2010 SPRING DIS ANNUAL MEETING

Vancouver, BC, Canada

The Ductile Iron Society Spring Annual meeting was held at the Sheraton Inn Guildford in Surrey, BC, Canada on May 11-13th. Tuesday was a busy day with committee meetings and the Board of Directors meeting in the afternoon. On Wednesday the technical presentations consisted of 10 speakers and ended at 5:00pm. At lunch on Wednesday, Joe Farrar (Farrar Corporation) and President of the Ductile Iron Society, presented his annual report to the members in attendance.

"The past year has been one that was very similar to the last fiscal year in 2008/09. We have all suffered one way or another since the downturn of our industry in the fall of 2008. I understand from speaking with a few of you folks that the foundry industry certainly is not where we would like to be; however there seems to be light at the end of tunnel. This has also hit the Ductile Iron Society. Your society has done everything this past year to contain spending and costs associated with running the society. The society will end the 2009/2010 fiscal year in the black. Your Board of Directors is very pleased with the results. However, the society lost a few members since our last meeting in Sharon, PA. This has not only affected the foundry producers but also our associate members. We can also see the effect of the times by the turnout at this meeting. The attendance for this meeting was 93 and I want to thank all of you for taking the time and spending the money to attend.

The proposed budget for the Fiscal Year 2010-2011 is predicting a small loss mainly due to the funding of research but also takes into account that we may lose some members. The good news is that Ferrosource joined the Ductile Iron Society just last month. Also there is a good chance that we may have some new members join in the next few months. Most of the members that did drop out of the DIS have committed to re-join once the economy turns around.

During this past year we held two general meetings. The first one was our Annual Meeting held in Lancaster, PA with a tour of Buck Company with 81 folks attending. The second meeting, last fall was a special meeting because we combined with the ICRI for a joint meeting. The attendance for that meeting was 142 and we toured Hodge Foundry in Greenville, PA.

The Ductile Iron Society did not offer a Production Seminar back in March 2010 due to the foundry
economy. We hope when things turn around in 2010/11, we will be able to offer the seminar and our members will once again send their employees to this meeting.

At this year’s AFS Cast Expo, the DIS had their first ever display booth. According to Jim Wood the turnout at the booth was steady for the number of people attending. He obtained many new leads for new members and he has already followed-up on those leads. We hope that many of them will join. He also was approached by a few people wanting to know more about ductile iron and where they could find some producers. All of them were directed to our website for those names. Jim feels that this was a very successful venture. A big thanks goes out to Jerry Call and Al Spada for assisting the DIS in getting a booth set up.

Also, I want to thank all of those that contributed to our “Hot Topics” publications and those that wrote articles for the “Ductile Iron News”.

Four Keith D. Millis Scholarships were awarded at the 2009 College Industry Conference held on November 19 & 20, 2009 at the Drake Hotel in Chicago. They went to Patrick Kelso of Pittsburg State, Kory Kruger of the University of Northern Iowa, Joseph Santa Maria of the University of Wisconsin-Milwaukee, and Steven Williams of the University of Alabama-Birmingham. Each student received $2000 each.

Jim Wood attended this past year’s conference. We also had a booth for the Industry Information session where we distributed the “Show Me Your Nodules” T-shirts. They were a very popular handout during this session as you would well understand. Thanks go out to Bill Sorenson for his invitation to the DIS to attend this important conference.

The Research Committee met three times during the past year. We completed two projects in 2009-2010 and we have currently one fairly large active project. Last year your Board of Directors approved the funding of $23,500 each year for 2 years on a new DIS Project Number 46. We are part of a 3 way group of investors consisting of the AFS, DIS and a consortium of foundry companies on a ductile iron structure/property optimization project. The total cost of this project is $155,000 over the next 2 years.

The Board of Directors has now completed a 2 year project to update the By-Laws of the society to reflect how the society is currently operated. This was needed as the By-Laws had not been revised for over 20 years.”

