

SUGGESTED READING

For those who are interested in furthering their knowledge of this subject it is recommended that they obtain copies of the following:

- J. Herivel, Compactability for Production Control, H. W. Dietert Company.
Experiences in Problem Solving
VENTING - "THE LOST ART"
By George DiSylvestro, DiSylvestro Videography Service

ABSTRACT
With the enormous progress made in new production casting methods during recent years, the art of venting has been LOST. One of the main reasons is due to automation, mechanization procedures, design, and costs, to retain the successful venting practice of the past. Only when casting quality has suffered and casting losses increase, does the necessity of venting become important. (However the time to maintain training of personnel was challenged as foundries downsized with loss of technical people and increased tooling cost.)

The review of basic fundamentals and creativity of the tooling engineer is of the utmost importance in the competitive atmosphere of today. We must continue to have the desire to increase productivity and maintain a high degree of profitability. The what, why, how, types of examples, and cost of venting will be reviewed to assist the metalcaster in boosting and maintaining production.

BASICS OF METALCASTING PROCESS
The casting process utilizes a sand mold to contain the molten metal. The aggregate is usually silica sand that is bonded with bentonite clay or a chemical binder to maintain its shape. The sand provides natural pore spaces between the grains that lend themselves ideally to the casting process that accomplishes a basic requirement to produce a quality casting. That is a permeable mold or core surface that allows air or gas to pass without allowing the molten metal to penetrate.

There are three major basic factors why natural permeability is necessary:

1. To allow the air in the mold cavity to escape, permitting the molten metal to take its place with a minimum of turbulence
2. To permit the gases that evolve from oxidation of molten metal, from moisture of the mold, and any gas produced by chemical reaction to escape during and after pouring is complete
3. To allow a closed mold to be filled at an acceptable rate of speed with the minimum restriction of air entrapment and back pressure

PERMEABILITY IS AFFECTED BY:

- size of sand grains
- shape of sand grains
- bonding mechanism
- compaction characteristics
- degree of compaction
- amount of water or other
- additives used
- expansion of silica during heating
- mold and core coatings
WHAT IS VENTING?
Venting is a part of the mold or core forming process that is usually necessary to a variable degree, to produce a quality casting. In some extreme design configurations it is associated with safe pouring practice. It allows air and gases to escape from the mold.

As molds are made with a granular refractory aggregate such as silica sand, the pore spaces produce some natural venting. Unfortunately, to improve casting surface finish with increased compaction, these pore spaces are drastically reduced. This leads to the increase in gas pressure during and after pouring. To prevent gas entrapment, some means of venting becomes necessary.

Venting molds and cores is a simple means of reducing internal gas pressure during and after pouring.

VENTING PREVENTS:
- metal boiling in the mold
- mold explosions
- mold lifting
- mold runouts
- misruns
- blows and gas related porosity

VENTING IMPROVES:
- production of net shape castings
- casting soundness
- safety during pouring

Unfortunately, all these benefits cannot be guaranteed, and assurance be given completely to prevent the entrapment of gas because of high temperature pouring and solidification rates. Pouring temperature is extremely influential in the effectiveness of venting as well as gating geometry.

For these reasons, some auxiliary means of venting to enhance permeability must be incorporated to insure quality. The venting art now becomes a science.

BASIC VENTING METHODS

1. Use of a coarse base molding or core aggregate and/or use of a center filler such as cinders, core, slag, Styrofoam pellets, or similar filler material and hollowing out core center if applicable.

2. Mechanically form vents such as can be drilled, round rod or flat plate poked vents made during the forming process.

3. Pattern and core box fixed vents designated in the tooling and casting geometry as part of the formed mold or core. These could be mounted at the parting or in conjunction with loose pieces.

4. Formed wax or flexible textile tubing implants inserted in the mold or core during production.
5. Selective gating geometry such as: bottom gating favoring directional metal flow to pre-align favorable gas escape pattern and reduced mold pressure. Or, using pop off, flow off, or open cope riser.

6. Selective or variable degrees of mold or core compaction, such as: making the cope less mold hardness than the drag.

WHEN TO VENT

- when the casting design presents compressive restrictions that delay or prevent air or gasses in the mold to escape normally without pressure build-up during or after pouring.
- when gasses generated from mold and core materials, molten metal oxidation or chemical reactions are not allowed to escape normally without the build-up of pressure during or after pouring.
- when internal cores are used that are surrounded by metal more than 50%.
- gas problems occur and increase when cores are located below the parting line and more severely in the drag.
- when internal cores are used that are not completely cured, of high compacted density, have a refractory coating with increased thickness and depth of penetration.
- cores with high organic binder content, and when cores have been subjected to high humidity and used.
- when extremely hard green sand molds are made (over 90 mold hardness) without openings other than the pouring sprue.
- when pouring extremely hard and at a high ferro-static head to facilitate running or metal fluidity by pressure to run light section or high surface area design castings.

HOW TO VENT

To improve permeability and reduce core and mold pressures during and after pouring, consider these parameters:

1. Use coarser base sand aggregate.
2. Use a rounded sand grain shape.
3. Decrease core and mold compacted density.
4. Cure cores to optimum cycle.
5. Make judicious use of pre-mounted mold and core parting vents, especially at the core prints and take them out to the edge of the flask.
6. Hollow out cores whenever convenient and economical. Vent the cavity.
7. Venting vertically is usually more effective than horizontally if choice permits.
8. Vent at highest point of mold cavity if possible. Carry core vents to highest point of design when possible.
9. Reduce pouring speed and ferro-static height whenever possible to reduce mold pressures when gas problems occur.
10. Reducing organic content, drying humidity laden cores, drying coatings, etc., all reduce gas pressure and if venting procedures are followed, improved venting effectiveness occurs.

CAUSES OF GAS-RELATED PROBLEMS ASSOCIATED WITH VENTING PRACTICE

1. Failure to recognize the importance, and apply the basic metalcasting fundamentals.

2. Failure to document and retain successful basic venting technology for use in future similar casting designs.

3. Failure to automate, simplify, venting technology for easy communication and training when installing new production processes.

4. Tooling engineers practicing undue caution in their methods to prevent runouts and vent cavities being filled with molten metal.

5. Lack of, or unavailability of, technical information for operational supervision for use in training and available for quality assurance programs.

6. Failure to understand the basics of permeability and the importance to include in the decision-making process where necessary.

7. Management's continual endorsement for any cost cutting measures to yield higher production without conforming to the laws of nature.

