

Ductile Iron Society Visits



At the 116th Meeting



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Located in Strongsville, Ohio, USA

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PMI Answers Questions on Investment Casting

[PMI Answers the Ten Most Asked Questions About Investment Casting](#)

Since ductile iron was developed in the 1940s, this remarkable metal has proved 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's 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, you need PRECISION METALSMITHS, INC.

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, PRECISION METALSMITHS, INC. has developed proprietary processes and equipment which enable us to provide castings that take full advantage of this metal's properties. Our on-going research and development efforts ensure that our castings reflect the latest advancements in foundry technology. Operating from facilities in Cleveland, Ohio, and Markesan, Wisconsin, PRECISION METALSMITHS, INC. has earned a worldwide reputation for industry leadership, innovation, and customer satisfaction.

PMI was the first investment foundry to be certified by the Ductile Iron Society. We remain the only investment casting house whose process controls meet the strict certification standards of this organization.

Right: PMI's investment casting process offers superior quality and economics. An original sand-cast part is shown on the left. The converted ductile iron investment

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casting from PMI on the right provided the customer with better quality, near net shape, improved surface finish, elimination of most costly machining, reduction in rejected parts and significant cost savings. 0.1471bs., actual size of both parts together is 4.25".



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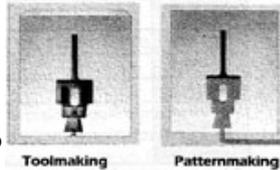
Ten Most Asked Questions About Investment Casting



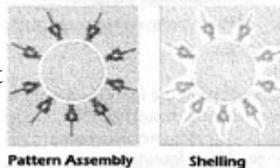
1. What is an "Investment Casting"?

An investment casting is a near net shape part made by the "lost wax" process that features cast-in detail, tight tolerances, and excellent surface finish. The term "investment" refers to the ceramic materials that are used to build a hollow shell into which molten metal is poured to make the castings. Originally, a plaster type material was poured or "invested" into a container that held a clustered tree of small wax patterns, which were identical to the desired casting. After the plaster was set, the disposable patterns were melted out, leaving a hollow cavity into which the metal was poured. While some non-ferrous castings are still made this way, most investment castings are now made by the shell method.

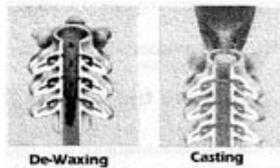
Every casting requires a pattern that is made by injecting wax or plastic material into a steel or aluminum die. If the finished part is to have complex internal configurations, a soluble or ceramic core is inserted in the die at this stage. Once the wax has hardened, the machine operator opens the die and removes the pattern. The completed patterns are then wax welded on a cylindrical shape for further processing.



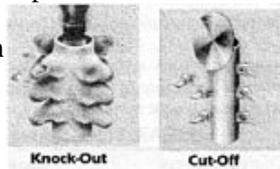
Assembled patterns are dipped in a prime coat of agitated ceramic slurry and then coated with a stucco of fine sand to build a good surface finish. The process is repeated until a thickness of approximately 3/8" surrounds each part. Once the shell has dried, the wax is melted out in a pressurized steam autoclave or by flash firing at high temperatures (1400°F.) The hollow shells are preheated to 800-2000°F, depending on the alloy to be cast and then immediately filled with molten metal.



When the metal has cooled, operators remove the shell or investment material from the cast "tree," cut off the castings, and grind off any of the gate, which remains. Depending on your requirements, the parts may be shipped "as cast" or may be heat-treated, plated, or otherwise processed before shipment.



PMI has been and continues to be a pioneer in investment casting technology. We strive to maintain our early technical leadership in the industry with a continuing investment in both research and development and state-of-the-art equipment.



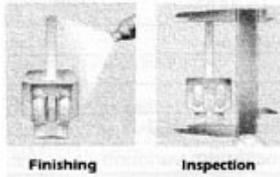
2. What alloys can be poured as investment castings?

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Generally, most ferrous and non-ferrous alloys can be cast. Among ferrous metals, the most commonly poured are carbon, tool, and alloy steel, along with the 300, 400, 15-5 PH and 17-4 PH stainless steels. Of the non-ferrous metals, aluminum and copper-based are the most common alloys used in investment castings.

In addition, there are super alloys used primarily in the gas turbine industry to produce blades and vanes. These alloys are usually composed of nickel and cobalt with a variety of secondary elements added to achieve specific strength, corrosion, and temperature-resistant properties. Often, a vacuum process is used in casting the super alloys.

PMI specializes in air-melt alloys. In our 50 year history, we have successfully cast nearly 200 alloys, including ductile iron and austempered ductile iron. PMI is the only investment foundry that is a member of and certified by the Ductile Iron Society.

Process	Ductile Iron	Tool Steel	Steel	Stainless Steel	Aluminum/Magnesium	Copper Bronze Brass	Titanium	Super Alloys *
Investment Casting	•	•	•	•	•	•	•	•
Die Casting					•	•		
Forging		•	•	•	•	•	•	•
P/M High Density		•	•	•			•	
Stamping			•	•	•	•		
Weldments			•	•	•	•	•	•
Extrusion			•		•	•	•	
Permanent Mold				•	•	•	•	
Roll Forming			•	•	•	•	•	

**includes nickel and cobalt.*

3. What size range of parts can be produced by the investment casting process?

Depending on the foundry, investment castings can be produced in all alloys from a fraction of an ounce (such as for a dental brace for a tooth) to over 1,000 pounds (complex aircraft engine parts.) Of the approximate 300 commercial investment casting foundries nationwide, most cast parts in the ounces to 20 pound range. Many foundries are increasing their capacity to pour larger parts, so that pieces in the 20-120 pound range are becoming quite common.

PMI, which produces parts from fractions of an ounce to 10 pounds, specializes in parts under three pounds.

4. What are the "as cast" dimensional tolerances I can expect?

Typically, a linear tolerance of + .005 in./in. is standard for investment casting. This varies depending on the size and complexity of the part. Subsequent straightening or coining procedures often enable even tighter tolerances to be held on one or more specific dimensions.

By working closely with the investment caster's engineering staff, you can often get an as-cast part that is within 90% or more of the

requirements for your finished part. As a result of good casting design, the as cast part should require minimal or no machining.

Linear Tolerance	
Dimensions	Normal
up to 1"	± .005
up to 2"	± .010
up to 3"	± .015
up to 4"	± .020
from 5" to 10"	add ± .003
maximum variation	± .040

Minimum Wall Thickness		
Alloy	Small Area (.25 x .25)	Normal
Beryllium Copper	.030"	.060"
Ductile Iron	.030"	.060"
Aluminum	.030"	.080"
300 Series Stainless	.040"	.080"
Cobalt Alloys	.040"	.090"
400 Series Stainless	.050"	.090"
Carbon Steel	.050"	.090"

5. What type of surface finish can I expect from an investment casting?

Because the ceramic shell is built around smooth patterns produced by injecting wax into a metal die, the resultant casting finish is excellent. A 125 microfinish is standard and even finer finishes (63 or 32) are not uncommon on aircraft engine castings. In general, lower melting point alloys will produce better as-cast surface finishes than higher melting point alloys, while non-ferrous alloys will result in better surface finishes than ferrous.

Surface Finish	
Casting Process	RMS Range
Die	20-120
Investment	60-200
Steel Mold	120-300
Centrifugal-Permanent Mold	20-300
Static- Permanent Mold	200-420
Normal Non-Ferrous Sand	300-560
Normal Ferrous Green Sand	560-900

Each foundry has its own standards for surface blemishes (positives, negatives), which it should discuss with you prior to constructing tooling.

6. Aren't investment castings expensive? If so, how can they save me money?

Investment castings can offer a total lower cost for precision metal parts. The process builds many features into the cast part that translate into benefits for you. While the piece price of an investment casting is generally more than that of a forging or of other types of casting, investment castings can make up for the possibly higher piece price by requiring less machining due to their near net shape tolerances. Many parts are usable as cast with no finishing required, while parts that require milling, turning, drilling, and grinding to finish can be

investment cast with only .020 - .030 finished stock.

Again, communication between you and the casting engineers early in the process is crucial to determining what can be cost-effectively cast vs. what should be achieved through after cast machining.

7. How many pieces do I need to purchase to make an investment casting practical?

The bulk of investment castings that are produced fall in the 100-10,000 annual piece requirement range. However, since tooling cost is reasonable, investment casting might be a practical choice for even smaller quantities. For example, in the machine tool industry, investment castings are often specified on 25 pieces of a new part, with subsequent orders being for only a piece or two. On the opposite end of the spectrum, companies that provide investment castings for automotive users might produce 100,000 parts per month.

Your projected annual volume will help you determine if investment casting is the best process for you. Investment casting is most price competitive at medium to high volume, but companies vary according to their effective order size and minimum order requirements. There are companies which offer small quantities of prototype or replacement parts, while other firms are particularly equipped for higher volume work.

8. What type of tooling or pattern equipment is necessary?

Investment casting patterns are produced in a die machined from a block of aluminum or steel. Depending on your volume requirements, the die can include one or more cavities. When the two halves of the die are locked together, wax is injected into the cavity. The hardened wax is an exact replica of the as-cast part, plus "gates," wax tabs which will direct the flow of the metal from the pouring chamber to the individual part.

Because the die is built to withstand wax injection rather than metal injection, investment casting tooling is usually much less expensive than tooling for other "hot" casting methods. The American Foundrymen's Society estimates that most investment casting tooling falls in the \$1,000-10,000 price range.

9. What about the integrity of an investment casting? Will I have problems with porosity and shrinkage that are usually non-existent in bar stock or forgings?

The integrity of an investment casting is often far superior to that of parts produced by other methods. Porosity can be controlled in the casting process, while good tooling design and proper selection of pattern materials can compensate for other normal occurrences such as shrinkage. Although some porosity will not affect the mechanical properties of the casting, you can specify x-ray and other NDT tests to verify that the part meets soundness criteria for critical applications where minimal porosity is required.

10. What lead times can I expect when ordering an investment casting?

Lead times vary according to part complexity and foundry capacity. Since investment castings are custom-made to your specifications, 8-14 weeks is typical for tooling and sample casting and 8-14 weeks for

production orders.

To make lead times more livable in a business climate that demands Just-In-Time ordering, many companies offer stocking programs. By determining your projected use of a part over a given time period (such as a year), by communicating this need to your supplier, and by committing to purchase the projected quantity upon release, you can shortcut the normal lead time. Advance planning on your part will enable your investment casting supplier to have parts available when you need them.

In summary, investment casting can offer you a near net shape part with cast-in detail, tight tolerances, and excellent surface finish. Because PMI and other investment casting companies can design so much of what you need into the actual casting, you save money in machining, welding, assembly, and other secondary operations. When a part is designed as an investment casting or converted to one from another process, you can receive a finished part at total lower cost.

By communicating your exact specifications and performance requirements to the casting engineer, you will receive the most castable part possible, thus assuring the best value for your money.

PMI is committed to offering you quality metal parts that are easy to buy, ready to use, and available when you need them. Our value-added services include:

- Prototyping using our patented Proto-Cast® system
- EDI and Barcoding
- CAD transfer of your print
- Stocking programs
- Machining, surface finishing, and heat treating

Our sales engineers and field sales agents will be pleased to further discuss with you the particular advantages that the investment casting process can offer for your application, as well as show you how PMI can maximize those advantages. For further information about the process or to get the name of our sales agent nearest you, please call us at (216) 481-8900.

Much of the information in this brochure was provided courtesy of the Investment Casting Division of the American Foundrymen's Society. For further information about their programs and literature, please contact them at (800) 537-4237.



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Shrinkages in Iron Castings

Some facts and hypotheses related to thermal analysis with ATAS.

Author: Rudolf Sillén
Technical Director, NovaCast AB

Shrinkages are one of the most common casting defects. The main cause of shrinkage cavities is the fact that all commercial alloys contract when a casting cools from the pouring temperature to solidus. The contraction is usually between 1-5 % depending on the type of alloy and the pouring temperature. The main contraction occurs between the pouring temperature and the liquidus temperature. If the contraction is not compensated for by feed metal, either by supplying feed metal or by forming a depression of the outer surface, a shrinkage cavity will occur. Cast iron alloys, which solidify with a precipitation of graphite, represent a more complex behavior, the reason being that the dissolved carbon partly precipitates as graphite with a lower density than the base iron. The precipitation is therefore associated with an increase in volume, which in some cases partly might offset the contraction of the liquid and the austenite.

In the following we have classified shrinkages in four basic types. We will discuss how they occur and how they can be avoided. The four basic types are Outer sunks (pull downs), Macro shrinkages, Micro shrinkages and Porosities.