We had a great time during the banquet held on Thursday evening. First we made the presentations of service plaques to our two retiring directors, Gene Muratore of Rio Tinto and Jim Csonka of Hickman Williams and Company who have served as Directors for the last three years and the society thanks them for their dedicated service.
The next event on the program was to announce the “Member of The Year” award. The Awards Committee voted and named Denny Dotson of Dotson Company as this year’s recipient. Our President, Joe Farrar called on Jean Bye, President of Dotson Company to roast Denny. She did an awesome job of entertaining the group on Denny’s past history. Great job Jean!

The society felt that Denny deserved the award this year because of his efforts over the years in marketing ductile iron. Denny is also a past President of the society. Following the words by Jean, Joe Farrar the outgoing president of the DIS, offered his own personal comments about Denny.

Next, Joe Farrar gave a short overview of the Board of Directors meeting held on Tuesday and also the accomplishments of the DIS over the last three years under his watch. He also said a few
words about the future of the DIS and the foundry industry and the need to be willing to change as the industry and the business environment changes. We should also remember that Joe was asked by the board to remain on as president for an extra year. Thanks Joe!

With that being said, the next thing on the agenda was to introduce the new President, Vice President, and two new Board Members. The new President, starting July 1, 2010 for two years, is Scott Gledhill of Thyssenkrupp Waupaca. The incoming Vice President is Patricio Gil of Blackhawk de Mexico. Patricio is the first VP from Mexico in the history of the DIS. Congratulations Patricio!

Joe then announced the two new board members to replace the outgoing members Gene Muratore and Jim Csonka. They are Andy Adams of Foseco and Fred Linebarger of Miller and Company.

Joe then called on Scott Gledhill to come to the podium to make a presentation to the outgoing President and say a few words about the direction the DIS is heading over the next few years.
New President Gledhill with Joe & Nancy Farrar

On Thursday morning the group visited two foundries. Century Pacific Foundry and Robar Industries both hosted a visit by the attendees. The DIS would like to THANK Eric Hasselmann and his staff at Century Pacific Foundry and Derek Morrison and his staff at Robar Industries for their hospitality.

Century Pacific Foundry

Robar Industries

Our next DIS meeting will be held October 27-29, 2010 in Cleveland, Ohio. This will be a first time “Heavy Section Ductile Iron Conference” directed towards the Energy and Mining Industries. For more information, please visit the DIS website at www.ductile.org and click on the link at the top of the page.

The Ductile Iron Society would like to acknowledge a new member. Ferrosource – a Division of
Stemcor USA, Inc. joined in April, 2010 as an Associate Member.

6/15/2010

James Wood
Executive/Technical Director
Ductile Iron Society

Located in Strongsville, Ohio, USA
15400 Pearl Road, Suite 234; Strongsville, Ohio 44136
Billing Address: 2802 Fisher Road, Columbus, Ohio 43204
Phone (440) 665-3686; Fax (440) 878-0070
email: jwood@ductile.org
PETE GRADUATED FROM OHIO STATE UNIVERSITY IN 1994 WITH A BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. PETE IS CURRENTLY THE MANAGER OF ENGINEERING FOR ALLIED PRODUCTS, INC. IN COLUMBUS, OHIO. BEFORE JOINING ALLIED PRODUCTS, PETE WAS EMPLOYED BY FORD MOTOR COMPANY IN CLEVELAND, OHIO AT THE CASTING PLANT AS A PROCESS ENGINEER, REFRACTORY SUPERVISOR AND MAINTENANCE PLANNING SPECIALIST. ALL POSITIONS WERE IN THE MELTING DEPARTMENT OF THIS CAPTIVE GRAY AND DUCTILE IRON FOUNDRY. PETE HAS BEEN A MEMBER OF THE AFS FOR 20 YEARS AND IMMEDIATE PAST CHAIRMAN OF THE DIVISION 8 – MELTING METHODS AND MATERIALS, AND PAST CHAIRMAN OF THE AFS 8-F CUPOLA COMMITTEE. HE ALSO SERVES AS A CMI INSTRUCTOR FOR SEVERAL MELTING RELATED COURSES.
Refractory Concerns for Melting, Holding, and Treating Ductile Iron