8. Lack of common sense, respect for the basics of metalcasting.

PREVENTION OF GAS-RELATED PROBLEMS ASSOCIATED WITH VENTING PRACTICE

1. Incorporate venting where applicable in any future quality casting procedures and methods, the gas pressure potential in the mold that would cause gas problems.

2. Formulate means for the most effective, economical venting methods and options possible, to insure against gas problems.

3. If in doubt, over vent the venting methods. Do not add unfavorable core or molding cost burden.

4. Establish and incorporate mandatory training of new tooling engineers or production supervision, such as with in-house video training cassette programs specifically designed for this subject.

5. Encourage management to approve investing in venting practices that can improve quality, lower cleaning costs, and provide a measure of safety during pouring.

6. Apply common sense to any gas related casting problems.

CONCLUSIONS
As continual successful metal-casting processes have emerged, the "art of
"venting" has been lost. It has forced the serious profit-oriented metalcaster to develop venting into a science. Production experiences have brought to the surface the following general basic parameters.

1. Natural mold or core permeability of the molding aggregate may not be sufficient to maintain consistent casting quality, especially with the increase in design complexity or the restrictive production processes and equipment used today.

2. Natural permeability is drastically reduced as increased compacted density is developed to increase mold strength and improve surface finish.

3. Mold and core gas pressures are increased when permeability is restricted. Evacuation of air and gasses during and after pouring can create a host of casting problems if restricted, including mold explosions which impose on the safety of personnel.

4. Multiple means of venting have been developed and improved to take care of gas evolution and in many cases they are "cost free".

5. Knowing the basic parameters of venting has stimulated creativity and progress in this important process area.

6. Proper venting of complex molds and cored casting configurations should be mandatory at the initial pre-production layout engineering.

7. During pouring of the casting with the multiple of process variables such as speed of pouring, ferro-static head, etc., internal mold pressures can be great enough to create a reaction and explosion that could create scrap and could injure the pouring crew.

8. To benefit by cost effectiveness, the initial tooling engineering should include all the various types of venting that can be affixed or designed into the pattern or core equipment. This could provide insurance against pressure build-up in the mold, which could be difficult to determine later.

9. A continual training program with new personnel or apprentices should be included in any quality assurance and auditing program. This can be done effectively and economically by the use of videography with video recording and training tape cassettes. This allows personal and/or group training.

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"Venting Cores and Molds" Bex, Tom - Modern Casting, page 42 (August, 1991)

"Venting - The Lost Art" DiSylvestro, G. - Wisconsin Annual Foundry Conference, (February 14, 1985)
The Effect of Boron in Ductile Iron

by Lyle R. Jenkins

For several years there has been a problem with pearlitic ductile iron castings which exhibited hardness values less than usual or what was expected. Investigation revealed that the problem was related to the presence of boron in the castings.

When ductile iron is melted in a coreless induction furnace containing a silica lining with boron oxide to produce the crucible, the first iron used to sinter in the lining contains a boron pickup which causes low hardness in pearlitic ductile iron. Normal boron content of ductile base iron is 0.0015%. During sintering in the furnace lining, the boron climbs to about 0.0028%. This level reduces the effect of copper being used to produce pearlite and will continue to do so until the boron level drops below 0.002%. The first iron out of a newly lined furnace should be used for ferritic castings and the higher boron will not be noticed.

Since there is minimal data on the effect of boron on ductile iron it is helpful to consider the effect of boron on steels and also on malleable iron.

Boron is a strong carbide and nitride-forming element and increases strength in quenched and tempered low carbon steels through the formation of martensite and the precipitation strengthening of ferrite. Boron-containing killed carbon steels are available as low-cost replacements for the high-carbon and low-alloy steels used for sheet and strip. The low carbon boron containing steels have better cold-forming characteristics and can be heat treated to equivalent hardness and greater toughness for a wide variety of applications, such as tools, machine components, and fasteners. Boron is added to fully killed steel to improve hardenability. The amount added is a range of 0.0005 to 0.003%. It is most effective in low carbon steels. The effect of boron improving hardenability varies notably with the carbon content of the steel. The effect is much less in high carbon steels. The full effect of boron on hardenability is obtained only in fully deoxidized (aluminum-killed) steels. High-temperature treatment reduces the hardenability effect of boron. Only 0.001% boron is required for an optimum hardenability effect when appropriate protection of the boron is afforded by additions of titanium or zirconium. In carburizing steels, the effect of boron on case hardenability may be completely lost if nitrogen is abundant in the carburizing atmosphere.

Boron has no effect on the tempering characteristics of martensite, but a detrimental effect on toughness can result from the transformation to nonmartensitic products. For quenched and tempered steels, a practical way of improving toughness without reducing strength is to use a boron-containing grade of steel with a lower carbon content. The benefit of boron is applicable only to quenched and tempered steels: boron reduces the toughness of as-rolled, as-annealed, and as-normalized steels. Boron can cause hot shortness and can impair toughness. Boron has no effect on the strength of normal hot rolled steel but can considerably improve hardenability when transformation products such as acicular ferrite are desired in low-carbon hot-rolled plate.

Nickel-base superalloys show an improvement of creep properties by very small additions of boron and zirconium. It is believed that boron and zirconium segregate to grain boundaries because of their effects on carbide and gamma-prime distribution. Boron may also reduce carbide precipitation at grain boundaries by releasing carbon into the grains. The segregation of misfitting atoms to grain boundaries may reduce grain-boundary diffusion rates.
The addition of boron to malleable iron increases the number of nuclei available for the solid-state graphitization reaction. This can be achieved in two different ways, as follows:

1. By adding elements that increase undercooling during solidification. Typical elements in this category are magnesium, cerium, bismuth, and tellurium. Higher undercooling results in finer structure, which in turn means more gamma-Fe/3C interface. Because graphite nucleates at the gamma-Fe/3C interface, this means more nucleation sites for graphite. This also prevents the formation of unwanted eutectic graphite (mottle).

2. By adding nitride-forming elements to the melt. Typical elements in this category are aluminum, boron, titanium and zirconium.

Sources of boron may include:

- Wrought nickel-base alloys
- Cast cobalt-base superalloys
- Wrought iron-base alloys
- Boron treated steels
- Malleable iron
- Normal ductile iron
- Ductile produced during lining sinter

The boron pick-up experienced during lining sinter is only one furnace full and decreases with tap and charge back. The condition usually lasts about four hours under normal operating conditions.