A. Outer Sunks

A1 - Definition and location

Outer sunks (pull downs, sinks) can be seen from the outside of the casting, usually as a smooth depression in the casting surface. They are normally located on thick sections of the casting and on surfaces located on the top of the casting during pouring. Outer sunks are also referred to as "pull downs" and they can occur not only on horizontal top faces of the casting but sometimes also on vertical surfaces.



A2 - The basic mechanism behind outer sunks

The metal starts to solidify at the surfaces of the mould cavity and a thin skin is formed. The temperature drops further, which causes the liquid and the semi-liquid metal inside the casting cavity to contract further. If no feed metal is available either from the gating system or from a feeder then contraction will cause a negative pressure inside the cavity. In order to equalize the pressure difference between the atmosphere and the interior the solid outer skin will be "pulled" inwards. The effect is that the contraction is compensated for by a reduction of the volume of the casting. Thus outer sunks develop at an early stage of the solidification process before the massive eutectic freezing has commenced.

A3 - Variables that influence the creation of outer sunks

The major variables that influence the likelihood for development of outer sunks and their effect are as follows:

1. Too high pouring temperature. The volumetric contraction is about 1.4% per 100 C for cast iron. Thus an increase in pouring

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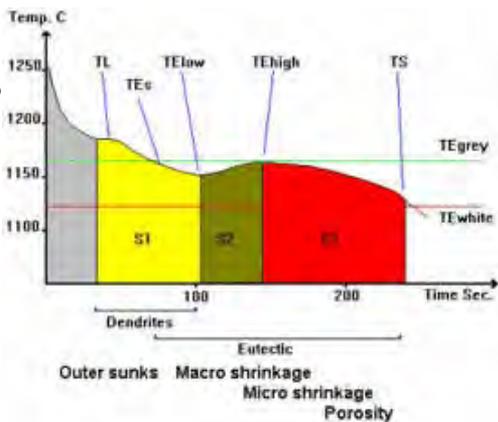
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temperature of 50 C will increase the need for feed metal with 0.7%. When pouring castings with small modulus in ductile iron, a higher pouring temperature might decrease shrinkage tendency especially in hard moulds. The reason is a better temperature distribution in the mould and less fast initial cooling.

2. Insufficient amount of feed metal available at early stages of the solidification. Normally no feeder is needed for castings with small modulus (less than 0.4 cm). Feed metal can be supplied from the pouring cup through the gating system. However, if the modulus of the ingate is too small then feed metal might be lacking.
3. Deformation (expansion) of the casting cavity. This might happen in green sand moulds and cause mould wall movement, which increases the casting cavity.
4. Too high liquidus temperature. A liquidus temperature higher than what the system has been designed for will cause the surface skin to form earlier and thereby increase the risk for outer sunks.
5. Too high amount of primary austenite (S1) cause by too low active carbon equivalent. A higher amount of primary austenite than usual for the alloy means that the contraction increases at an early stage.
6. Too low eutectic minimum temperature (TElow). A eutectic temperature that is lower than the normal minimum level means that the contraction of austenite is higher than normal as the distance between liquidus (TL) and the eutectic temperature (TElow) increases. Iron undercooling below the graphitic eutectic due to lack of nucleation - too little or wrong type of inoculation or faded inoculation.
7. A solidification that favors skin freezing (Also see number 5).
8. Insufficient weighting or clamping of the mould. This might have the same effect as a deformable mould especially if the casting has some parts with lower modulus than solidify quickly and cause a pressure that tends to separate the mould halves.
9. Riser does not pipe due to too low height, too low modulus or too large modulus of the ingates.

A4 - Which variables can be monitored by ATAS?

Thermal analysis can be used to monitor the metallurgical variables that influence the development of outer sunks. ATAS is especially designed to monitor and interpret cooling curve data and to predict the potential risk for shrinkages and also other problems. The metallurgical variables used to predict outer sunks are liquidus (TL), liquidus plateau, primary austenite (S1) and the low eutectic temperature (TElow). (Parameters number 4,5,6 and 7). The illustration shows a typical cooling curve for a hypoeutectic iron and the "time-position" for various types of shrinkages.



ATAS makes it possible to monitor and control these metallurgical variables. However, as can be understood from chapter A3, several other variables do influence the outcome. Even if the metallurgical variables are within their acceptable limits outer sunks might occur, e.g. if the pouring temperature is higher than normal or the mould is softer. Also the reverse might be true - the metallurgical variables might be slightly outside their normal limits but no shrinkage will occur because the mould was much harder than normal or the pouring temperature was lower than normal.

The important fact is that ATAS allows the foundry man to ensure that 4 out of 8 variables are within the specification.

A5 - How can out sunks (pull downs) be avoided?

The pouring temperature must be chosen individually for the casting - e.g. castings with small modulus and/or long flow length must use a high pouring temperature and/or be poured very fast to avoid casting defects such as cold shuts. Castings with a high modulus and/or short flow length can be poured with a low temperature. To minimize the volume contraction in liquid state, the general advice is to use as low a pouring temperature as possible without getting any casting defect. The feeding system can be designed and dimensioned once the optimal pouring temperature has been established for a casting. Mould hardness must also be considered when dimensioning the feeding system. It should be as high as possible.

Feeding from the gating system is normally sufficient if the casting modulus is less than 0.3 cm. However, make sure that the ingates do not freeze off too early and thereby block the flow of feed metal from the pouring cup.

In some cases where a casting has been successfully made without a feeder, that is using ingate feeding, shrinkage occurs when a ceramic filter is placed in the gating system. A filter reduces the modulus locally and might block the feeding path.

If the modulus is larger than 0.3 cm then it is recommended to use a feeder. A feeder, which only has the purpose to eliminate outer sunks, can be made smaller than if it also has to assist in eliminating macro shrinkages (as they are developed at a later stage).

From a metallurgical standpoint the main thing is to reduce variations in the process variables TL, S1 and TE_{low}. If ATAS is used to monitor these variables it will soon become evident how to melt, hold and treat the metal to reduce variations.

B. Macro shrinkages

B1 - Definition and location

Macro shrinkages are usually found inside the casting and close to heat centers. They appear as larger holes, usually with rough surfaces, often dendritic and are often larger than 5 mm. Macro shrinkages are usually not revealed unless the casting is machined or deliberately cut through sections of heat centers. Can also appear in or close to ingates.



B2 - The basic mechanism behind macro shrinkages

Macro shrinkages develop after the initial solidification on the surface when a shell that can not be deformed by the pressure difference to the atmosphere. If no more feed metal is available at that point in time then the contraction of the liquid and semi liquid metal as well as the already solidified parts results in a cavity.

B3 - Variables that influence the creation of macro shrinkages

Shrinkages are influenced by the behaviour of both the alloy and the mould. The dominating variables for macro shrinkages are:

1. Insufficient supply of feed metal - too small feeder modulus or feeder neck or feeder does not pipe due to too large ingate modulus or height position.

2. Feeding path closed too early - wrong position of feeder. More dendrites than usual at an early stage (CLF factor in NovaSolid). Too low active carbon equivalent (ACEL=the true carbon equivalent measured with ATAS). For ductile iron, ACEL should be eutectic and carbon minimum 3.6%.

3. Mould hardness during solidification. Soft moulds which favor mould wall movement. A green sand mould, hard at room temp can be soft during solidification due to the high water level in the condensation zone.

4. Mould weighting or clamping insufficient to stand the pressure during solidification. Eutectic pressures up to 50 kg/cm² has been claimed!

5. Higher liquidus temperature (TL) than normal. In hypoeutectic irons this means too much primary austenite and more difficult feeding. In hypereutectic it means more primary graphite which reduces the amount of eutectic graphite.

6. Higher amount of primary austenite (S1) than normal. Too low ACEL.

7. Too high recalescence and recalescence rate causes expansion from graphite to occur too early. (In ductile - too much late inoculation with low ACEL).

8. Too low eutectic temperature might cause some primary carbides to form.

B4 - Which variables can be monitored by ATAS?

ATAS can monitor variables 5,6 and 8. The length of the liquidus plateau can also be used to indicate anomalies in the initial dendrite growth and precipitation of a pro-eutectic phase.

B5 - How can macro shrinkages be avoided?

The remedies are basically the same as for outer sunks. However to avoid macro shrinkages the feed metal must be available longer than for Outer sunks because macro defects occur at a later stage during solidification. A solidification simulation e.g. using NovaSolid is highly recommended to ensure that feed metal can reach critical areas and that feed metal is available during the contraction period.

C. Micro shrinkages

C1 - Definition and location

Micro shrinkages are smaller cavities with irregular surfaces often with signs of dendrites. Sizes are often less than 3 mm. The defects are usually located close to heat centres in the casting. Micro shrinkages are often referred to as porosity or "leakage" as castings with this type of defect often leak during a pressure test. Micro shrinkages are usually not revealed unless the casting is machined or deliberately broken.



C2 - The basic mechanisms behind micro shrinkages

The defects occur at the latest stages of solidification. It is therefore more difficult to solve micro shrinkage problems by changing the gating or feeding system. Micro shrinkages are more of a metallurgical problem. There are three basic mechanisms behind micro shrinkages.

The first and most common mechanism behind micro shrinkages is that the contraction of the austenite (primary and eutectic) at the end of freezing can not be compensated for by the precipitation of carbon into graphite, which is associated with an increase in volume. (The density of the

austenite is approximately 6.9 g/cm³ at temperatures around 1100 and the density of graphite about 2.3 g/cm³).

Another reason especially in gray iron is too high levels of nitrogen. In ductile iron this is less likely as the high CEL-level reduces solubility of nitrogen. High nitrogen levels cause an increased solubility of hydrogen. During the end of solidification a dispersed type of shrinkage usually occurs in almost all of the casting. The cavities look like a "comma" and are often referred to as "comma" cavities or sometimes comma gas blows. Adding about 0.02% titanium usually helps. Another alternative is to use zirconium especially with ductile iron.

The other mechanism is that due to the composition of the iron there are one or more phases that solidify at a lower temperature than the austenite-graphite eutectic. The most well-known case is the formation of iron phosphide (Fe₃P) in gray iron if the phosphorus level is higher than 0.15 %. The Fe₃P phase segregates to cell boundaries where it continues to contract even after most of the alloy has solidified. The solidus temperature for Fe₃P is about 850 C.

C3 - Variables that influence the creation of micro shrinkages

1. Mould stability. Too soft moulds, which might cause mould wall movement.
2. Too little sea coal addition to green sand.
3. Bentonite (Calcium) with low wet compression strength in green sand. Sodium bentonites are optimal for reducing shrinkages.
4. Insufficient weighting or clamping of moulds.
5. Too little eutectic graphite especially at the end of freezing; its precipitation can not compensate for the shrinkage of the austenite. A true eutectic composition with relatively high silicon level is preferred as the amount of eutectic graphite is maximized. (Note that the eutectic point is a function of the thermal modulus!).
6. Too much inoculant in gray iron that reduces cell size.
7. Too high hypereutectic composition in ductile iron. If too high then some of the dissolved carbon will be precipitated as primary graphite and the amount of eutectic graphite might be insufficient. Evidenced by too many large size nodules which have been growing early in the liquid.
8. Too high phosphorous in gray iron - max 0.12 % and max 0.03% if molybdenum or high chromium levels are used in the alloy.
9. Too much magnesium in ductile iron. Levels of Mg and RE must be consistent with the thermal modulus of the casting.
10. Too high amount of phases which exhibit solidus below 1100 C. e.g. Fe₃P.
11. Too high recalescence and recalescence rate causes expansion too early.
12. Too low eutectic temperature might cause some primary carbides to form.
13. Too small Graphite Factor 1 (GRF1) indicating too small amount of eutectic graphite during the second part of the eutectic.
14. Too high Graphite Factor 2 (GRF2) indicating too little eutectic graphite precipitation at the end of freezing.
15. Too low solidus (TS) which may induce carbides at the last portions to freeze. Too high levels of Mg, Nb, V or similar elements tend to segregate to the grain boundaries and form carbides that contract during their solidification. For normal ductile iron TS should be above 1100 C.
16. Too high silicon will increase segregation of carbide forming elements, which increases the tendency for micro shrinkage.

C4 - Which variables can be monitored by ATAS?

The mechanism behind micro shrinkages is dependent on the metallurgical status of the melt, which can not be measured by chemical analysis. The ATAS thermal analysis method is therefore a powerful tool for measuring and verifying that a melt is within acceptable metallurgical threshold values. ATAS can also be used to study the result of changes in melting and treatment variables and alloying materials, whereby the most optimal alloying materials as well as melting and treatment processes can be established. ATAS factors 10, 11, 12, 13 and 14 as mentioned in the previous chapter are good indicators for micro shrinkages.

C5 - How can micro shrinkages be avoided?