Ductile Iron Society
May 2010

Pete Satre – Manager, Product Services
Allied Mineral Products, Inc.
Equipment for Melting Ductile Iron

- Cupola
- Coreless
- Channel Furnace
Equipment for Holding/Pouring

- Vertical Channel
- Pressure Pour Furnace
Equipment for Ductile Iron Conversion

- Tundish ladles
- GF converters
- Pouring Ladles
Melting Process Considerations
Gray vs. Ductile Iron

- ↑ Carbon Levels
- ↓ Silicon Levels
- ↑ Melt Temperatures
- Desulphurization
- More selective scrap usage
Melting Process Considerations
Gray vs. Ductile Iron

- Ductile iron treatment process
- Lower yield, increase in % back scrap charged
- Insoluble buildup in process equipment
Cupola

• Traditional Products
  – Fused alumina, graphite enriched rams, plastics, and castables
  – Carbon Block

• Concerns:
  – Increased erosion due to higher temps
  – Increased limestone to limit sulfur content
Cupola

- Process review
- Ultra low cement castables (decreased CaO), low water
- SiC enriched refractories
- Low clay plastics and rams
Cupola

- Changes in tuyere height, velocity, and diameter
- Review of iron dam, separator width, and metal residence time
**New Trough Design**

- **SRT 1.97 min.**
  - Rounded corners on skimmer block reduced cracking at slag line.
  - No backup lining

- **8” castable backup.**

- **Increased iron-slag width to 15” with same slope and increased SRT to 3.94 min.**

- **Reduced refractory usage by 40% .**
Cast Cupola Well
Cast Cupola Separator
Pre-Cast Panels
Coreless Furnace

• Traditional Products
  – Silica based dry vibratables

• Issues
  – Saturation
  – Erosion
  – Carbon/sulfur vapor deposits
  – Spalling
  – Top cap wear issues
Lining Installation
Coreless Furnaces
Wear Issues
Coreless Furnace

- Process review
- Bond content adjustment
- Enhanced silica products
  - Fused silica
  - Zircon
  - Chrome containing
- Mica products
Spalling
Enhanced Products
Slip Plane
Top Cap

- Silica with high bond
- Fused silica dry vibes
- Plastic
- Wet Rams
- Castables
Top Caps
Channel Furnaces

• Vertical induction furnaces used for melting and holding, pressure pour for holding and pouring.
• Buildup in throat, inductor, and uppercase are the primary issues
Melting Furnaces
Holding Furnaces
Pressure Pour Furnaces
Pressure Pour Furnace

- Buildup in the throat, inductor and receiver spouts
Channel Furnaces
Throat Area
Inductor
Inductor Lining
Heat-Up of Channel Furnace
Metal Priming of Furnace after Sinter
Ladle
Ladle
GF Conversion Ladles

- Buildup – MgO based
Cast Ladle Liner
Ladle Maintenance - Washes
Ladies Maintenance
(Consumable)
FEATURES

• 2010 Spring Meeting Summary

2010 SPRING MEETING SPEAKER BIOS AND SELECTED PRESENTATIONS

Refractory Concerns for Melting, Treating & Pouring Ductile Iron - Pete Satre

Fluxing in Ductile Iron Melting and Pouring - Dave Williams

Process Compensated Resonant Testing for Ductile Iron - Bob Nath

Carbidic Ductile Iron - Marc King

Melt Deck Safety - Chuck Cushing

Ductile Iron Slag Management in Coreless Furnaces - Chris DeRosa

Innovations in Medium Frequency Induction Melting - Charles Pete

Front End Nodularity Determination Using Standard Coupons - Matt Meyer

A.R.M.S. - Automatic Robotic Melt System - Paul Webber

Studies of Nuclei in Ductile Iron - Why Is This Important For Foundrymen - Rob Logan