The boron content is not lost in melting in cupola or induction furnace except by dilution. The addition of boron to the pouring ladle may result in carbides at lower level than when it is picked up in melting or during the sintering of a coreless induction furnace with a silica-boron oxide lining.

The method of chemical analysis for boron is faster by spectrometer, but care must be taken because the spectral lines of sulfur and boron are very close and sulfur can splash over into the boron and cause an error. The method for chemical analysis for boron is atomic-absorption. This is a little slower, but reliable. Another method for analysis for boron is a wet method, which requires boron-free glassware and takes about seven hours.

There is a need for research to determine if boron, causing soft castings, also causes reductions in toughness and fatigue strength. It should be determined if boron can improve nodule counts and reduce segregation in heavy section castings. It should also be determined if the use of boron can improve heat-treated ductile iron.

Because of the effect of boron on steel, it becomes necessary to determine similar or other effects on ductile iron. Until such time as an investigation can be undertaken, please be advised to watch carefully for the presence of boron in your castings and low hardness on pearlitic iron.
Four participants from an SAE Committee on engine manifold materials reviewed the past, present and future in design, performance, and material properties employed for exhaust manifolds. Silicon-Moly cast ductile irons are emerging as the material of choice and the replacement material for others in order to meet the increasing operating temperature requirements for manifolds.

**Design Considerations**

Chandran Santanam, Development Engineer
for Exhaust Manifolds, GM Powertrain

**SAE Committee Activities**

The committee consisting of manifold users, producing foundries, and research institutions, is focusing on helping end users by a four-pronged program: develop design information; produce a material selection guide; produce a standard for material selection and evaluation; and publish technical papers. This work is driven by emerging requirements: service temperatures reaching 1500-1600°F, extreme temperature differentials, manifolds cannot be water cooled, yield strength is lost in service, premature cracking develops, and industry is requiring 100,000 mile vehicle in-service life. A future goal is 200,000 miles.

**Design Procedure**

Design must take into account functionality, part/system performance, and exhaust emission characteristics. The manifold design procedures and factors affecting each are:

- Begin with a CAD part design for smooth gas flow.
- Conduct computer simulation gas flow tests.
- Generate FEM for in-service heat flow, heat transfer and imposed strains.
- Dynamometer test on the engine for fatigue resistance (usually 500-1000 hours).
- Dynamometer test for durability (100-200,000 miles).
- Vehicle service test for high engine load and induced peak stresses.

**Factors affecting design:**

- Packaging – must fit available envelope.
- Weight – reduced for high fuel economy (thin wall design).
- Emissions – HC, CO₂, NOₓ emissions lowest feasible.
- Back pressure – handle pressure from exhaust system.
- Sensor adaptability – must accommodate O₂, EGR, gas temperature sensors, all required for emission control.
- Air gap installation – to protect other engine areas.
- Heat shielding – to protect electronics.
- Gas temperatures – 1800°F plus anticipated.
- Material capabilities – cast Si-Mo ductile iron, high moly ductile irons and cast stainless have best potential.

**Emission Factors**
Trends in requirements are reduced vehicle emissions all around. This requires lean burning engines, high power density, and higher exhaust temperatures. Use of catalytic converters increases temperatures, requires exhaust gas recirculation, requires sensors be installed in the manifold, which results in large, cold operating areas in the manifold, gas flow interruption, and huge operating temperature swings and gradients. Manifold air injections are required for catalytic converter hydrocarbon combustion. On the other hand, to reduce initial engine emissions, and provide maximum fuel economy, higher air/fuel ratios are employed. This complicates temperature distribution in a manifold. The results, as demonstrated by heat transfer computer models, are huge swings and differentials in manifold temperatures in different locations in the same part. Additionally, fastener mounting on the engine, mechanically constrains growth of the manifold in service. The manifold must resist thermal fatigue, hot cracking, differential expansion stressing, and possess high yield strength at high temperatures.

**Material Requirements**
Cast stainless steels and silico-molybdenum ductile irons offer the best potential to meet the following requirements: corrosion resistance, low thermal conductivity, low thermal expansion coefficients, high temperature fatigue strength, high temperature creep resistance, antioxidation properties and high temperature yield strength.

**Material Applications**
The initial choice for manifolds was gray cast iron. Exhaust temperatures seldom exceeded 1200°F. By the 1970’s, emission systems forced temperature requirements above 1400°F, resulting in the introduction of ferritic ductile irons for durability. The 80’s saw increased usage of welded tubular assemblies. But because of cost, noise problems, and durability, cast silicon-molybdenum irons (Si-Mo irons) were introduced. By 1990, exhaust temperatures increased to 1800°F and beyond, resulting in a switch to cast NiResist and Si-Mo ductile irons. For temperatures exceeding 1800°F, cast stainless steels are being introduced in some heavy-duty truck applications. However, today Si-Mo irons are the materials of choice, amounting to 58-1/2% of use by the big three auto companies. Ductile irons are still used in about 32% of the models. Tubular constructions are still used in 7-1/2% of heavy-duty applications.

Welded tubular manifolds are difficult to manufacture, often provide poor fit-up (causing air-in leaks) and cause obstructed, turbulent exhaust gas flows, hence, a choice of cast manifolds. Coupling material and design are everything. A series of manifold applications were illustrated, showing the required design complexity and the extreme operating temperature differentials. For example, mounting flanges may operate at only 350-400°F, whereas 2” away ports are 1600°F or higher, exceeding the yield strength of a material.
**Basic Cast Manifolds**

There are four basic types of cast manifolds of interest today shown in the table below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferritic DI (65-45-12)</td>
<td>Excellent machinability, mid-temperature operating capabilities,  [CE 4.8%, \text{Si} 3%, \text{Elongation} 16-20%], \text{typical mechanical properties}.</td>
</tr>
<tr>
<td>Si-Mo DI Irons</td>
<td>Reduced machinability, higher temperature capability, CE 4.8%,  [\text{Si} 3%, \text{3 moly grades: A.)} 7-9%; B.) 0.5-0.7%; C.) 0.3-0.5%. 10-15% pearlite, contains moly carbides.</td>
</tr>
<tr>
<td>NiResist</td>
<td>Use being phased out.</td>
</tr>
<tr>
<td>High Silicon-Moly Irons</td>
<td>Similar to Si-Mo DI irons, but Irrons lower ductility, brittleness and difficult to cast. Not widely used.</td>
</tr>
</tbody>
</table>

For Si-Mo irons, the higher the moly content, the lower the ductility and machinability, but the higher the yield strength and hardness. These irons are usually 10-15\% pearlitic and contain intercellular molybdenum carbides. **Figures 1-3** illustrate the mechanical properties of Si-Mo and ferritic ductile irons.