The first condition is to have a hard mould - ideally chemically bonded sand moulds. A green sand mould is compressible, however hard at room temperature, because of the formation of a condensation zone. In the condensation zone, which travels from the surface of the cavity and inwards, the moisture content can be up to 3 times higher than the initial value. This means that the bentonite layer becomes semi-fluid and can easily be compressed. However green sand moulds can be made more stable by means of the following recommendations:

- A sodium bentonite is most favorable, as its wet compression strength is high.
- Use sea coal as carbon additive. It will "coke" and increase the friction between sand grains. The carbon level in the sand should be at least 5 %.
- Use as low moisture as possible. The compactability should be less than 40%.
- The moulding machine should be able to compact the sand properly.
- On Disamatics check that the mould conveyor is working properly so that the moulds are kept together tightly (sometimes a gap can be formed).
- For larger flasks use flasks with bars - make sure the moulds are clamped properly or that enough weights are put on the cope.
- The forces during solidification of cast iron can be very high - therefore normal weighting to avoid run-out at the parting line is not enough.

Metallurgically, the most important factor is to ensure that a sufficient amount of carbon is precipitated as graphite during solidification. It is important that the initial growth rate is not too high. This can be indicated by studying the recalescence and recalescence rate on ATAS. A too high rate means too much graphite too early, which is associated with an expansion that can cause mould wall movement and thus increase the likelihood for shrinkages. Base iron nucleation status is important. Super heating above approximately 1520 C too long reduces the nucleation level. (ATAS users can easily make some tests with some melt to find the exact limits valid with their iron composition (equilibrium temperature), type of furnace (surface area, stirring action), etc).

Graphite factor 1 indicates the precipitation of graphite during the second phase. Higher values are more favorable. However this factor requires that the Quik-Cup always be filled to the brim, otherwise the weight of the samples is different, which will influence this factor.

It is essential that enough graphite be precipitated at the end of freezing. Studying graphite factor 2, the first derivative at solidus and the solidus temperature can indicate this. A low graphite factor 2 is favorable. The first derivative (dT/dt_{TS}) should be as low (deep) as possible. Solidus should be high to ensure that the last metal solidifies gray and not as partly white

(which does not expand).

These metallurgical factors can be influenced by selection of charge materials, charging sequence, the melting cycle (temp/time steps) as well as type and amount of alloying materials, inoculants and FeSiMg. With ATAS it is possible to find the optimal melting and treatment practice to reduce the likelihood for shrinkages. Such an optimization can NOT be made using traditional chemical analysis alone. The behavior of a melt depends not only on the percentage of each element but also on formed compounds such as oxides, silicates, sulphides, nitrates and their interaction during solidification. The total behavior can however be revealed by means of ATAS thermal analysis. A quantitative analysis of the solidification can also be made which allows the user to study the precipitation of graphite and the associated volume changes in details. ATAS shows the weight of precipitated graphite during the different phases of solidification as well as the need for feed metal.

Metallurgically it is also important to avoid phases that have a solidus temperature below the main solidus temperature. In gray iron the phosphorous level should normally be less than 0.12 %. If molybdenum or chromium are present then the phosphorus level must be lower - in some cases less than 0.4% to avoid porosity. In ductile iron phosphorous should be less than 0.03%.

D. Porosities

C1 - Definition and location

Porosities are small, dispersed cavities with irregular or rather smooth surfaces, often less than 1 mm in size. The defects are usually located close to heat centers and in grain boundaries. They are more dispersed than micro shrinkages. Typically, the defect is not discovered until the casting is subjected to a leakage test with water or air.



C2 - The basic mechanism behind porosities

The defects occur at the very latest stages of solidification. Therefore it is not possible to solve porosity problems with changes in the gating or feeding system (unless a very steep temperature gradient is maintained). Porosities are a metallurgical problem mainly depending on the chemical composition.

The main mechanism is that due to the composition of the iron, one or more phases solidify at a lower temperature than the austenite-graphite eutectic. The most well-known case is the formation of iron phosphide (Fe₃P) in gray iron if the phosphorus level is higher than 0.15 %. The Fe₃P phase segregates to cell boundaries where it continues to contract even after most of the alloy has solidified. The solidus temperature for Fe₃P is about 850 C. The problem is aggravated by Mo and Cr. Another cause can be that the iron has too high levels of elements like Nb and V that usually originate from steel and segregate to the grain boundaries and form carbides.

In ductile iron too high magnesium levels can cause similar problems as magnesium segregates to the rest melt and can induce formation of carbides which contracts and creates porosity.

C3 - Variables that influence the creation of porosities

1. Too high phosphorous in gray iron - max 0.12 % and max 0.03% if molybdenum or high chromium levels are used in the alloy.
2. Too much magnesium in ductile iron.

3. Too high amount of phases which exhibits solidus below 1100 C.
E.g. Fe₃P.
4. Too high levels of Nb, V etc.

C4 - Which variables can be monitored by ATAS?

As the mechanism behind porosities is more dependent on solidification of minute phases with a temperature below the normal solidus it is normally not detectable by thermal analysis. Some guidance might be available by studying TS and the last part of the first derivative curve.

C5 - How can porosities be avoided?

The phosphorous content should be less than 0.12 % in unalloyed gray iron. (But minimum 0.08% in order to avoid expansion penetration!). The gas content can also influence this type of defect. Metallurgically it is important to avoid all phases, which have a solidus temperature below the main solidus temperature. In gray iron the phosphorous level should normally be less than 0.12 %. If molybdenum or chromium is present then the phosphorous level must be lower - in some cases less than 0.04% to avoid porosity (leakage). The amount of magnesium in ductile should be kept to a minimum.

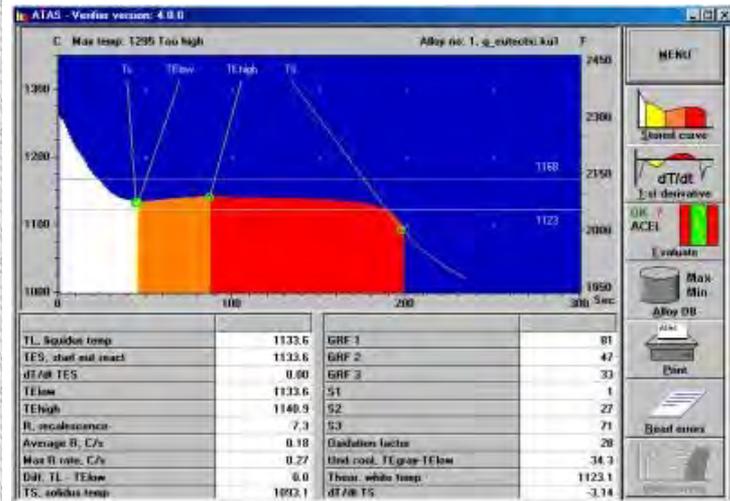
E. "Riserless" methodology

Many castings are successfully produced without a riser (i.e. a feeder). Basically there are four possibilities:

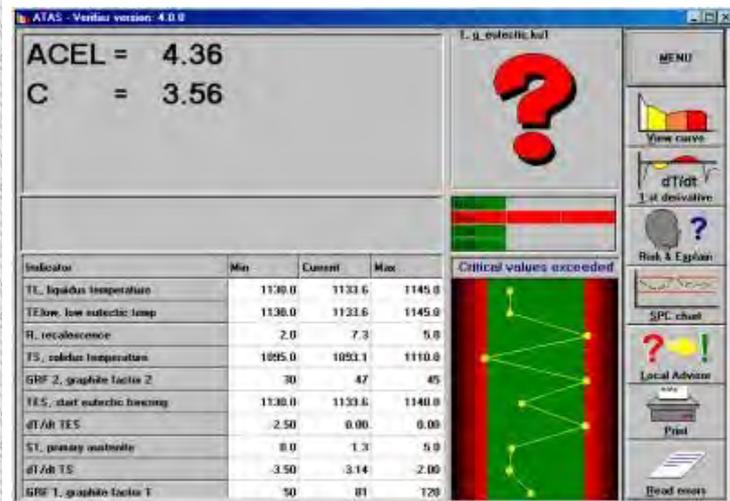
1. The customer accepts some shrinkages as their influence on the functionality of the casting is negligible, e.g. a counterweight can be allowed to have inner shrinkages. Many micro shrinkage defects influence neither the strength of the part nor the appearance - however the foundry often takes for granted that the customer expects a completely sound casting. Usable castings are often scrapped without any rational reason! A dialogue between the foundry and the customer based on solidification simulations before start of production can often result in more realistic quality demands, which will benefit both parties (higher yield, less problems!).
2. The modulus of the casting is fairly small (less than 0.3 cm) and the pouring time is relatively short. In this case the feed metal is taken from the pouring cup as long as feeding is possible through the ingates. Note that the modulus, i.e. the solidification time of the gating system, must be related to the modulus of the casting in order to allow feeding. A simulation e.g. with NovaSolid is ideal to find the optimal design.
3. The modulus of the casting is fairly small and a main part of the casting geometry is like a thin plate. In such cases the initially solidified thin skin is depressed inwards by the atmospheric pressure. The depression might only be fractions of a millimeter but on a larger surface this will add up to a large volume, which will compensate for the shrinkage.
4. The alloy (ductile) should be close to true eutectic composition which is related to the cooling rate. That means that the liquidus temperature is very low (around 1145-1150) and the solidification starts with the precipitation of eutectic (graphite and austenite). Thus the contraction of pro-eutectic austenite is eliminated. A hyper-eutectic solidification in the casting should be avoided as it will reduce the amount of carbon during the eutectic reaction. (Note that the chemical composition can be hyper-eutectic but the solidification hypo-eutectic if the cooling rate is high). The pouring temperature must be very low in order to reduce the contraction of the melt in liquid state. Pouring temperatures for "riserless" castings are preferably around

1200 C. Due to the low pouring temperature, the pouring time must be short, to avoid defects. Two other conditions must also be fulfilled. First the modulus of the casting must be at least 1.5 cm. This will ensure that the solidification time is slow enough to allow the eutectic reaction to occur slowly in order to precipitate as much eutectic graphite as possible. In order to avoid mould wall movement due to the forces during solidification the moulds must have sufficient strength. Chemically bonded moulds using binders such as furan or cement must be used. The moulds should be firmly clamped (instead of using weights).

Illustrations from ATAS Screens:



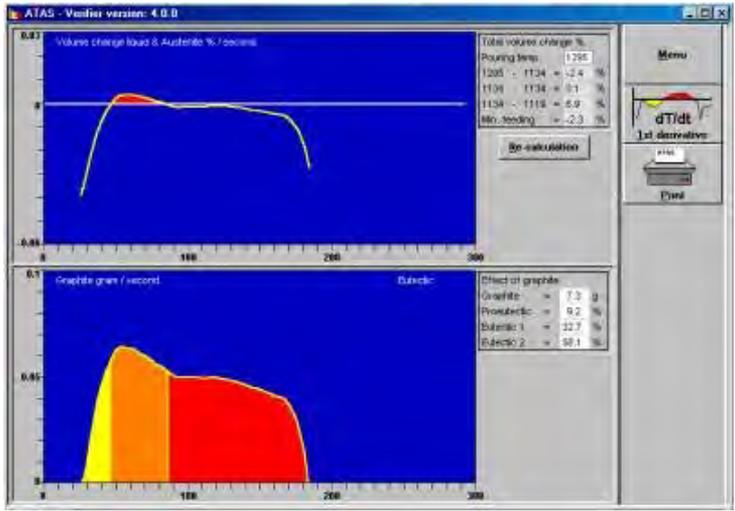
Pic. 1. The cooling curve shows a eutectic ductile iron with a high recalescence.



Pic. 2. The same cooling curve evaluated by ATAS. Several parameters are outside the allowed thermal limits. The expert system gives a warning that this iron is prone to micro shrinkage defects. Pressing the Risk&Explain icon will give further information.



Pic. 3. This screen shows how the expert system has interpreted the thermal data.



Pic. 4. The cooling curve has been analyzed quantitatively by ATAS. In total 7.3 grams of graphite has been precipitated. Some of it has been precipitated just before the eutectic temperature (at the walls of the Quik-Cup). The problem is that too much is precipitated too early (Eutectic 1=32.7%). The solution is to improve the treatment and inoculation process. As the effect of various modifications now can be visualized and quantified it is easy to optimize the various processes.

Version 02-07-22.

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Machinability of Ductile Iron

Submitted by Jim Mullins, Technical Director

This is an excerpt (with DIS comments) from work done by University of Alabama, Birmingham, for the American Foundry Society (AFS) and several foundry companies with support from the US Department of Energy. The original report was presented by Dr. Charles Bates at the AFS Convention, 2002 and is copyrighted by AFS. This is paper # 02 - 160 for those who would like to review the entire paper, which is available from AFS.

The two-year research program was conducted to develop an understanding of the factors that effect Ductile Iron machinability. Samples of continuous cast round bars of various chemistries and microstructures were turned on a lathe and tool wear rates were measured. The CNC lathe used was programmed to keep a constant surface speed. Un-coated fine-grained carbides inserts were the tools and flank wear curves were generated for each case of chemistry and microstructure as well as at different surface speeds.