DEPARTMENTS

• News Briefs

• Advertisers

• Back Issues

• DIS Home Page

Link to Presentation: Use of Fluxes in Ductile Iron Melting, Holding and Pouring

DAVE GRADUATED FROM THE ILLINOIS INSTITUTE OF TECHNOLOGY IN 1978 WITH A BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. DAVE IS CURRENTLY THE VICE PRESIDENT OF TECHNOLOGY FOR ASI INTERNATIONAL IN CLEVELAND, OHIO.

PREVIOUS TO ASI, DAVE WAS THE MANAGER OF PRODUCT SERVICES AND STAFF METALLURGIST FOR 21 YEARS AT ALLIED MINERAL PRODUCTS. BEFORE ALLIED, DAVE WORKED 6 YEARS AS A PROCESS METALLURGIST FOR LEBANON STEEL & NATIONAL CASTINGS/MIDLAND ROSS, CICERO. DAVE HAS BEEN AN ACTIVE MEMBER OF THE AFS FOR 28 YEARS. HE SERVED ON THE AFS 8D CHANNEL FURNACE COMMITTEE FOR 25 YEARS AND THE 8C CORELESS COMMITTEE FOR 8 YEARS. DAVE IS ALSO AN ACTIVE INSTRUCTOR FOR THE AFS CMI FOR THE LAST 21 YEARS. DAVE HAS BEEN AN ACTIVE PRESENTER/AUTHOR OF REFRACTORY & METALLURGICAL RELATED TOPICS WITH THE AFS, DIS, GIFA AND NUMEROUS OTHERS. HE ALSO HAS NUMEROUS PUBLICATIONS IN VARIOUS TRADE MAGAZINES.

Located in Strongsville, Ohio, USA
15400 Pearl Road, Suite 234; Strongsville,Ohio 44136
Billing Address: 2802 Fisher Road, Columbus, Ohio 43204
Phone (440) 665-3686; Fax (440) 878-0070
e-mail:jwood@ductile.org
Use of Fluxes in Ductile Iron Melting, Holding and Pouring

Mr. David C. Williams
ASI International Ltd.
Columbus, Ohio

Any information whether visual or written that is presented, is intended for education purposes only. These represent general suggestions of what foundries have found to be useful for their own operation. It may or may not work for you. This presentation must not be used as a reference for your program.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Why add Fluxes?

Integrated Steel Mill Processing

- Adding fluxes has been a vital part of steel making for decades.
- Lime/Fluorspar (CaF2) additions are commonly used for desulphurization, phosphorus reduction, deoxidation and improving metal cleanliness.
- Steel mill furnace and ladle linings are very robust.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Fluxes in Non-Ferrous Applications

Aluminum Casting Industry

• Fluxes are used to remove impurities, reduce dross formation, improve Al recoveries.
• Most fluxes are based on a mixture of metallic salts, especially Chlorides, Fluorides, and Borates.

Copper / Brass / Bronze Casting Industry

• Fluxes are used to remove impurities, reduce oxide formation, improve Cu, Zn recoveries.
• Most fluxes are based on a mixture of metallic salts, especially Chlorides and Fluorides.
Iron Casting Foundries

Benefits of fluxing mostly ignored

- Until recent years, most fluxes were based on fluorspar
- Refractory erosion and inclusions resulted, causing negative aspersions within the industry.
- New developments in non-chloride, non-fluoride fluxes now offer numerous benefits of improved refractory life, cleaner iron, and improved melting efficiency

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Examples of Ductile Build-up in Induction Melting

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Fluxing, Why is it needed?
Controlling Build-Up

Conventional methods of dealing with Build-Up in a melting, holding or pouring application,

- Low heel superheating
- “Green Poling”
- Addition of iron oxide and manganese oxide
- Addition of Silicon Carbide
- Mechanical Scraping

Now what?