Numerous solidification modeling studies using Magmasoft® illustrated how large differential thicknesses in various manifold designs present challenges in casting feeding design, and problems in avoiding mold shift for wall thickness down to 3mm of less than 0.8mm. A new challenge facing industry is to develop weldability of ferritic and Si-Mo iron designs by matching chemistry and process techniques.

**Material Properties**

Richard Gundlach, President, Climax Research Services

**Material Properties**

Si-Mo ductile iron, as a preferred choice, offers the following features:

- Inexpensive in composition and producibility.
- Forms a stable ferritic microstructure.
- Has improved oxidation resistance (no oxidation scale flaking if 3.5\% Si or higher).
- High upper critical transformation temperature is 1500-1600°F, and hence resistant to brittle fracture (below 1000°F).
- Improved elevated temperature properties (Mo increases elevated temperature strength - Si improves room temperature strength raising the minimum 40 to 65 ksi).
- Mo content raises in-service creep strength.
- Si-Mo irons have desirable, reasonably low thermal conductivity and expansion properties.
Ductile Iron News

Physical Properties of Manifold Materials

• Ductility can reach 20%, and Young modulus approaches that of steel.

Thermal Failures

The primary mode of failure in service is by fatigue. In an operating temperature range of room to 1500°F, a ferritic casting will expand 1%, and can produce tensile stresses of up to 200 ksi upon cooling down. This continuous cyclic straining and high temperature creep yielding induces a time-delayed, progressive failure - that’s thermal fatigue. As the silicon content increases to 3% plus, room temperature yield strengths increase from 40-65 ksi. Increasing moly content up to 0.8% has a similar percentage increase in the elevated temperature properties.

Thermal Fatigue Properties

Climax Research Services evaluated the fatigue properties for a series of different composition irons. Tests are conducted on machined tensile type bars in uniaxial fatigue straining. Bars are fixtured at each end to prevent being axially pulled apart and cyclically heated by an induction coil between 200°C and 800°C. An attached strain indicator measures induced strains (tensile and compressive). Yielding is detected by bar bulging. Stress levels to failure are calculated from the strain data, and plotting the number of thermal cycles to failure. Figure 4 illustrates the maximum service temperatures for various manifold materials. A typical stress level at room temperature for a room to 800°C cycle is 35 ksi. This test procedure permits determination of the flow stress during both the manifolds heating and cooling cycles, which can now be used in simulation studies and manifold design considerations. The amount of bulging in fatigue test specimens is an indication of the amount of yielding and creep. The higher the moly content, the less the amount of bulging.

Fatigue failures initiate at nodule sites and voids. High temperature creep and yielding produces internal voids. These voids are then the initiation sites for failure, due to a "notching effect" or due to internal oxidation around the void. Other failure origins can be areas at DI cell boundaries. These can transform to pearlite on thermal cycling above the critical temperature. Thus, high critical temperatures promoted by Si and Mo contents have a significant beneficial effect.

Figure 4. Allowable manifold temperatures

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**Nickel**

*by Kelly Naro*

**Editor's Note:** Many ductile iron foundries use nickel in the production of their castings and we thought the following article would be of interest.

**Nickel – a history**

Although nickel is one of the most useful metals today, it was virtually unknown until the 1600's and wasn’t isolated as an element until 1751. Early chemists called it Kupfer-Nickel – kupfer for copper because nickel was originally found in copper ores and nickel for the German “Old Nick,” or Satan, because nickel was so difficult to extract from those ores.

Nickel is malleable, resists corrosion and maintains its mechanical and physical characteristics under extreme temperature. These properties make it useful in the manufacture of stainless steel, which accounts for about 65 percent of primary nickel demand worldwide.

Nickel is also used in steel alloys, batteries and coins.

**Suppliers**

In 2000 world production of nickel was expected to total more than 1.1 metric tons. Russia, the world’s largest supplier of nickel, boasts annual production of 230,000 metric tons. RAO Norilsk Nickel accounted for nearly 96 percent of total Russian nickel production in 1998 and 22.2 percent of world production.

Ranking second in world nickel production, Canada produces annually 150,000 metric tons. Canada's Inco Ltd., which has mines in Canada and Indonesia, accounts for 19 percent of world production and markets another 10 percent of the world's nickel.

The United States’ sole nickel producer closed its mines in Oregon in 1998 because of low nickel prices.

**Consumers**

Since 1960 the demand for nickel has grown at an average annual rate of nearly 4 percent. Primary consumers are the United States; Germany, Italy, Japan, the Republic of Korea and Taiwan.

**Market**

Nickel is traded on the London Metal Exchange, where both a cash and futures market exists for the commodity. Prices are determined twice a day in what is called a morning ring and an afternoon ring.

In 2000 labor disputes drove the spot price of nickel. In mid-1999 anticipation of a strike at Inco's Manitoba refinery and the ensuing 3-month labor strike resulted in depletion of world nickel inventories, causing nickel prices to increase from $2.35 per pound in mid-1999 to more than $4.53 per pound at yearend. Anticipation of a second strike at the Inco's other Canadian refinery in Sudbury. Ontario on May 31 caused prices to continue to increase to a 5-year high of $4.80 per pound. Within days of the settlement announcement, prices declined almost 73 cents per pound.

Labor disputes also riddled another
Nickel

Canadian producer, Falconbridge Ltd. The producer's workers, who went on strike in early August, ratified a new labor contract on Feb. 22, ending the seven-month strike.

Outlook
Currently, oversupply of nickel and a plentiful supply of stainless steel scrap – a source of nickel – have caused both the futures and the spot prices to fall.

However Asia's economic recovery should help the demand for nickel. An increase in demand for nickel alloys used in the aerospace sector and for batteries used in electronics and in hybrid automobiles may also increase nickel demand.

Russia, and in particular Norilsk, is the wild card in the supply of nickel. Although Norilsk's production generates an important source of revenue for the Russian economy, it is unknown whether the producer will be able to upgrade and modernize its current operations and to explore new mines.
Miller and Company Offers Ceramic Filters

In a landmark expansion of their services beyond the raw material field, Miller and Company LLC, one of the most integrated and diversified suppliers of raw materials to the foundry and steel industry in the United States, Canada and Mexico, has joined forces with Saint-Gobain Advanced Ceramics Hamilton of Paris, Ontario, Canada (formerly Hamilton Technical Ceramics) to offer Flow-Rite foundry filters for iron, steel, aluminum and non-ferrous foundries in the United States.