Test data - final chemistry ranges:

C.E.	4.09 - 4.16	Cu	0.030 - 0.32
C	3.53 - 3.59	Sn	0.006 - 0.035
Si	2.00 - 2.43	Cr	0.025 - 0.031
P	0.024 - 0.028	Mo	0.006
S	0.004 - 0.007	Ti	0.008 - 0.011
Mn	0.20 - 0.23	V	0.004
Ni	0.044	Al	0.013 - 0.019

Physical properties (on tested samples):

Tensile strength	81,059 - 94,820 psi
Yield strength	51,709 - 55,975 psi
Elongation	5 - 9 %
Hardness	205 - 221 BHN

Statistical analysis was used to evaluate data and provide a high confidence level to determine the significance of an input variable.

Many graphs of the data were prepared and shown in the original report; they include turning speed vs. tool wear, tool wear vs. combined carbon, silicon, copper, nodule count, pearlite volume, pearlite colony thickness, and BHN hardness. Other variables evaluated in the project include graphite volume percentage, nodule diameter, graphite spacing, graphite shape as measured by the roundness formula, and spacing between pearlite colonies.

Conclusions;

1. With the exception of one soft iron tested (179 BHN) the wear slope in the graphs was higher at 600 sfm (surface feet per minute) than at 450 sfm. They surmised that this was due to increased tool heating at

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the faster speed, which can accelerate tool wear.

2. Higher tool wear rates were seen in irons with a higher BHN hardness.
3. Lower wear rates were seen in the irons with higher silicon levels, but the data was limited and the silicon content was on the low side at 2.4% max. Note that at higher silicon levels of > 2.6% machinability is generally reduced.
4. Higher wear rates were seen in irons with a higher combined carbon contents.
5. Higher wear rates were seen in irons with higher copper concentrations. Note, it appeared that in irons of the same hardness that had both copper and tin, strengthening of the iron by using copper gave higher tool wear rates than strengthening with tin.
6. Higher tool wear was seen in irons with less rounded nodules, but these irons also had higher hardness, so it is difficult to give a direct comparison.
7. Irons with the highest volume of pearlite, lowest pearlite colony spacing and highest pearlite colony thickness had the highest tool wear rates. The pearlite colony thickness seemed to be the most significant on predicting wear rate.
8. Higher nodule counts can make irons with lower pearlite colony thickness.
9. Overall this was not a truly comprehensive study of a typical 80-55-06 grade of material since continuous cast bars will have some large changes in nodule count and hence microstructure based upon the severity of cooling. They tried to compensate for this in the project by pre-machining the bars removing the surface layer. This allowed them to study some of the other casting parameters more closely. However, sand foundries must keep in mind that the surface condition (sand, slag, etc as well as the amount of shot peening the part receives) will have a significant effect on the first cut of machining.



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DIS FAQ's

Submitted by Jim Mullins, Technical Director

Questions

1. [What is good melting practice for gray and ductile iron?](#)
2. [How do I know what chemistry to aim for in ductile iron production?](#)
3. [Describe controls for good ductile iron treatment practice?](#)
4. [What are the basics for inoculation of cast iron?](#)
5. [What sulfur and manganese do I need in gray iron?](#)
6. [Describe the usual tramp elements in ductile iron and how to control them?](#)

Answers

1. Melting practice for gray & ductile iron. (Note melting for ductile iron and gray iron are the same)

The charge will include pig iron, return scrap, steel scrap, silicon carbide and carbon. It is important to remove as much slag from the furnace prior to charging, since carbon will be caught in the slag. A rinse heat may be necessary after an alloyed metal heat. This is especially true with a ductile base iron heat.

The charge should be melted quickly, except that we do not want to exceed 2800 F. Slagging the furnace may be required if more carbon needs to be picked up. Carbon will not go through a slag layer. So bath must be clean.

Wedge tests can help determine whether or not the carbon as graphite is in solution. (Carbon exists in two forms in cast irons; graphite and combined carbon such as carbide - primarily as part of the pearlite). In graphitic cast irons such as gray iron, ductile iron, and compacted graphite iron we need to have the graphite in the proper form such as flakes, nodules, etc to obtain the correct properties. The wedge value is high when there is an excess of carbide in the fracture.

Chemistry samples need to be taken after good stirring of the top of the metal bath. Do not want to get loose carbon in the sample, as it will give erroneous readings.

Usually silicon is added after the carbon is in solution, but should have at least 1% silicon in the base while melting in. Silicon will reduce the carbide promoting effect and reduce the wedge value.

The iron should not be held for long periods of time especially at higher temperatures (>2750 F), because the wedge value will increase with holding time. Adjustments to wedge (pig iron and silicon will reduce the wedge value and must be done prior to tapping, if wedge is high. Holding for as little as 15 minutes at higher temperature will destroy nucleation in the iron and wedge.

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2. Metallurgy of ductile iron

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The rate of solidification, melting and processing dictate what the chemistry should be, to determine the microstructure in a certain area of the casting. It is very important to have the chemistry correct not only to obtain the right grade of ductile iron but also to avoid problems in the casting and microstructure.

Thin section (1/2 to 1 inch) ferritic irons can tolerate higher carbon (3.7%) and silicon (2.7%) contents, but must be low in all other elements to achieve good toughness. For maximum toughness silicon can be lowered to 2.2% while phosphorus should be a maximum of 0.02%.

In most cases Cr, V and other hardening elements must be kept below 0.04%. Usually only Cu with some Mn (residual of 0.20%) is used for strengthening. An addition of 0.30% Cu in this case will usually harden a 65-45-12 iron to an 80-55-06 iron in thin sections.

Elements such as B, Ti and Mo should be kept very low as they can segregate in the last areas to freeze and form carbides.

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3. Treatment practice for ductile iron

The control of the treatment step is critical to obtaining consistent magnesium recovery. In order to control it the following items must be carefully monitored:

- Sulfur and oxygen levels of base iron prior to treatment
- Treatment temperature of the metal (variations will give variable recovery)
- Rate of metal transfer from the ladle into the treatment device (as fast as possible)
- Measuring and controlling the inlet and outlet hole sizes of the device
- Placement of the treatment alloy & temperature of the alloy (cold as possible)
- Sizing of the alloy compared to the weight of the tapped metal

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4. Inoculation practice for gray & ductile iron

All graphitic cast irons need to be inoculated. The amount added is very important. Too much can cause high cell counts and more shrinkage in gray iron. Gray iron requires between 0.1-0.3% additions depending upon the section size (cooling rate of the casting). Faster cooling requires more inoculation than slowly cooled thick sections.

Ductile iron needs considerably more inoculation due to the removal of most of the sulfur and oxygen from the melt during the treatment step and the carbide - promoting tendency of the magnesium alloy. Additions can range from 0.4 to 1.0%.

The strength of the inoculant must also be considered. Most inoculants have some Al and Ca. Stronger inoculants, which have additional elements added such as Sr, Ba, etc. will allow reduced additions and still give the same effect. The stronger inoculants for gray and ductile are different and should not be interchanged. Sr base inoculants are not used in ductile iron as the Ca in the metal retards the effectiveness of the Sr.

The addition method can be any good way to distribute the inoculant

evenly and get it dissolved uniformly in the metal. This is usually done in the pouring ladle (with ductile, after the treatment step). It can also be done on a reduced scale (never more than 0.2%) in the pouring box of the mold.

All inoculant effects fade with time after addition. Usually 20 minutes is the maximum time to insure any residual effect. For this reason, many foundries do some inoculation in the ladle and some in the mold, as well as control the time of the ladle on the floor. Un-inoculated irons and those with faded inoculation behave much differently and can have unwanted graphite structures, carbides, and changes to the matrix structure. Shrinkage can also be affected.

Inoculants must be carefully weighed and be kept dry as they can pick up some moisture. Water in inoculants will produce large carbides in the metal.

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5. Melting practice and detailed chemistry control for gray irons

Sulfur and manganese are very important in gray cast iron. Sulfur is an active element - promoting more graphite and good type A graphite flakes, when it is in the proper range of 0.06 -0.09%. Sulfur can be added to the charge in the form of pyrite (25% S) or as small briquettes (30% S). Low sulfur (<0.04%) causes more chill (carbides) to form and can make the iron more difficult to inoculate well.

Manganese is necessary to form MnS in the melt, which is stable. The normal ratio of Mn to S is: $(1.7 \times \%S) + .30 \text{ Mn} = \text{total minimum Mn content}$ (usually kept about 0.60% for normal S levels). If the manganese is low for the amount of S present, the excess sulfur combines with iron and causes FeS (iron sulfide) to form and can cause slag like defects.

Manganese contents over the minimum required to tie up the S act as pearlite stabilizers to strengthen the iron up to about 0.80%. At higher levels of Mn (>0.80%), graphite flakes can grow large reducing the tensile strength.

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6. Metallurgy and tramp elements control in ductile iron

Cerium - this element is usually added to MgFeSi treatment alloys. The effect of Ce is similar to Mg in forming spheroidal graphite and so the effects of the two are additive. Increasing Ce allows for lower Mg additions. A small amount of Ce (about 0.005% is good) will promote good nodularity. However, it can be very detrimental in heavy sections (over 1.5 - 2 inches thick). In these sections chunky graphite will form. This greatly reduces strengths and elongation. Cerium must be closely controlled. The main advantage of Ce is to reduce the harmful effects of tramp elements such as Pb, Sb, and Ti, which can enter through the scrap stream.

Lead and antimony - Both of these elements promote flake graphite in ductile iron. Their effects are eliminated with a small Ce addition, but good scrap inspection and chemistry control should be practiced to keep them out as much as possible.

Titanium - produces vermicular (CG) graphite and is also a carbide stabilizer in heavy sections. It is not as strong as other elements, so up to about 0.03% can be tolerated with a small Ce addition. Ti comes with pig iron and steel scrap and is not lost upon melting without oxygen additions, so it tends to carry over.

Magnesium - Must be kept as low as possible and while still producing good graphite shape. In sections of ½ to 1" a final Mg of 0.03% should be okay. Mg levels will increase slightly until at about 2" section, it should be about 0.045%.

Sulfur - Level in base ductile iron should be 0.010- 0.015%. Too little will promote carbides in the final structure, also because Mg can be higher. Too much requires a larger Mg addition and the possibility of reduced nodularity.

Metallurgy of ductile iron - Nodularity checks

All separate ladles of ductile iron should be checked for nodularity, by one of the approved methods from the end of the pouring ladle. The sample is then polished sufficiently to reveal the graphite structure. The nodularity should be > 85% in the test sample. Also examination of the nodularity and nodule counts in fractured 1" test bar specimens should also show good nodularity and nodule counts > 100 mm². Good nodule shape and higher nodule counts are indicative of correct chemistry and inoculation practice. This micro-examination should be done frequently to insure quality. Irons with good nodule counts and shape will have less shrinkage and carbide problems.

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Nitrogen in Ductile Iron 2002

By George D. Haley

Corporate Metallurgist

HICKMAN, WILLIAMS & COMPANY

presented at The 2002 Ductile Iron Society Annual Meeting
Pioneer Resort & Marina; Oshkosh, Wisconsin
June 13, 2002

ABSTRACT

This is an update of the information provided in the AFS Transactions 79-58 "Nitrogen Levels in Ductile Iron: AFS Committee 12-H Report".

New information is provided on the effect of magnesium concentrations in treatment alloys, desulfurization, electric induction furnace frequency and cupola melting of base metal. Comments are offered on possible reactions between nitrogen and titanium, aluminum, magnesium and boron.

INTRODUCTION

Information on the nitrogen content of ductile iron has been accumulated over the past few years while working with various foundries. This paper will summarize some of this data.

The **LECO TC 436 inert gas fusion analyzer** was used to perform all the analyses reported. This inert gas fusion analyzer is both fast and accurate. All the nitrogen in each sample is released as molecular nitrogen and its thermal conductivity measured. The instrument is programmed to fuse a weighed sample under a helium atmosphere at a temperature of up to 3000°C. **This analytical method measures total nitrogen** in the sample. Previous nitrogen contents were done using the Kjeldahl method for soluble nitrogen and the Beeghly method for insoluble nitrogen. Wet chemical analysis is almost a lost art anymore and these methods have given way to procedures dominated by faster equipment. Machines and technology have replaced experience, technique and operator skill.