Something more Effective is needed to help with the Removal of the build-up in the melt operation. That is where fluxing worked.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
A Mild Fluoride-free, Chloride-free Flux, Redux EF40\textsuperscript{(patented)} is used successfully to combat most build-up conditions in ferrous melt and pouring conditions.
Daily Build-Up Problems facing Ductile Iron Foundries

Insoluble Build-up in Coreless Melting

Channel Induction Furnaces:
Loss of Inductor Power due to Throat or Inductor Restriction

Loss of Capacity/Uppercase Build-Up, Reduce Service Life

Pressure Pouring Channel Furnaces Build-Up
holding treated ductile iron

Magnesium Treatment Tundish Ladle Build-Up

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Coreless Induction Melting and Fluxing

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Insoluble Build-up depositing on walls of Coreless Induction Furnaces

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Possible Sources of Slag and Build-Up in Ductile Iron Melting

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Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Severe Build-Up in Ductile Iron Coreless Furnaces

Loss of Effective Melt Power, slower melting rate.
Loss of Capacity, less Production.
localized superheating of Refractory.
Increased metallic saturation in the Refractory

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Continuous Flux treatment: use 1-2 lbs of Flux per ton of metallic charge entering the furnace.

Never ADD ANY FLUX TO AN EMPTY FURNACE. ALWAYS 50% MOLTEN METAL BATH INSIDE OF THE FURNACE BEFORE FLUXING.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
An Example of Controlling Build-Up in Coreless Melters and Improving Energy Loss

Comparison of KWH melt count temperature with and without Flux addition

- 1080 KWH with Redux
- 1100 KWH with Redux
- 1120 KWH without Redux

Overlay of test data

1080 KWH average Temp= 2738
1100 KWH average Temp= 2750
1120 KWH average Temp= 2770

2.5 ton medium frequency Coreless Melter

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces

Foundry D1 operates 12 M Ton Coreless furnaces in a 100% batch melting Ductile-base melt operation

Two 12 M Ton 9000 Kws 180 Hz Coreless furnaces lined with domestic silica dry vibratable refractory / boron oxide

Each charge consisted of ductile “pig iron,” carbon steel, and ductile returns. Typical tap temperature 2750-2825 F

Build-Up would occur in the “freeboard” area above the active power coil. After a 24 hour period, serious downtime was experienced due to delays in charging, Each melt cycle required an extra 5 to 15 minutes for each heat daily.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces

Foundry D1

Adding 6 lbs of Flux to each heat, the build-up was eliminated. Lining life increased from 4500 tons to 7500 tons per campaign. Foundry D continues to realize the following benefits:

- Furnace capacity remains consistent at 12 M tons
- Normal melt cycle of 40-50 minutes is uninterrupted
- Less frequent top cap cleaning
- Delays at the mold line for molten metal from holding furnace, fed by the coreless melters, was reduced by 50%
- Reduced mechanical damaged to the top cap refractory
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces

Foundry D2 operates 7 Ton Coreless furnaces in a 100% batch melting Ductile-base

Three 7 Ton 6000 Kws 180 Hz Coreless furnaces lined with domestic silica dry vibratable refractory / boron oxide

Each charge consisted of ductile “pig iron,” carbon steel, Machined turnings and ductile returns. Typical tap temperature 2775-2850F

Build-Up occurred along the front wall area in the active power coil. After a 72 hour period, serious downtime was experienced due to delays in charging, Each melt cycle required an extra 30-45 minutes for each heat daily.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces

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Typical Daily Slag

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Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Ductile–Base Build-Up in Coreless Induction Furnaces

Foundry D2 operates 7 Ton Coreless furnaces in a 100% batch melting Ductile-base

Adding 10 lbs of Flux per 7 ton heat, build-up eliminated.