Gary A. Wickham, Miller's President and CEO commented, "We are extremely pleased to be teaming with one of the world's leading manufacturers of molten metal filters. This is truly the collaboration of two companies with the same goals: to provide total customer service and product excellence. With this new partnership, Miller is proud to take our commitment to our customers to the next level by expanding our product range with these outstanding, cost-effective filters."

With over 400 million mullite-based ceramic filters produced and having achieved QS 9000 and ISO 9001 certification, Saint-Gobain Advanced Ceramics Hamilton has helped the cast metal industry to achieve both new, stringent quality standards and higher profits at the same time. Available in a broad range of sizes, Flow-Rite foundry filters enhance the purity and modify the flow of the molten metals used to make metal castings. The removal of dross, slag and other impurities from the molten metal results in higher casting quality and improved surface finish. Flow-Rite filters combine the desirable attributes of consistent flow rates, uniform metal capacity, excellent filtering efficiency, premium strength and dimensional accuracy.

About Saint-Gobain Advanced Ceramics, Hamilton

Founded in 1852 as "Hamilton Potteries," the company manufactured articles such as soap dishes, spittoons and wash basins. From its humble beginnings in Hamilton, Ontario, the company has experienced tremendous growth and change - earning a solid reputation for quality products and unrivaled customer service. With the advent of electricity and the need for electrical insulators, the company evolved away from household items and toward more technical products for electrical applications. "Hamilton Porcelains Limited" was born in 1946 to meet new challenges and changing customer needs.

In 1985, the firm entered the foundry filtration business with products and services for the foundry sector and in 1989 became a member of the Saint-Gobain group of companies, with total access to Saint-Gobain's vast international facilities and technical expertise, including research centers in France and the United States.

Today, the newly renamed "Saint-Gobain Advanced Ceramics Hamilton" has a commitment to excellence, evident in its ambitious in-house R and D programs; advanced manufacturing systems; highly trained and dedicated staff; and ever-expanding network of customers. The result - an industry leader with the unique ability to close the loop between product design, manufacturing and application.

About Miller and Company

Established in 1919 as a regional distributor of Pig Iron and coke to the
Miller and Company Offers Ceramic Filters

In the ferrous industry, Miller and Company LLC has grown to become a premier resource in North America, supplying unsurpassed quality products, technical expertise, and superior services to the foundry and steel industry. Miller and Company's solid positioning and penetration in the North American markets led to its acquisition in 1977 by Frank and Schulte. Miller and Frank and Schulte are under the umbrella of Stinnes AG of Germany - one of the world's largest logistics companies.

Through the Stinnes / Frank and Schulte relationship, Miller is able to offer a global network of resources ranging from mining operations to an intercontinental transportation network, providing its customers with Briquetted alloy products, Silicon Carbide grain, Sorelmetal, Pig Iron, INCO Nickel products, MILCO Carbon products, Ferro-alloys, and now, ceramic filters for molten metal filtration.

Miller and Company LLC is headquartered in the Chicago suburb of Rosemont, Illinois.

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email:jwood@ductile.org

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MEETINGS

The Annual meeting of the Ductile Iron Society will be held on June 13, 14, 15, 2001 at the Waterloo Motor Inn in Waterloo, Ontario, Canada with a visit to WesCast, Wingham, Ontario.

The next Research Committee Meeting will be held in conjunction with the Annual Meeting in Waterloo. It is scheduled for 8:00 a.m. at the Waterloo Inn.

PEOPLE IN THE NEWS

Matt Liptak has joined Buck Company, Inc. as Manager of Quality Assurance.

Former DIS Vice President, Robert Bigge, has assumed the position of Technical Director at ICRI.

Grede Foundries, Inc. has named Randy Priem, as Vice President of Operations of its Iron Mountain foundry in Kingsford, Michigan.

Ashland Specialty Chemical Company has named Randy C. Helmick, plant manager for its Cleveland West, Ohio, operations. Dana R. Cooper, has been named plant manager of the companies Cleveland East, Ohio, operations.

Intermet Corporation announced that Terry C. Graessle is joining the Company as Vice President of Sales and Marketing. Graessle will also be a member of the Corporate Operating Committee.

Climax Research Services has announced the following appointments: Amadee Roy, Technical Consultant; Allison Nolting, Mechanical Testing Supervisor; Charles K. Deak, Technical Consultant.

DISA Industries, has named Ronald A. Mutch, Vice President & General Manager of the Holly, MI facility.

Tecpro Corporation, has announced the following: Charles F. Wright, President; John R. Cameli, Vice President.

Magma Foundry Technologies, Inc. has appointed Matt Proske, Project Engineer and Winston Sequeira, Applications Manager.
BUSINESS

Milwaukee, Wisconsin (May 29, 2001) - Grede Foundries, Inc. of Milwaukee, Wisconsin, is proud to announce that its Greenwood, South Carolina foundry received its ISO 14001 certification in May. ISO 14001 is an international environmental standard. Grede's efforts in building its environmental management system received praise from NSF-ISF, the third-party auditor that recommended Greenwood for certification.

Troy, MI (May 17, 2001) - INTERMET Corporation Executive Vice President of Technical Services Dr. Gary Ruff received the 2001 Ray H. Witt Award Tuesday, May 15, at the Advanced Casting Research Center Spring Meeting held at Worcester Polytechnic Institute in Worcester, Mass.

Chicago (May 7, 2001) - Governor George H. Ryan Awarded Superior Graphite Co. with a Technology Challenge Grant as one of eighteen Illinois businesses, universities and research centers that are on the cutting edge of 21st Century technology.

The Technology Challenge Grant is designed to fund science and technology projects, partnerships between universities and industry, high-tech commercialization projects, transfer projects and infrastructure improvements. The program is administered through the Illinois Department of Commerce and Community Affairs (DCCA).

The Foundry Products Division of Ashland Specialty Chemical Company has developed and introduced the MAGNAset no-bake binder, answering the foundry industry’s call for improved productivity, better castings and lower costs, while also meeting increasingly stringent environmental regulations.

Wescast Industries, Inc. has been awarded a number of business contracts by several major automobile manufacturers, including General Motors, Nissan and Jaguar. The product produced will be machined exhaust manifolds.

Inductotherm Corporation has acquired HI T.E.Q., Inc. of Miamisburg, OH.