The **samples utilized for analysis were spectrographic chilled discs or pins**. They were broken up to produce the required sample weight. In some cases three samples were run and the results were almost identical. In other cases, one number would occur that was much higher or lower. This was probably due to the presence of segregated nitrides. **Average results reported are probably plus or minus 5 ppm of the amount present.**

Two foundries sampled were melting ductile base in cupolas. Both cupolas were acid lined and the charge contained ductile returns. Foundry "A" desulfurized the iron from 0.08-0.09% sulfur to 0.010% sulfur or less using a **porous plug vessel** patterned after the GM process developed at Defiance, OH. In this process nitrogen gas was injected through four porous plugs in the bottom of the ladle. The dwell time in the continuous treatment ladle was 10 minutes on average. The metal temperature was over 2700°F. Fine calcined lime and spar were fed into the ladle continuously. The nitrogen content of the cupola metal fell from 100 ppm to 82 ppm after treatment. The iron was then put in a holding furnace where no further drop in nitrogen was observed. The magnesium treatment in an open ladle using a 5% alloy resulted in a final nitrogen of 72 ppm.

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Cupola "B" produced a base metal of 82 ppm nitrogen with a sulfur of 0.07-0.08%. **The nitrogen content in the holder further dropped to 65 ppm.** The metal was treated with 5% magnesium wire to desulfurize and nodulize. **This was an excessive use of wire.** The final nitrogen level was 52 ppm. When electric induction melted base iron with a 0.015% sulfur and a nitrogen of 56 ppm was treated with 5% wire the nitrogen content of the treated metal was 58 ppm. **The amount of wire consumed was about half that consumed by the cupola foundry.**

Five foundries that melted base iron in medium frequency induction furnaces reported nitrogen contents in the **41-56 ppm** range with the average in the mid to high 40's. After treatment with 5% MgFeSi the nitrogen contents were about the same or slightly higher, **averaging in the low 50's.** The treatment was done in either open or tundish ladles. One foundry treated in an open ladle with **3% alloy** and the nitrogen **dropped from 48 ppm to 44 ppm.** This was a very quiet reaction.

Another foundry melted a base iron with a 41 ppm nitrogen and **reported a 74 ppm after treatment** using pure magnesium and the **Fisher** process.

Several foundries using line frequency induction furnaces reported nitrogen levels of 57, 56 and 71 ppm. The nitrogen levels held about the same after treatment.

The nitrogen content of Brazilian nodular pig iron for three different lots was reported as 14, 20 and 30 ppm.

DISCUSSION

W.J. Evans, J.C. Harkness and J.F. Wallace reported in their paper "Factors Influencing the Formation of Pin Holes in Gray and Ductile Iron", DIS Project No. 6 (April, 1974) **an estimated solubility of nitrogen**, in a ductile iron of 3.80% carbon and 2.50% silicon, **to be 72 ppm.** The data reported in this study showed that when the **nitrogen content was below** the equilibrium level of **72 ppm** in the base metal the content tended to **increase.** When the **levels were higher they fell** toward the equilibrium point. The exceptions were 1) the **excessive wire treatment** that may have created a high nitride level that floated out and, 2) the magnesium **treatment using 3% MgFeSi.**

The use of the equilibrium value of 72 ppm for total nitrogen makes a nice package of all the data. Most of the gas content levels, changes and results can be related to this value. It has always been taken as faith in ductile iron production that nitrogen content will approach this value due to the flushing effect of the magnesium.

The **increases** reported for the low nitrogen base metals are thought to be **due to pick-up from the air** during treatment as the gas content moved towards equilibrium. The more violent reactions picked up more gas. Whatever the mechanism, **the total nitrogen, soluble and insoluble, moves toward the equilibrium value.**

S. Morita and N. Inoyama reported that **ductile irons of identical composition** were **carbide free and highly ferritic at 25 ppm soluble nitrogen** and **at 37 ppm the iron was carbidic.** Further, they reported that graphite nodules could not be formed and that flake graphite occurred at 60 ppm soluble or mobile nitrogen.

Titanium and vanadium, present in some nodular pig iron, **can practically eliminate soluble nitrogen.** Morita and Inoyama report that, regardless of the nitrogen content of the base iron, **both soluble and**

insoluble nitrogen are nearly **constant at 50 to 60 ppm**, somewhat lower than the Evans number. This is **verified** in the data presented for the **medium** frequency electric furnace induction melted iron.

The reported nitrogen content of **gray** iron is probably mostly soluble nitrogen as it is known that if certain levels are exceeded in the absence of titanium and zirconium, porosity will be present in the castings.

Ductile iron, however, is usually produced with about 50% returns. The magnesium in the returns can form MgSiN₂ nitrides as reported by H. Wada and R.D. Pehlke. The tendency to react with nitrogen is higher for magnesium than it is for titanium, aluminum or boron. This may account for the softening of flake graphite irons when ductile iron returns are included in the charge. Nitrogen is an important alloying agent in gray iron. The increase in graphitic carbon could also be a factor.

In "The Physical Metallurgy of Cast Iron", I. Minkoff reports the following: "The sensitivity of gray, ductile and malleable cast iron to the melting process lies in the influence of small concentrations of impurities on graphite nucleation and subsequent growth. In spheroidal graphite cast iron, after reactive elements, in particular magnesium, have combined with some of the impurities including sulfur, the remaining impurity elements interact with graphite during the solidification process. The concentration of the impurities increases in the liquid due to segregation. **Dissolved gases play a role in this process** and composition control therefore relates to gases as well as all other elements."

Elements such as magnesium, aluminum, cerium, titanium, boron, bismuth, lanthanum, etc. can form a variety of compounds such as oxides, nitrides, sulfides and carbides. The presence or absence of these compounds and their composition can affect the graphite morphology. The effect of oxygen content on nucleation is beginning to be acknowledged. **Nitrogen may have an important if dissimilar role in the process.**

BORON

Where does it come from, what is its effect and how can its effect be controlled?

Boron, when added to a well deoxidized steel, will act as a hardenability intensifier in hypoeutectoid steels (less than 0.77% carbon). Boron oxide and boron nitride are totally ineffective, however, in producing any degree of hardenability. **The boron present that is free of oxygen and nitrogen reduces ferrite nucleation, slows the diffusivity of carbon, reduces the number of nucleation sites and can precipitate as a complex carbide** (this is why boron is considered a strong carbide former in gray iron). Boron steels are favored because they are inexpensive to produce.

Another grade of boron-containing steel used primarily by the auto industry is interstitial free (I-F) **ultra low carbon sheet steel**. This is a superior grade for hot dip galvanizing. This grade has recently seen greatly increased usage. **The boron is added to this grade of steel to tie up the nitrogen.**

Boron treated steels are also utilized for wire drawing. For these steels **the formation of boron nitride is favored** because of its **small inclusion size** and **interstitial dispersion within the austenite matrix.**

Note that controlling the formation of the boron compound produces very different types of steel. Adding boron as ferrobore results in the formation of boron nitride. Adding an alloy of titanium, aluminum, zirconium and boron produces **boron carbide.**

"Russian Castings Production", 1975, contains an article describing the addition of boron and nitrogen to high strength iron. Greatly decreased hardness and chill were observed. Either element added separately had the opposite effect. **The boron nitride formed was thought to act as a graphite nucleus.**

Boron is present in a wide variety of steels. Boron has also been reported in some pig irons. When both items are added to the charge and the recycling of the returns are considered, the boron content may increase to the point that the production of pearlitic grades of ductile iron is hindered.

In ductile iron, boron will combine with soluble nitrogen to form boron nitride. Boron nitride is considered to act as a nucleus for graphite formation. Titanium, as indicated in the example for steel, is a stronger nitride former than boron, consequently, if the magnesium and titanium are present in sufficient quantities to convert all the nitrogen to nitrides, the boron will not form boron nitride. The boron thus will not promote the formation of graphite but it could, however, promote carbides. **If there is soluble nitrogen available, boron nitride will form, promoting graphite nucleation, excessive graphitic carbon and a ferritic matrix.** To counter the presence of boron in the base metal, additional titanium should be added to remove any soluble nitrogen.

CONCLUSIONS

Ductile base iron melted **in medium frequency** electric induction furnaces with graphite recarburizers and approximately 50% ductile iron returns with the balance steel or steel and pig iron, **will produce a nitrogen content in the 41-57 ppm range.** The average was in the high 40's.

Line frequency electric furnace melting of ductile base appears to produce an iron with a **nitrogen content of about 55 ppm.**

Treatment with **5% MgFeSi** tends to raise the nitrogen content of irons when initial concentrations are in the 40-50 ppm range. **3% MgFeSi** treatment alloys do not raise the nitrogen levels even when the base iron is very low.

Cupola melted base iron, when large amounts of ductile iron returns are utilized, **produce nitrogen levels of 80-100 ppm.**

Treating the cupola iron in a **desulfurizing vessel** using lime spar results in a 20 ppm drop in nitrogen content.

The nitrogen content of the base iron in the holding furnace was observed to drop when the cupola iron went directly to the holder. This was probably due to nitrides floating out. When the iron went through the desulfurization vessel the nitrides present were flushed out and no further loss was experienced in the holder.

No meaningful difference in nitrogen content could be detected between open and tundish ladles.

It is proposed that **if the formation of boron nitrides can be prevented,** boron should not hinder the ability to produce pearlitic ductile iron that meets the required mechanical properties. The **addition of titanium** to prevent the formation of boron nitrides is **suggested.**

It is concluded that **most of the nitrogen present in ductile iron is in the form of insoluble nitrides.** The total nitrogen reported is related to the **equilibrium value of 72 ppm,** as stated by Evans, Harkness and Wallace.

The nitrogen content either increases or decreases depending on its relationship to the equilibrium value.

The 50-60 ppm nitrogen value reported by Morita and Inoyama **was consistent for electric induction melted ductile iron.**



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Inoculation

Do you inoculate your iron?

You probably do, since it is an essential part of most foundry operations. Aside from reducing chill, inoculation promotes the uniformity of properties throughout varying section sizes, as well as improves machineability and strength. Calcium bearing 75% Ferrosilicon is a common inoculant. In addition, there are several proprietary inoculants on the market.

Control of this inoculation practice is very important. The correct technique must be used to obtain satisfactory and consistent results.

Let's look at some basic procedures of an inoculation practice.

Do's and Don'ts of Inoculation Practice

DO:

- ▶ Keep the inoculant dry.
- ▶ Accurately meter the amount of inoculant addition by weight or volume.
- ▶ Properly weigh the amount of metal to be inoculated.
- ▶ Devise mechanical or automatic means of adding inoculants to the ladle.
- ▶ Check the efficiency of gray iron inoculation by chill tests taken at the pouring station.
- ▶ Code castings so that they can be related to test pieces.
- ▶ Remove all slag from the metal surface before making the inoculant addition.

DON'T:

- ▶ Make unnecessary large additions of inoculant.
- ▶ Attempt to inoculate metal of low temperature.
- ▶ Hold inoculated iron for varied or prolonged periods.
- ▶ Collect metal test samples from the immediate surface of a ladle of metal.
- ▶ Rely on melt department personnel to make regular additions of inoculant while collecting metal from the furnace.
- ▶ Place inoculant in the bottom of an empty ladle that is to be refilled.

Submitted by Tom Davies and Mike Morrison; Carpenter brothers, Inc.

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FOR IMMEDIATE RELEASE
JUNE, 2002

College Industry Conference November 7-9, 2002, Drake Hotel, Chicago, IL

One of the highlights of the year for metal casters is the annual Foundry Educational Foundation College Industry Conference.

o Speakers

- The Keynote address will be given by Roger Stanbridge, President of Foseco.
- The panelists this year will be Andrea Kay of EST Co. (Div. of Pace/Leggett & Platt), Matt Cribbs of Bosch Braking, and Bill Powell of Waupaca Foundry. Each represents a different stage in work experience and will discuss their outlook for the future of the industry.
- Nancy Zimpher, Chancellor of the University of Wisconsin-Milwaukee, will be the Awards Breakfast speaker.

o Industry Information Session

All companies are invited and encouraged to participate in the Industry Information Session on Friday, November 8. This unique opportunity allows your company to see and be seen by over 130 of the top engineering students in the country, all of whom have already expressed an interest in our industry. Even if your company is in a non-hiring year, your presence will give students an important view of companies that are working with castings and who are interested in their future. If you are hiring, this is the most cost-effective way to have access to many students in one afternoon in one location.

o FEF Annual Banquet

This year, through the outside sponsorship of companies and individuals, the Annual Banquet will be held at the Crystal Gardens on Navy Pier in Chicago. Join us for a delicious meal, special industry awards, and the opportunity to visit one of Chicago's premier attractions, including shops and shows.

o Awards Breakfast

The finale of the conference is the Awards Breakfast on Saturday morning when over \$30,000 in special scholarships will be awarded.

For More Information contact the FEF Office at 847/299-1776;
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Monday Morning Iron - Phase I

Restoring Techniques for Monday Morning Iron - Phase I

Submitted by: *Jim Mullins Technical Director*

The primary work was done by M. Popescu from Materials Technology Laboratory (CANMET), Ottawa, Ontario, Canada and the results presented to the public at the AFS Convention in Kansas City, May 2002. A complete report is available from AFS and is copyrighted by them.