Refractory lining was unaffected by the flux. Current Flux addition of 4 lbs per heat per campaign.

Foundry D2 continues to realize the following benefits:
- Furnace capacity remains consistent at 7 tons while recycling machined turnings in the melt
- Normal melt cycle of 40-50 minutes is uninterrupted
- Less frequent top cap cleaning
- Delays for molten metal from the coreless melters to the holding channel furnace was reduced

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Build-Up in Coreless Induction Furnaces

Foundry G a medium sized captive foundry casting grey iron

Four 3 ton medium frequency Coreless furnaces lined with European silica dry vibratable Boron Oxide bonded

Experienced extensive sidewall build-up in a semi-batch melting operation.

The charge make-up is 100% metallic fines, < 20 mesh.

After 48 hours of operation, 3 inches of build-up occurred along the entire sidewall. This led to increased power consumption due to significant downtime to allow for scraping.
Controlling Severe Build-Up in Coreless Induction Furnaces

The Build-Up is approximately 2.5” and dense, Fused glass-like material, (Alumino Silicate phase)

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Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Controlling Severe Build-Up in Coreless Induction Furnaces

Foundry G

Solution was to add 2 lbs of Flux per ton of metallic charge added to every backcharge.

Immediate improvements were observed.

Once build-up was removed, continuous 1 lb flux per ton of backcharge was part of their melt procedure.
Foundry G observed the following benefits:

- Using flux, less tendency for “bridging”
- Reduced power consumption during each melt
- Hourly maintenance for scraping reduced
- Consistent furnace capacities
- Improved “electrical coupling” due to improved temperatures
- No adverse effects on dry vibratable refractory
Channel Induction Furnaces
Uppercase and Inductor Build-up

Courtesy of Ajax Tocco

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Severe Restriction of Metal Flow in Throats or Inductor Channels can cause heavy saturation leading to refractory wear or metal leakage. Inability to superheat the molten iron.
Channel Induction Holding furnace Uppercase Build-up, Causing Loss of Capacity, and Service Life

Furnace history will indicate when to flux. Establish the “threshold” indicator such as a minimum/maximum limit to conductance/reactance depending on equipment.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
When Do I Flux?

Use “Inductor Condition.” This is determined by dividing the new, daily reactance reading by the baseline reactance calculation at the beginning of each campaign.

\[
\text{Inductor condition} = \frac{\text{Daily reading}}{\text{Base line reading}} \times 100
\]

A number greater than 100% is blockage & less than 100% is erosion, saturation or penetration.
When Do I Flux?

A number greater than 100% is blockage & less than 100% is erosion, saturation or penetration.

Examples:
107% means 7% blockage
97% would be 3% erosion, saturation or penetration

If a given inductor’s “Inductor Condition” is 7% or better blocked for a week or longer, the decision is made to flux the inductor.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Inductor Conductance Ratio for 45 ton Ajax Channel

Comparison Conductance Chart

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Treatment 1: Continuous Additions, Daily Maintenance

Continuous Addition of Flux to Uppercase

1) Continuous Flux Addition rate of 1–2 lbs flux per ton of metal entering the furnace

2) This was continued for every day.

3) Furnace continued to operate until daily Deslagging has been performed.

4) Flux addition resumed each consecutive day and the steps were repeated, Deslagged every day.

The quantity of the Flux will vary depending on the build-up.
Restoring Original Furnace Capacity in Holding Channel Furnace holding Ductile-base Iron

Two 65 ton Vertical Channel Holders

Capacity was less than 35 tons after 11 months of operation.

0.05% flux was added continuously to transfer ladles feeding the channel holders for 3 weeks.

The buildup removed AND capacity was restored.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Restoring Original Furnace Capacity in Holding Channel Furnace holding Ductile-base Iron

3 months later, each furnace was taken off line for its yearly reline and carefully examined. No sign of refractory erosion.