Ward Manufacturing Inc. (Hitachi Metals America, Ltd.) has reached a 5-year information-technology services agreement with Perot Systems Corporation of Dallas, Texas.
Charles W. Mooney Jr., 85, of Carlton Drive, died of natural causes Thursday at home.

Mooney was president of Buck Company Inc. Foundry, Quarryville, from 1971 until his retirement in 1988. He was vice president works manager of Hamilton (Ohio) Foundry Company from 1965-71 and worked for the Olney Foundry division of Link Belt Company, Philadelphia, from 1934-65.

Mooney was a member of Highland Presbyterian Church, Mount Moriah Lodge 155, Free & Accepted Masons, Lancaster Kiwanis Club, Caper Club and Olde Hickory Golf Club.

He also was a member of American Foundrymen's Association and Ductile Iron Society; past chairman of American Foundrymen's Association, Philadelphia chapter, past national director of Gray Iron Foundrymen's Association' past member and chairman, Foundry Educational Foundation Advisory Committee to Penn State University group; and past treasurer, vice president and president of Ductile Iron Society.

Mooney received several service awards from the foundry industry and was an active speaker at foundry industry meetings.

He graduated from Abington (Pa.) High School in 1934 and continued his education at Temple University Evening School and Penn State University Extension Center.

Born in North Glenside, he was the son of the late Charles W. Sr. and Josephine Jenkins Mooney.

He was married 35 years in March to Phyllis R. Goodrich Mooney. His first wife, Elsie Kohler Mooney, died in 1964.

Surviving are two daughters, Suzanne J. Lewis, married to Steven Thiel of Cincinnati, and Barbara R. Mooney of Salt Lake city; a son, Ted A. Schmitt of Jacksonville, Fl; and five grandchildren.
Gearing Up For The 21st Century

“Gearing Up For The 21st Century”

Located in Strongsville, Ohio, USA
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email:jwood@ductile.org
Dura-Bar is the world's largest producer and the only manufacturer in North America of continuous cast iron bar stock offering rounds, rectangles/squares, tubes an shapes in a large selection of sizes and grades. Continuously cast iron bars offer outstanding machinability advantages over carbon and alloy steels and can significantly decrease the cost to manufacture machined parts in a wide variety of applications and industries.

The key to Dura-Bar's unique properties comes from the **Continuous Casting Process**. A water-cooled graphite die that is machined to form the shape of the bar is mounted at the bottom of a bar machine crucible. Molten iron enters the die and a solid skin begins to form that takes the shape of a bar. When the bar exits the die, it consists of a solid shell surrounding a molten metal core.

As the bar is cast horizontally along the barline, iron is constantly fed into the die under the ferrostatic head pressure of the metal in the bar machine crucible. Molten iron is delivered to the bar machine at precise temperatures in regular intervals. Impurities that could form inclusions remain at the top of the molten metal bath, well away from the opening of the die.

Dura-Bar's most notable characteristic is its extremely dense, fine grained microstructure that allows excellent surface finishes after machining and parts are free from dross, slag and other tool wearing inclusions. Common casting defects such as porosity and shrink are virtually eliminated by the process of continuous casting.

**Gears** are one of the many applications that are well suited for Dura-Bar. The microstructure consists of solid graphite particles in a metal matrix making gears easier to machine and quieter in operation. Wear resistance, inherent vibration damping characteristics, weight reduction over steel and the ability to be used as-cast or heat treated to a wide variety of properties are just a few of the many benefits customers are realizing by converting their steel gears to Dura-Bar continuous cast iron bar stock.

**DURA-BAR vs. STEEL**

- Improves machinability
- Superior vibration damping
- Higher strength-to-

**DURA-BAR vs. CASTINGS**

- Consistent quality
- Short lead times
- Optimal
weight ratio
- Improves surface finishes
- Eliminates heat-treat distortion

fatigue strengths
- Exceptional surface finishes
- Shrink-Free Material
Gearing Up For The 21st Century

Total Cost Savings

<table>
<thead>
<tr>
<th>PROCESS &amp; percentage of total cost</th>
<th>DURA-BAR® Continuous Cast Iron Bar Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUY MATERIAL 10%</td>
<td>Steel 8620</td>
</tr>
<tr>
<td>$1.80</td>
<td>$2.50</td>
</tr>
<tr>
<td>CUT TO SLUGS</td>
<td>$0.50</td>
</tr>
<tr>
<td>MACHINE GEAR BLANKS 15-20%</td>
<td>$2.00</td>
</tr>
<tr>
<td>$0.75</td>
<td></td>
</tr>
<tr>
<td>MACHINING 35-40%</td>
<td>$4.00</td>
</tr>
<tr>
<td>$1.38</td>
<td></td>
</tr>
<tr>
<td>SHAVE 15%</td>
<td>$1.50</td>
</tr>
<tr>
<td>$0.56</td>
<td></td>
</tr>
<tr>
<td>DEBURRING 0-30%</td>
<td>$1.50</td>
</tr>
<tr>
<td>$0.75</td>
<td></td>
</tr>
<tr>
<td>HEAT-TREAT 15%</td>
<td>$1.50</td>
</tr>
<tr>
<td>$1.50</td>
<td></td>
</tr>
<tr>
<td>GRIND</td>
<td></td>
</tr>
<tr>
<td>5-10%</td>
<td>$1.50</td>
</tr>
<tr>
<td>$1.50</td>
<td></td>
</tr>
<tr>
<td>POLISH</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$134.80</td>
</tr>
<tr>
<td></td>
<td>$9.44</td>
</tr>
</tbody>
</table>

Clearly the use of Dura-Bar continuous cast iron bars instead of carbon or alloy steel can significantly decrease the cost to manufacture machined parts.
NOISE REDUCTION

All gears make noise when they are operating. Noise comes from the design, from allowable variations in dimensional tolerances and from the material used for the gear. With everything else being equal, a set of gears made from a material that has good damping characteristics will be quieter than a set made from a material that does not.

Graphite flakes in gray cast iron will cause significantly better damping properties by comparison to any other ferrous metal. The nodules in ductile iron behave similar to the graphite flakes in gray iron, cushioning vibrations as they are transmitted through a part.

Figure 3.1 shows the relative damping capacity of as-cast and heat treated gray and ductile iron compared to steel.

The ability to dampen vibrations using Dura-Bar means that ductile iron gears made to the same dimensional tolerances and have similar surface finish will be quieter than steel or ductile iron gears and are an excellent choice for low stress applications.

Automotive balance shaft gears require high precision when made from steel in order to meet the noise standard. The tolerances are not as critical when using gray or ductile iron, which allows the gear to be made at a lower cost.