The project was commissioned by the AFS 5L committee on Molten Metal Processing to answer a number of questions regarding the holding of ductile base (prior to treatment) iron on the "Monday morning effect" and the effect of this on the nucleation potential and possible promotion of carbides and shrinkage. Note that experiments were also run on grey iron, but not reported upon in this summary.

Heats of ductile iron were produced using 10% pig, 40% steel, returns and trim additions of C & Si. Originally the heats were melted and held in a 220 pound induction

Crucible, but the C & Si losses were high so a second set of experiments were done in a larger furnace of 550 pounds capacity utilizing a synthetic slag cover to minimize losses and variation. Holding was done at three temperature levels; 2456°F, 2565°F, and 2709°F. The chemical composition was to be held consistent, but this proved impossible over the holding time of up to 10 hours, so some trimming was done at the end of the holding periods in one data set to normalize the results.

All test samples were made in CO₂ bonded silica sand molds. Pouring temperatures of the test molds were relatively low (2460°F typical maximum) even from the heats with the highest holding temperatures, since no heating up was allowed from the holding temperature.

The conclusions drawn were as follows:

1. The higher temperature of holding contributed to changes in chemistry at all three levels of holding temperature. The changes depended upon the holding temperature and the synthetic slag protection. At higher temperatures carbon decreased and silicon increased slightly. At lower temperature both elements decreased slowly. There wasn't much difference in chemistry at the two lower temperatures.
2. All trimming performed on the base irons had re-nucleation effects that were picked up in the mg treated final results. Test samples taken at the end of the holding period, from the base iron and the final iron, both before and after trimming, show that the nucleation potential of the base iron affects the final nodule counts. The project did show that ductile base iron having a good nucleation potential generated higher nodule counts in the final structures. They surmised that a systematic control of the base iron microstructure and chilling tendency could predict the metal quality before the magnesium treatment, but said that more investigative work should be done in this area.

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3. Examination of final microstructures of test samples with similar carbon equivalents indicated the holding time at lower temperatures (2456 & 2565) increased the nodule counts (some had trimming additions), while holding at high temperature (2709) did not seem to have any effect on the nodule count.
4. While the holding time did not seem to affect the matrix in the 1 inch samples, the microstructural study indicated that holding at lower temperatures encouraged more ferrite formation in 6 & 9 mm diameter samples. However these also had higher nodule counts.
5. The 5 % MgFeSi plus 1% TRE used for treatment and the 75% FeSi used for inoculation had strong nucleation effect, which seems to make the ductile iron less susceptible to the holding time effect compared to grey irons.

DIS comments about this topic and conclusions are:

1. Holding temperature was relatively low for two out of three temperatures studied. Holding at the lowest possible temperature for your operation is always best as less alloy losses occur and nucleation is changed less. Holding time after superheat should also be kept as short as possible before pouring.
2. Trimming additions had a re-nucleation effect. So it is possible to return the base iron to normal nucleation levels. This is true even as wedge values go to very high numbers. Using small additions of carbon, silicon, silicon carbide and pig iron can reduce the base chill value.
3. Checking base iron chill values so that there is a known base value is important. This can be done with chill wedges or with thermal analysis techniques.
4. Checking chill values when there is additional holding time due to breakdowns, etc, can tell you what needs to be done to re-nucleate the melt to avoid low nodule counts, carbides and sporadic shrinkage.
5. Starting with a good charge and keeping a good nucleation value carries through to the final iron and keeps high nodule counts.



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Newest Developments in Sand Testing

Mary Beth Krysiak, DISA Industries Inc.

(Click on Figures to see enlarged view)

In recent years there have been several advancements made in the area of sand testing and control. Some of these advancements involve incorporation of more modern technology to conventional sand tests, others involve development of new tests and equipment to address current challenges in sand control.

Example of an advancements involving incorporation of more modern technology to conventional sand tests include the development of more modern permeters and strength machines (**Figures 1 and 2**).



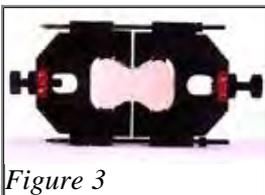
Modern strength machines utilize load cells for measuring sand strength characteristics, and modern permeters use new air flow technology for measuring permeability. In addition, these modern devices provide digital readouts of the data and allow exportation of the data to PC computers so that trends can be identified more quickly, leading to better control.

An example of the development of new tests to meet current challenges

includes the introduction of the disc transverse test for testing of chemically bonded sands. First introduced to foundry sand control by Prof. D. Boenisch, this test offers a new alternate or supplement to tensile strength.



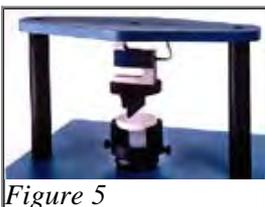
Figure 2



Tensile strength has been the conventional test used to control the strength characteristics of the sand, but the tensile strength test is quite variable as far as repeatability, and is not sensitive enough to humidity which can cause deterioration of cores. **Figure 3** shows the conventional tensile strength specimen (often

referred to as a "dog bone" specimen. **Figure 4**

compares it to the new disc transverse specimen which is 50 mm diameter x 8 mm thick. **Figure 5** shows how the disc is supported on its edges and loaded across its diameter in the disc transverse



strength test. The new disc transverse test offers several advantages over tensile strength including better repeatability due to a more consistent plane of failure, better simulation of stress that



Figure 4

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can cause core breakage, especially to many of today's thin and complex cores such as water jacket cores (**Figure 6**).

The stress is better simulated because rarely are cores pulled apart as dog bones are in the tensile test. When thin, problematic cores break, the stress causing the core breakage is usually more similar to the stress applied in the disc transverse test. Another advantage to



Figure 6



Figure 7

this test arises from the fact that the disc transverse specimen is thin. As Boenisch pointed out, when a core is first prepared, when it leaves the core box, the strength gradient will resemble **Figure 7**. The exterior will have the highest strength where the core was in contact with the core box when blown, while the interior will have slightly less density and strength. After a core is stored, however, and its surface is subjected to the

effects of humidity, the strength gradient can invert, producing a strength gradient as shown in **Figure 8**. If a thick core specimen, such as a dog bone is tested for this effect, the effect can be masked by the high strength interior, and the degradation, which is a surface effect, can go unrecognized. A final advantage of this test is its simple shape, a simple disc 50mm in diameter and 8 mm thick. Because this shape does not have critical contours like the dog



Figure 8

bone, it can very easily be incorporated into production core boxes. Incorporating the test specimen into the core box allows several advantages. Differences in core machine or core box performance can be identified. Vent locations can be optimized to produce the highest density and strength. Disc specimens can also be left with the cores, if cores are stored, and if degradation due to humidity is a question, controls can be set up to specify a maximum shelf life or a minimum disc transverse strength. This type of control program would be much better than the conventional program of testing the sand mixture in the laboratory. While a sand mix can produce good laboratory strengths, the same sand mixture can produce bad cores in production if the core is not blown well, or if the cores are subjected to humidity during storage.

Another common challenge facing U.S. foundry men today is in dealing with the affects of core sand dilution. Today, the core binders used break down rapidly and thoroughly at the pouring temperatures resulting in a much higher influx of burned core sand entering the sand system at shakeout. This results in the formation of brittle sand. Core sand dilution is not the only cause of brittle sand, as hot sand, poor moisture clay relationships and even excessive new sand additions can also cause brittle sand. In dealing with brittle sand and the effects of core sand dilution, there are two types of effects; effects of condensates, and effects on rebonding.

Effects of condensates are chemical effects that result from a waterproofing of the clay. As shown in **Figure 9**, water molecules, which are polar, orient themselves between the clay platelettes and they move in and out as the clay is hydrated and

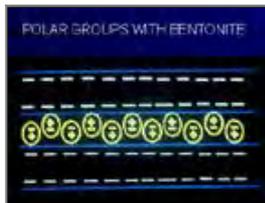
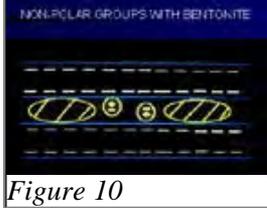


Figure 9

dehydrated. If organic condensates accumulate in the



bentonite, however, these organic condensates can hinder the movement of the water molecules in and out from between the clay platelets as illustrated in **Figure 10**. This produces a

waterproofing effect that deteriorates the properties of the molding sand. The wet tensile test, **Figure 11**, is sensitive to this type of deterioration. In this test, as illustrated in **Figure 12**, a specimen is formed in the specimen tube and the specimen has a taper on the one end which fits into a lift off ring. During the test, the end of the specimen with the ring is

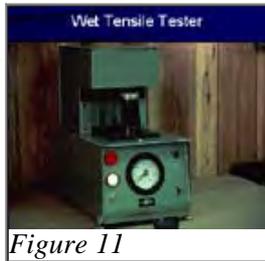


Figure 11

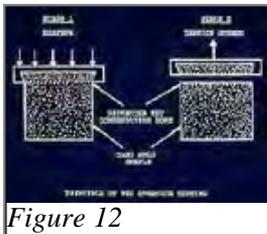


Figure 12

subjected to a heat, and the heat drives the moisture in the sand back, creating a wet layer or condensation zone. This simulates what happens in the mold from the heat of the molten metal. A tensile stress is then applied to the lift off ring, and the wet tensile strength, or the strength of the wet layer is measured. Wet tensile strength is critical because it represents the weakest layer in the

mold. Failure of the wet layer produces expansion defects such as scabs, buckles and rattails.

When condensates build up in the molding sand, wet tensile strength drops off. It must be understood, however, in applying the wet tensile test, that wet tensile strength is affected by the bond formulation if a blend of Western and Southern bentonite are used (**Figure 13**). The higher the amount of Western bentonite, the higher the wet tensile strength. The more Southern bentonite there is in the blend, the lower the wet tensile strength. Wet tensile strength lower than that predicted by the bond formulation then can signal effects of condensates, and can indicate that not enough new sand and clay are being added to the sand system to dilute this effect.

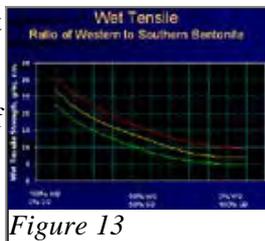


Figure 13

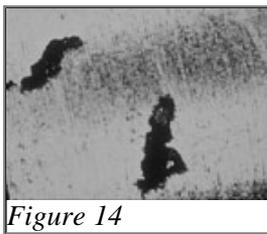


Figure 14

Another condensate from core binders is ammoniacal nitrogen (depending on the chemistry of the binder system employed). Some core binders give off ammonia as a decomposition product when they pyrolyze. This ammonia can

become absorbed in the clay in the molding sand and can be picked up by the molten metal and rejected during solidification to cause subsurface nitrogen fissure defects (**Figure 14**). **Figure 15** shows a ammoniacal nitrogen tester that can be used to measure ammoniacal nitrogen in molding sand. **Figure 16** shows several sand systems along with their ammoniacal nitrogen contents and



Figure 15

Ammoniacal Nitrogen and Nitrogen Fissure Defects		
Sample	Ammoniacal nitrogen ppm	Reported Fissures
A	81	Yes

B	36	No
C	30	No
D	9,5	No
E	32	No
F	25	No
G	195	Yes
H	107	Yes
I	81	Yes
J	83	Yes
K	61	Yes
L	73	Yes

Figure 16

whether or not nitrogen fissure defects were being experienced. With the exception of the first system which went through both good periods and bad periods, the remaining systems fell into two categories based on the presence or absence of the defect. The systems with ammoniacal nitrogen levels over 60 ppm were all reported to produce the defect, while those that ran below 60 ppm did not produce the defect. So as a general guideline, ammoniacal nitrogen levels over 60 ppm indicate the sand is prone to producing nitrogen fissures. The main source of ammoniacal nitrogen is from decomposition products of certain core binders, especially hot box binders cured with ammonium salt catalysts, shell binders, and phenolic urethane cold box binders as well as others.

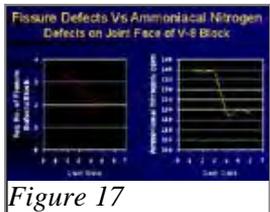


Figure 17 shows results of a case study from a foundry in Australia that was at one time running as high as 200 ppm ammoniacal nitrogen and which was experiencing severe problems with nitrogen fissures on a joint face of an engine block. The foundry was using a hot box binder at the time, and due to the problem, eventually switched to a warm

box binder. **Figure 17** shows the ammoniacal nitrogen level dropping along with the occurrence of the defect. Core binders are not the only source of ammoniacal nitrogen, however. Sometimes it appears from unexpected sources. In one foundry, it came from a woodflour that was from particle board. The resins and glues in the particle board were the source of the ammoniacal nitrogen and when the foundry switched to a woodflour containing only natural wood fibers, the problem disappeared. In another case, ammoniacal nitrogen came from well water that became contaminated from fertilizer.

Effects on rebonding are a physical effect of core sand dilution. Certain core binders leave a layer of lustrous carbon on the sand grain that can inhibit clay bonding. **Figure 18** shows core sand grains that were exposed to heat with no lustrous carbon



Figure 18

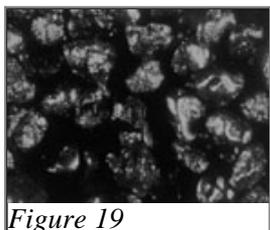


Figure 19

formation, whereas, **Figure 19** shows core sand grains that were left with a layer of lustrous carbon after exposure to heat. Whether or not lustrous carbon forms on the sand grains is largely dependent on the binder chemistry (phenolic urethane binders have the highest tendency to produce lustrous carbon) and the amount of oxygen present when the binder

pyrolyzes. If lustrous carbon is a residual left on core sand grains, when the core sand enters the greensand system at shakeout and eventually goes into the muller, it will be difficult to mull the clay onto the sand grain because

lustrous carbon is almost like a lubricant. Negative effects on rebonding are difficult to detect with the conventional tests, such as green compression. The most sensitive tests to detect these effects include the friability test, and the cone jolt toughness test.

Figure 20 shows the friability test. In this test, two standard test specimens are rotated in a screen for one minute, and the weight percent of sand that abrades from the surface is measured. Molding sands that have a high friability are prone to producing erosion and inclusion type defects. Generally, under 10% friability is considered good. Molding sands that run over 10% friability are generally prone to erosion and inclusion type defects, because the molding sand cannot withstand the erosive flow of the molten metal.

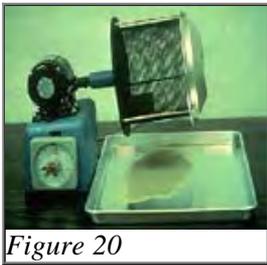


Figure 20

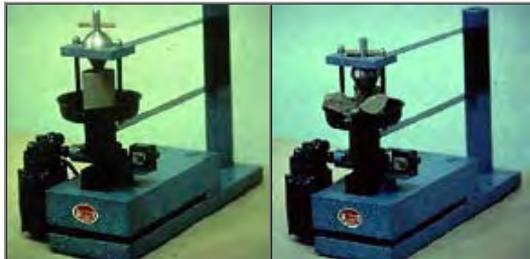


Figure 21

Figure 22

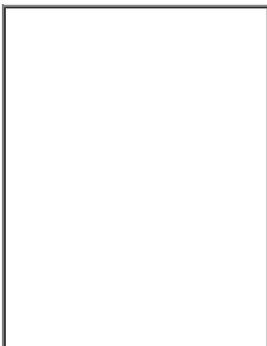
The cone jolt toughness test is shown in **Figures 21 and 22**.

In this test, a standard specimen is formed with indentations in the top and bottom. The bottom indentation accommodates a centering pin on the test platform of the instrument, while the top indentation

accommodates the rounded point of a cone shaped weight. In the test, a cam raises the test platform and then drops it repeatedly. The specimen is then subjected to a jolting action, while its top is under the weight of the cone. Eventually, the specimen fails and the number of jolts until failure is recorded. Molding sands that fail with less than 40 jolts are considered brittle and are prone to difficulties in pulling deep pockets in a pattern/broken molds. Molding sands that have a high influx of burned core sand often have very low cone jolt toughness. Cone jolt toughness, in contrast with friability which is a measure of surface brittleness, measures the bulk brittleness characteristics of the molding sand. Neither friability nor cone jolt toughness directly correlate with green compression. Some molding sands with high green strengths are actually very brittle and friable and are prone to producing molding difficulties in addition to erosion and inclusion type defects.

There are ways to reduce the effects on rebonding, including increasing the clay level prior to running heavily cored jobs, ensuring good mulling, mulling at a slightly higher compactability, adding or increasing Western bentonite, and adding a limited amount of moisture (less than 2.0% prior to the silo). Another tip in reducing effects of core dilution is to ensure that all lumps in the return sand are reduced to grain size, and avoidance of shakeout systems that produce lumps.

Another fairly recent advancement has been made in the area of controlling incoming bentonites and preblends. **Figure 23** shows a soluble and leachable calcium and magnesium determinator that can be used for this purpose. This unit measures the soluble salts and exchangeable ions that affect the physical properties that the bentonite will develop in the sand mixture. Ensuring that the soluble salts and exchangeable ions are consistent provides assurance that the bentonite or preblend will perform



consistently.



Figure 23

Soluble and leachable calcium and magnesium, Southern Bentonites, Meq/100g bentonite

Region	Soluble Calcium	Soluble Magnesium	Leachable Calcium
Lebanon	52 - 65	10 - 16	80 - 72
Alabama	57	13	84
Aberdeen	60 - 70	4 - 9	100 - 134
Mississippi	64	7	117

Figure 24

Figure 24 shows typical values for Southern bentonites. Note that by observing leachable calcium, one can distinguish between Southern bentonite from Alabama versus Southern bentonite from Mississippi. Typical values for Western bentonites are shown in Figure 25. Note that there are high magnesium and low magnesium Western bentonites.

Figure 26 shows the values obtained on an incoming preblend containing Southern bentonite and sea coal over various dates. It can be seen that the incoming preblend was consistent and consistent performance could therefore be expected. It also shows, from the leachable calcium figure, that the preblend contained the Alabama Southern bentonite as opposed to the Mississippi Southern bentonite. There are no other simple tests that provide this information.

Soluble and leachable calcium and magnesium, Western Bentonites, Meq/100g bentonite

Sample	Soluble Calcium	Soluble Magnesium	Leachable Calcium
A	11 - 11	1 - 1	23 - 28
	62	2	38
B	18 - 24	2 - 4	23 - 23
	58	3	31
C	18 - 24	2 - 4	28 - 28
	22	3	42
A2	15 - 26	7 - 13	46 - 105
	68	18	88
C2	18 - 28	11 - 18	38 - 58
	75	14	55

Figure 25

Soluble and leachable calcium and magnesium, In a Consistent Preblend, Meq/100g bentonite

Date	M.S. Res. %	Soluble Calcium	Soluble Magnesium	Leachable Calcium
3/23/87	79	50.0	12.9	66.4
4/07/87	38	58.0	15.8	65.8
5/02/87	78	57.3	13.3	61.5
6/12/87	29	57.1	12.1	64.8

Figure 26

Figure 27 shows an example of inconsistent shipments of Western bentonite supplied to a

f foundry in Canada. When laboratory mixes were prepared using the two different clays, the hot strength data, also shown in Figure 27, confirmed that the bentonites would produce different physical properties. If using the first bentonite, and then suddenly and unexpectedly supplied with the second bentonite, the molding sand properties would begin to change as the new bentonite was slowly introduced as new clay added at the mixer. This may necessitate changes in moisture, bond level, or other system parameters, in order to maintain sand within specifications, and may even contribute to molding difficulties and/or casting defects.

Hot Compressive Strength of Laboratory Mixes Prepared from a Variable Shipment of Western Bentonite, Meq/100g bentonite

Sample	Moisture (%)	Bond (%)	Hot Comp. (psi)	Hot Comp. (MPa)
1	17.4	91	112.8	7.8
			1000	70
			1000	70
			1000	70
			1000	70
2	16.1	85	107.8	7.6
			1000	70
			1000	70
			1000	70
			1000	70

Figure 27

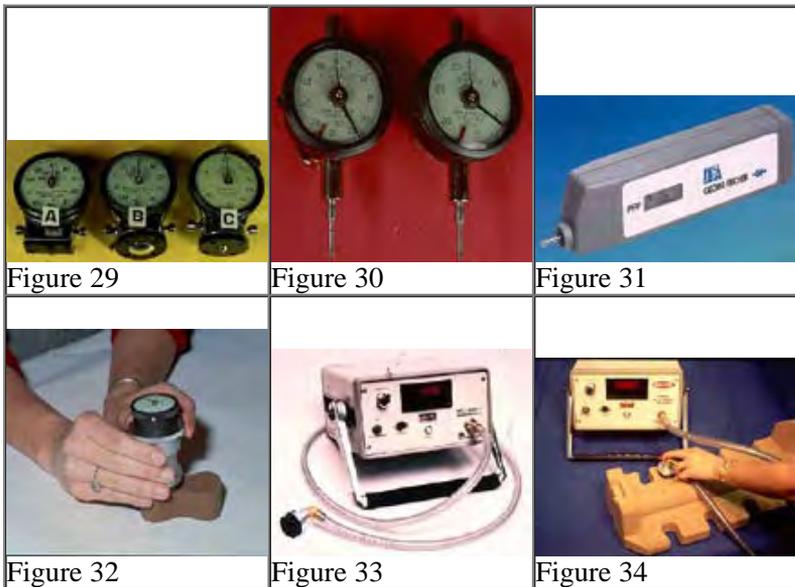
Formulation Check on Two Preblend Samples, Meq/100g bentonite

Sample	Moisture (%)	Bond (%)	Hot Comp. (psi)	Hot Comp. (MPa)
Western	17.4	91	112.8	7.8
Southern	16.1	85	107.8	7.6
Preblend	16.7	88	110.3	7.7
Preblend	16.7	88	110.3	7.7
Preblend	16.7	88	110.3	7.7
Preblend	16.7	88	110.3	7.7
Preblend	16.7	88	110.3	7.7
Preblend	16.7	88	110.3	7.7

Figure 28

Figure 28 shows application of the test to a preblend containing Western bentonite, Southern bentonite and carbons. A particular foundry was using preblend from two different suppliers, and while the formulation for the preblend was identical for the two suppliers, the performance was different. When using a preblend identified as Bond #1, the foundry experienced severe mold break up after pouring. When using Bond #9, there was no problem. The foundry suspected that Bond #1 contained more Southern bentonite than specified by the formulation and that the low hot strength of Southern bentonite was creating the problem. The top two rows of data show the base values obtained on the raw Western and Southern bentonite used in Bond #1. The next row shows the theoretical

values that were calculated from the base values and the preblend formulation. The next row of data shows the actual data obtained when testing Bond #1. Since the theoretical values matched extremely well with the actual values, this proved that the preblend was properly prepared according to its formulation, and there was not more Southern bentonite in the preblend as suspected. Examining the values for Bond #9, shown in the last row, indicates that there was a difference between Bond #1 and Bond #9. Bond #9 apparently contained a low magnesium Western bentonite. In general, low magnesium Western bentonites have higher hot strengths. It is important to point out that this does not suggest that high magnesium Western bentonites are inferior. Many foundries use high magnesium Western bentonites quite successfully, and even prefer them due to better shakeout. The point here is that these tests can be used to check preblend formulations and raw bentonites for consistency as an incoming material test.



Figures 29 - 34 show various mold test tools that can be used to monitor mold and core quality. **Figure 29** shows mold hardness testers, the B scale being the most common. This is a good mold test tool for low pressure greensand molds. **Figure 30** shows mold strength testers for high pressure greensand molds. **Figure 31** shows an electronic mold strength tester that is digital and has no delicate indicating hands that can become damaged or bent by misuse. **Figure 2** shows a scratch hardness tester that can be used on chemically bonded sand. **Figures 33 and 34** show the Mold Quality Indicator which can be applied to greensand or chemically bonded sand.

The Mold Quality Indicator is different than the other mold test tools in that it does not measure strength. The Mold Quality Indicator measures how open or porous the mold or core is. The higher the reading, the less porous, and more dense (grain to grain), the mold or core. This test is very similar to the old mold permeability test, except that the readings are the reverse (dense molds have lower permeabilities), and the MQI package is more portable and uses more modern technology including a digital readout. **Figure 35** shows that for a given sand fineness, the higher the MQI reading, the higher the mold or core density. To compare apples to apples then, one must compare the same grade of sand. Comparing different grades could be misleading unless charted as in **Figure 35**.