Figure 3.2 shows the qualitative relationship between noise level and AGMA classification using steel, ductile and gray iron.

HEAT-TREAT DISTORTION

Iron and steel grow when heat-treated because of the volume change in the atomic structure. With Dura-Bar, the growth is predictable because of the strict metallurgical process controls. Predictable growth minimizes additional processing steps after heat-treat.

**Plus...**

- Since Dura-Bar does not require carburizing, heat-treat distortion caused by variations in carbon diffusion into the part is eliminated.
- Due to the continuous casting process, Dura-Bar will not have residual stresses that can be present in rolled steel bars.
Machinability Ratings and Material Selection

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>TOOL LIFE COMPARISON at 450 SFM</th>
<th>RECOMMENDED SFM</th>
<th>Best for Applications Requiring:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray Iron, Alloysed Gray Iron</td>
<td>100%</td>
<td>1100</td>
<td>High noise damping, moderate strength and wear, relatively low contact stresses.</td>
</tr>
<tr>
<td>65-45-12 Ferritic Ductile</td>
<td>260%</td>
<td>1400</td>
<td>Excellent machinability, predictable growth after heat-treat, responds well to quenching and tempering and austempering</td>
</tr>
<tr>
<td>80-55-06 Partially Pearlitic Ductile</td>
<td>35%</td>
<td>900</td>
<td>Good machinability, responds well to induction hardening, good noise damping.</td>
</tr>
<tr>
<td>80-55-06 Modified for Enhanced Machinability</td>
<td>80%</td>
<td>1200</td>
<td>Used when elimination of heat-treat is a possibility, good strength and wear in the as-cast condition, good damping.</td>
</tr>
<tr>
<td>100-70-02 Pearlilitic Ductile</td>
<td>25%</td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

Machinability Ratings for Steel

<table>
<thead>
<tr>
<th>Material</th>
<th>Single Tooth Bending Fatigue Strength (psi)</th>
<th>Rotating Beam Fatigue Strength (psi)</th>
<th>Contact Fatigue Stress (psi)</th>
<th>Overall Relative Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>8620 Steel</td>
<td>35,000</td>
<td>75,000</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>4140 Steel</td>
<td>25,000</td>
<td>50,000</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>1144 Steel</td>
<td>20,000</td>
<td>40,000</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Cost Comparison

Dura-Bar's cost advantage over steel is made possible because of its ability to be machined faster, often 2 to 3 times faster than alloyed steel, which translates to more piece production per hour. Dramatic reduction in the cost of the finished part can occur by taking advantage of the free machining characteristics of the material. Deburring costs can also be reduced or eliminated.

Strength

Dura-Bar is available in gray and ductile iron with tensile strengths ranging from 35,000 psi to 100,000 psi in the as-cast condition and strengths up to 230,000 when heat treated. Mechanical properties are better than those in conventionally cast parts because of the continuous casting process and strict metallurgical controls.

The highly engineered process produces the best graphite nodularity, with control over nodule size, nodule count and distribution. This means optimal strengths in tension, compression and fatigue. Selecting the right heat-treat method will produce strengths to 90% of those in 8620 carburized and hardened steel and up to 80% of those in 4140 through hardened steel.

Fatigue Data for Heat-Treated Steel & Gray and Ductile Iron

<table>
<thead>
<tr>
<th>Material</th>
<th>Single Tooth Bending Fatigue Strength (psi)</th>
<th>Rotating Beam Fatigue Strength (psi)</th>
<th>Contact Fatigue Stress (psi)</th>
<th>Overall Relative Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2, as-cast</td>
<td>25,000</td>
<td>20,000</td>
<td>75,000</td>
<td>N/A</td>
</tr>
<tr>
<td>G2, Q &amp; T Rc 45</td>
<td>30,000</td>
<td>25,000</td>
<td>80,000</td>
<td>N/A</td>
</tr>
<tr>
<td>65-45-12 ductile iron, as-cast</td>
<td>35,000</td>
<td>40,000</td>
<td>60,000</td>
<td>N/A</td>
</tr>
<tr>
<td>80-55-06 ductile iron, as cast</td>
<td>40,000</td>
<td>40,000</td>
<td>65,000</td>
<td>N/A</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>100-70-02 ductile iron, as cast</td>
<td>50,000</td>
<td>35,000</td>
<td>115,000</td>
<td>N/A</td>
</tr>
<tr>
<td>Ductile Iron, quenched and tempered 50Rc</td>
<td>60,000</td>
<td>45,000</td>
<td>225,000</td>
<td>90%</td>
</tr>
<tr>
<td>Grade 1 ADI</td>
<td>85,000</td>
<td>80,000</td>
<td>130,000</td>
<td>N/A</td>
</tr>
<tr>
<td>Grade 2 ADI</td>
<td>80,000</td>
<td>75,000</td>
<td>140,000</td>
<td>N/A</td>
</tr>
<tr>
<td>Grade 3 ADI</td>
<td>75,000</td>
<td>73,000</td>
<td>180,000</td>
<td>85%</td>
</tr>
<tr>
<td>Grade 4 ADI</td>
<td>72,000</td>
<td>70,000</td>
<td>220,000</td>
<td>80%</td>
</tr>
<tr>
<td>Grade 5 ADI</td>
<td>67m,000</td>
<td>65,000</td>
<td>250,000</td>
<td>75%</td>
</tr>
</tbody>
</table>

**NOTE:**
1. Based on study conducted at the University of Dayton Research Institute on spur test gears using a specially designed fixture to test the strength in a test gear machined to specific standards.
2. All values listed are typical and not for specific design purposes.
3. Shot peening will increase fatigue strength properties up to 50%.

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**Wear Resistance**

Dura-Bar resists galling and scuffing and will outperform heat treated steel in a standard pin abrasion test when it is in the quench and tempered or austempered condition (ref graph). The graphite particles prevent friction welding which causes galling. The ausferrite matrix in austempered ductile iron will strain transform when loaded and the wear resistance over a range of hardness values is virtually unchanged.