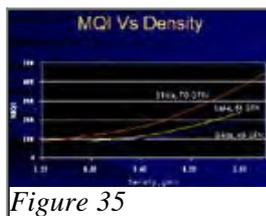


Figure 35

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Test Casting Results
Furan No-Bake
Compaction Varied

Core	Time	Eq. Secs	Dens. (lb/cu in)	MQI	Penetration (in)	Rocky	Defects
10	10	10	1.82	123	3.0	1.0	1.0
8	10	10	1.76	103	2.5	1.5	1.0
6	10	10	1.46	109	3.0	2.0	1.0
4	10	10	1.36	67	5.0	5.0	1.0

Ramming System: 1) 10-Ram, 2) 8-Ram, 3) 6-Ram, 4) 4-Ram
Time: 10 Secs

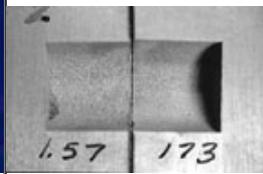
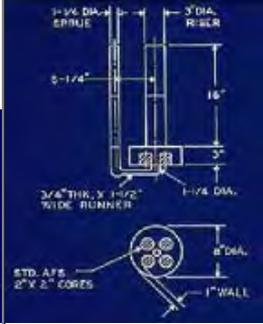


Figure 36

Figure 37

Figure 38

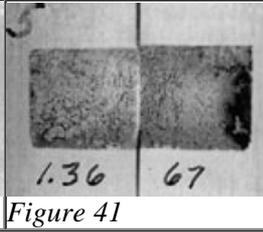
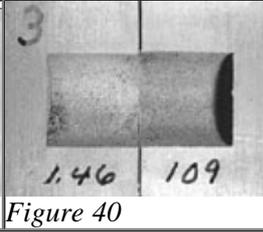
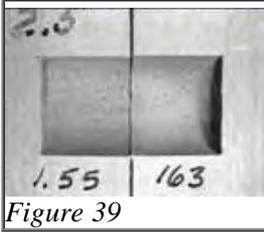


Figure 39

Figure 40

Figure 41

Figures 36 through 41 show how MQI, unlike any other sand test such as green compression, has a definite relationship to casting quality. In a laboratory test, furan no-bake specimens were prepared at different densities (number of rams) and different work times (Figure 36). Figure 37 shows a schematic of a Gertsman Penetration Test Casting that the core specimens were placed in. This test casting provides a very severe test for metal penetration. Figures 38, 39, 40, and 41 show the cored cavities in the test casting that were produced from the 10 ram, 8 ram, 6 ram and 4 ram specimens, respectively, with the MQI reading indicated in the lower right corner of each picture. It is very evident that as the ramming decreased and the sand aged, the MQI dropped and penetration increased.

A case study on application of the Mold Quality Indicator to greensand appeared in a paper entitled "Quality Improvements in Greensand Using the Mold Quality Indicator" by L. Hastings, Fahramet, Kubota Corp. In this particular case study, the foundry wanted to eliminate the need for a facing sand by obtaining higher compaction on their system sand. They monitored MQI on 53 molds over a 7 day period and rated them in terms of surface finish (Figure 42).

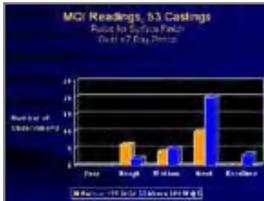


Figure 42

They found that the best results were obtained when MQI was over 155 in their particular case. Next, they selected a pattern with several flat areas on both horizontal and vertical surfaces (Figure 43). They made a mold at their standard jolt and squeeze times of 7 and 8 seconds and the average MQI was 149.9

(Figure 4). They increased both the jolt and squeeze times to 10 seconds and made another mold and the average MQI increased to 168.4. Figure 46 shows the casting results from these molds, which indicate an improvement on the vertical faces of the mold. They then ran at the new jolt and squeeze time for one month and reported a noticeable improvement in surface finish, especially on the vertical faces, and that roughness was rarely encountered. When roughness did occur at the new settings, it was felt to be more temperature related than compaction related. They consistently hold the MQI over 155 and reported that they find less need to "tweak" the system for clay content, moisture content, etc. They found that getting good compaction was half the battle. By using the MQI, they were able to optimize compaction and

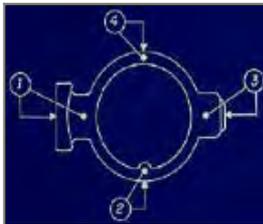
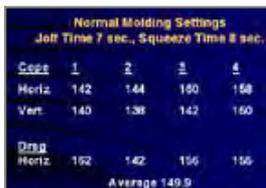


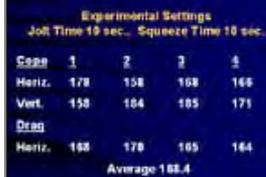
Figure 43

improve surface finish. The foundry then also decided to apply the instrument in their no-bake area as part of a continuing quality improvement program.



Normal Molding Settings				
Jolt Time 7 sec., Squeeze Time 2 sec.				
Core	1	2	3	4
Horiz.	142	144	150	158
Vert.	140	138	142	160
Disp.				
Horiz.	152	142	156	156
Average 149.9				

Figure 44



Experimental Settings				
Jolt Time 10 sec., Squeeze Time 10 sec.				
Core	1	2	3	4
Horiz.	178	158	168	168
Vert.	158	164	185	171
Disp.				
Horiz.	188	178	165	164
Average 168.4				

Figure 45

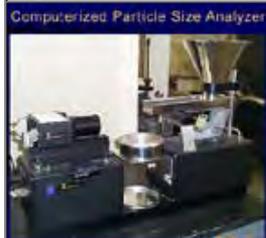


Figure 46

Figure 46 shows another area in which advancements are being made in the area of sand control. Sieving has been the conventional test for controlling sand fineness, but it is widely known that sieve analysis results are variable from sieve stack to sieve stack, from technician to technician, and from laboratory to laboratory. This presents many problems, especially when applied as an incoming material check between supplier and foundry.

Today, new technology utilizing photo-optical particle size measurement is being introduced to foundry sand testing and control (Figure 46). This technology measures the particle diameters of sand grains as they fall in front of a camera that samples at very rapid speed. This provides more true particle sizing that is not subject to error from oversize openings that exist in sieve analysis. The photo-optical data can be correlated to sieve analysis, however, in order to provide a comparison and a common frame of reference to sieve analysis. The technology also significantly reduces testing time in addition to automating the particle size and distribution analysis.

In conclusion, sand quality is of fundamental importance to casting quality. Considering the cost of re-work and scrap, no foundry can afford to be operate without a good sand testing and control program. Advancements in the technology available today, along with the changing needs in sand control that occur with changes in sand systems, and the ever more stringent quality demands shape the development of new tests and equipment for monitoring and controlling sand and casting quality.



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News Briefs

MEETINGS

The **World ADI Conference** will be held on September 25-27, 2002 at the Galt Hotel in Louisville, Kentucky.

The **June 2003** meeting has not been scheduled yet.

There will be a **Keith Millis Symposium** on October 20-23, 2003 at the Crowne Plaza Resort in Hilton Head Island, South Carolina.

PEOPLE

Dublin, Ohio (USA) - **Ashland Specialty Chemical Company** has announced that **Michael J. Shannon** has been named senior vice president. James A. Duquin, president of Ashland Specialty Chemical Company, made the announcement.

Dublin, Ohio (USA) - **Ashland Specialty Chemical Company** has announced that **Marcello Boldrini** has been named to the newly created position of vice president of marketing and business development. James A. Duquin, president of Ashland Specialty Chemical Company, made the announcement.

Dublin, Ohio (USA) - **Ashland Specialty Chemical Company** has announced that **Carl Scaccia** has been named vice president of Commercial Development. James A. Duquin, president of Ashland Specialty Chemical Company, made the announcement.

BUSINESS

Grede Foundries, Inc. Earns ISO 14001 Registration at All U.S. Locations

Leading Independent Foundry Company
Demonstrates Commitment to Environmental Standards

Milwaukee, Wisconsin - **Grede Foundries, Inc.** of Milwaukee, Wisconsin, recently completed ISO 14001 registration for environmental standards at all of its nine U.S. foundry locations. Each facility went through a rigorous registration process that includes review of the location's Environmental Policy and Environmental Management System by an independent registrar. Grede Foundries operates plants in the following U.S. locations: Wauwatosa, Milwaukee, and Reedsburg, Wisconsin; Kingsford and Vassar, Michigan; Wichita, Kansas; Greenwood, South Carolina; New Castle, Indiana; and St. Cloud, Minnesota.

"In the areas of pollution prevention and environmental performance, our goal is to meet or exceed regulatory requirements and lead the

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industry," said Jim White, director, Safety, Health, and Environment, Grede Foundries. "Undertaking the ISO 14001 process across the country demonstrates Grede's commitment to environmental standards and to being good neighbors in the communities where we operate. "

ISO 14001 is an international standard that defines the basic requirements of an Environmental Management System, including an Environmental Policy, setting environmental objectives, operational controls, management review, corrective action procedures, and continuous improvement.

Grede Foundries is an industry leader in developing ways to beneficially reuse foundry byproducts, which avoids landfill disposal and conserves natural resources. The Company's byproducts are actively being used as construction fill and in materials such as asphalt and concrete.

Based in Milwaukee, Wisconsin, Grede Foundries specializes in ferrous metals: gray iron, ductile iron, and steel castings. The Company also has operations in the U.K and Mexico. Grede Foundries supplies castings to the automotive, air conditioning, construction, farm, and mechanical power equipment markets, as well as other industries. For more information, visit its Web site at www.grede.com.

Dublin, Ohio (USA) - **Ashland-Avebene S.A., an affiliate of Ashland Specialty Chemical Company, a division of Ashland Inc.**, recently purchased the foundry business of Furtenbach S.A., a French subsidiary of the Austrian-based Furtenbach Group. Terms of the agreement, which closed May 27, 2002, were not disclosed. The newly acquired business will operate within Ashland Specialty Chemical Company's Foundry Products Division.

Foseco and Corning celebrate 20 years of their North America partnership in iron filtration technology... with more to come.

CLEVELAND, OH and CORNING, NY: August 26, 2002--**Corning and Foseco**, pioneers in the introduction of iron filtration in North America, announce the 20-year anniversary of the partnership that launched this technology.

In conjunction with this milestone, Foseco and Corning also announce that a multi-year agreement has been reached naming Foseco as the exclusive North American distributor of Corning extruded molten metal filters marketed under the Celtex® trademark. Since 1982, Foseco and Corning have collaborated to bring the benefits of filtration to production of a continuously growing range of iron castings.

"I have been privileged to be involved in this partnership from day one," said Hugh Kind, Foseco's Vice President of Marketing. " The advent of filtration gave the industry new tools to manufacture higher-quality castings at lower cost. The combination of Foseco's direct support to customers and Corning's manufacturing and ceramics research and development have enabled our customers to obtain these benefits. Our shared commitment to technology and production investment has moved filtration strategy from problem solving to standard practice. Corning's extruded cellular filters are the

most widely applied filters in North American iron foundries. Corning and Foseco will continue to refine product and application technologies to further expand their use and the value delivered to our customers."

Steven P. Suttle, Vice President and General Manager, Corning Environmental Technologies, said, "We are extremely pleased that we can continue delivering a full range of premium-quality, high-performance filters to customers in co-operation with our long-time North American distribution partner, Foseco."

Foseco Metallurgical Inc. of Cleveland Ohio is a member of the worldwide group of Foseco companies that has provided innovative solutions to foundries for the past 70 years.

Established in 1851, Corning Incorporated (www.corning.com) creates leading-edge technologies for the fastest-growing markets of the world's economy. Corning manufactures optical fiber, cable and photonic products for the telecommunications industry; and high-performance displays and components for television, information technology and other communications-related industries. The company also uses advanced materials to manufacture products for scientific, semiconductor and environmental markets.

® CELTEX is a trade mark of the Foseco Group of Companies.

Troy, Michigan, June 24, 2002 - **INTERMET Corporation** today said that the casting industry is experiencing a surge in secondary aluminum and scrap steel prices.

The recently implemented U.S. steel tariffs have effectively reduced supply at a time when steel consumption is on the rise. As a result, during the second quarter, INTERMET has incurred a 20-percent price increase for scrap steel when compared to the first quarter of this year. Steel scrap is a primary melt component used in casting ductile-iron automotive components. The company now expects to absorb approximately \$1.5 million in scrap price increases in the second quarter before surcharge pass-through contracts take effect in the third quarter. Material pass-through contracts typically have a 60-90 day lag before becoming effective.

This year, secondary aluminum prices posted the steepest increase in a number of years before recently moderating to some extent. INTERMET uses secondary aluminum in casting aluminum automotive components. The company anticipates approximately \$1.2 million in aluminum secondary material increases for the second quarter compared to the first quarter of this year.

"There may be some relief in sight," said Mike Becker, INTERMET's Corporate Director of Purchasing. "Scrap steel is looking a little better in June, but very recently, it has been quite a scramble to keep up with the increases."

In a press release on June 13, 2002, announcing a successful \$175 million bond issue to repay outstanding term-loan indebtedness and for working-capital, INTERMET reported the expensing in the second quarter of the \$927,000 unamortized fees associated with the termination of the current bank term loan. The cumulative effect of the raw-material price increases and the expensing of early termination costs for the term loan, is expected to reduce

INTERMET's earnings for the second quarter by about 7 cents as compared to analysts' consensus.

John Doddridge, Chairman and CEO, said, "INTERMET's second-quarter core operating performance looks strong. Revenue should approximate \$218 million, in line with our expectations, and our efforts to improve manufacturing efficiencies and lower breakeven points continue to meet our targets."

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