In addition to the wear resistance benefits provided by the graphite particles, localized thermal stresses are reduced because of Dura-Bar’s high thermal conductivity.
Ductile Iron News - Gearing Up for the 21st Century (6)

Gearing Up For The 21st Century

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**Features**
- Notice: AFS/SAE 2002 Meeting (Not a reprint)
- Ductile Iron Answers the Pipe Maker’s Dream
- Designing with Ductile Iron
- The Advantages of Investment Casting Technology
- Use of Bismuth in Ductile Iron
- Compactability
- Venting - "The Lost Art"
- The Effect of Boron in Ductile Iron
- Physical Properties of Manifold Materials
- Nickel (Not a reprint)
- Miller & Co. Offers Ceramic Filters (Not a reprint)

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Your One Stop Shop in the Metallurgical Industry

Picture it... it's 1987 and three colleagues of Anmax Materials Research Center (formerly Climax Molybdenum Company of Michigan) find out that the Ann Arbor facility at which they work, is being closed and part of its operation is moving to Colorado. Needless to say, Rick Gundlach, Duane Rose and George Eldis were at a loss. Rick had eighteen years experience at AMAX as a metallurgical engineer and research supervisor; Duane was an authority in electron microscopy, energy-dispersive x-ray spectroscopy, optical microscopy and photomicrography; and George had held research and management positions with AMAX Materials Research Center (formerly Climax Molybdenum Company of Michigan). Therefore, they definitely had the technical knowledge, so they decided to open a company of their own. With their severance packages and creative business wit, they opened Climax Research Services (CRS), a company that would become a full service metallurgical facility that specializes in providing a complete range of metallurgical analysis, engineering, testing and consulting. Although the name "Climax Research Services" can raise some eyebrows for a few reasons, the main reason for the name is its connection to the industry-known Climax Mine in Colorado and the reputation of the metallurgical engineering research group associated with that organization.

Even though CRS is among the very few that provide such wide-ranging services, the owners' philosophy is that the client always comes first. One of our company's strong points is its technical accuracy, no matter how large or small the job. Our employees have always prided themselves on applying the same expert attention to small or routine jobs as they do to failure analysis or complex development programs. Timeliness is a high priority at CRS. Two shifts are scheduled daily, along with a sample pick up service, which aids us in responding quickly to our customers' needs.

Considering the history of CRS, how unique we are in the industry and our commitment to customer service, it only makes sense to explain what we actually do.

With an average industrial metals experience of 25 years, the CRS staff has a broad range of expertise. Our professionals supply the two primary services offered: Engineering Consulting Services and Laboratory Testing Services. The Engineering Consulting Services group is comprised of three synergistic services: Consulting; Research and Development; and Engineering and Design. More specific examples of these services are: Failure Analysis; Metallurgical Processing; Phase Transformation Analysis; Residual Stress Testing and Analysis; Welding; Alloy Development; Inducti
Heating Development and Legal Expert Testimony.

The Laboratory Services are divided into specialties as well. These include Chemical analysis, Metallographic Characterization, Mechanical Testing, Fatigue Testing, Corrosion Testing, Wear Testing, Corrosion Testing, Wear Testing, Heat Treatment, Machining, X-Ray Diffraction, Fastener Testing and Technical Support, among others. One unique aspect of the Laboratory Services is our Technical Services Group which has seasoned professionals who are experts at determining your testing needs. They identify the correct testing method required and then route the incoming jobs to the appropriate departments. This service has proven to be very effective at minimizing the cost to our clients and the completion times for jobs.

Climax Research Services is continually striving to provide the best quality service our clients expect. In February 2000, CRS occupied a new facility that we build in Wixom, Michigan. We've doubled our capacity in order to better serve your needs in an efficient and timely manner. Now, with a fully equipped, state-of-the-art testing facility and laboratory, we expect to expand our list of services in the very near future. With all or our advances and customer service dedication, the future is very bright for CRS and for you, our client!

Anyone can give you data ...

Service Spotlight

Metallographic Services

Our metallographic laboratory is staffed with educated professionals and equipped with state-of-the-art instruments.

The efficient organization of this laboratory has been key in handling multiple samples and providing accurate answers for all jobs, including expedited projects.

The Metallographic Laboratory prepares samples and provides services such as Scanning Electron Microscopy with Energy Dispersive Spectroscopy, Optical Microscopy, Image Analysis and Microhardness.

Photomacrography (Film or Digital) Equipment

- Wild Stereo Microscope (Qty: 3)
- Polaroid MP-4, Macro Camera
- Wista Studio Camera
- Polaroid Digital Camera
- Kodak Digital SLR Camera

Scanning Electron Microscopy/Energy Dispersive Spectroscopy Equipment

- Amray SEM with EDAX EDS
- Hitachi SEM with Oxford EDS
Tasks Performed

- Denton Vacuum Coater

Metallographic Preparation

Equipment

- Buehler, Semi-Automated Grinder/Polisher, (Qty: 3)
- Buehler, Vibratory Polisher
- Struers Polectrol, Electrolytic Polisher/Etcher
- Struers Transpol, Portable Pre-grinding and Polishing Apparatus

Tasks Performed

- Mounting and Polishing
- Specialized Sample Preparation
- Microetching
- Macroetching
- Sulfur Prints

Optical Microscopy (Film or Digital)

Equipment

- Leitz MM6 Metallograph (Qty: 2)
- Leitz Metallovert Metallograph (Qty: 2)
- Nikon Epiphot Metallograph (Qty: 2)

Tasks Performed

- Optical Photomicrography (Digital or Film)
- Evaluating Graphite Microstructure in Iron Castings
- Macro- & Micro-Grain Size Determination
- Decarburization Depth by Optical Method
- Total Case Depth by Optical Method
- Metal/Oxide, Cross-Sectional Plating/Coating Thickness
- Estimate of Silicon Modification
- Aluminum Dendrite Arm Spacing
- Macroetching Aluminum Castings for Grain Size
- Maximum Pore Size in Castings
- Visual Evaluation of Discontinuities in Steel Castings
- Surface Discontinuities in Nuts, Bolts, Screws and Studs
- Apparent Porosity, Grain Size and Particle Determination in Cemented Carbides
- Inspection of Macroetched Steel Parts
- Decarburization in Fasteners
- Estimating Surface Porosity of Castings

Image Analysis

Equipment
• Two Clemex Image Analysis Systems, one with computerized Inclusion Rating Software

Tasks Performed

• Graphite Flake Size and Type
• Nodule Count and Nodularity
• Porosity Content and Size in Castings
• Percent Ferrite and Carbide
• Inclusion Content of Steel

Microhardness

Equipment

• Clemex CMT, Automated Microhardness Tester (10g to 1 kg; Vickers or Knoop)

Tasks Performed

• Average Microhardness
• Microhardness Traverse
• Effective Case Depth
• Decarburization Depth

Call the Technical Services Department at 248-960-4900 for all of your metallographic service needs.