These furnaces now last 24 months instead of 12 months!

Approximate savings of $100,000 for each furnace.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Build-Up in 110 ton \textit{Vertical Channel} Furnace
Holding Ductile-base Iron at Automotive foundry

Monday – Friday 5 DAY
Continuous Additions

Two 110 ton \textit{Vertical} Channel
Holders

0.4 Kg per ton of molten iron, was added to the cupola launder feeding the channel holder at the collector box of the receiver of the channel furnace for 5 days.

\textit{Ductile Iron Society}
\textit{The Guildford Sheraton}
Surrey, B.C Canada – May 12-13, 2010
The furnace deslagged twice during the five day period. Adding flux created more slag.

Molten metal temperature should be above 1440°C (2624°F) for effective fluxing to occur.
In 48 hrs, foundry experienced severe Build-Up in throat and each of the channels of a Double-loop inductor.
Emergency Flux Treatment of Restricted Channel Melter

AJAX #1 CONDUCTANCE and POWER RATIO

Feb. 19 - Superheated
Feb. 27 - Superheated
Mar. 5 & 6 - REDUX 40L
Mar. 12 & 13 - REDUX 40L

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The Guildford Sheraton
Surrey, B.C  Canada – May 12-13, 2010
Method 2: 2-Day, Low Metal Heel Superheat

Treatment (DAY 1)
1) Remove slag from the top of the molten iron.
2) Lower the molten iron level to Minimum Heel.
3) Add 2-4 pounds of Flux per ton of molten iron heel to 2750 F iron. DO NOT ADD ANY FLUX on top of any existing slag. It must be added on top of exposed molten metal.
   Close cover but DO NOT SEAL! Some smoke emissions will occur.
4) Turn inductor power on maximum power.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Method 2: 2-Day, Low Metal Heel Superheat

5) Leave inductor on max power for 4 hours. Monitor molten iron temperature so that it NEVER exceeds 2900°F(1600°C).

6) Depending on the severity of the build-up, it may be necessary to add another 2-3 pounds of Flux per ton of molten iron, after 2 hours of superheating has occurred.

7) After the superheating period has been completed, the molten iron should be cooled to normal holding temperatures. The slag created, SHOULD BE REMOVED. Close cover and check the spout openings.
Emergency Flux Treatment of Restricted Channel Melter

**AJAX #1 CONDUCTANCE and POWER RATIO**

- Feb. 19 - Superheated
- Feb. 27 - Superheated
- Mar. 5 & 6 - ReduxEF40L
- Mar. 12 & 13 - ReduxEF40L

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Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Emergency flux Treatment of Restricted Channel

/ Treatment 2: 2-Day Additions, Low Metal Heel
Superheat; Inductor Max Power

Restoration of Furnace with minimal
Downtime

Savings in Loss Production

Savings in Relining the Channel Furnace

Less Chance of Metal Runout

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Build-Up in 100 ton Drum Channel Furnace Holding Cast Iron At Large Automotive Foundry

A Severe Slag Ring.

Estimated loss of capacity 25-33%.

Unable to introduce new molten metal from the cupola, as the thick slag ring could not be penetrated.

Receiver partially open

A 2-Step Flux Process Used

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux added directly to the Receiver/Fill spout
Continuous Flux Addition rate of 2.0 lbs flux per ton of molten metal entering the furnace, was added at the Receiver / Fill Spout.

For five consecutive days, FLUX was added
Furnace was deslagged continuously, and eventually the furnace was allowed to operate.
It was necessary to add Flux directly on top of the solidified slag crust, at the rate of 0.1% flux

2.0 lbs per ton of molten metal along the surface area of the bath, through the slag door. It was left on top of the slag for 4 hours.

---

*Ductile Iron Society*

*The Guildford Sheraton*

Surrey, B.C Canada – May 12-13, 2010
Another similar flux addition was added on top of the slag and allowed to react for another 4 hours.

The slag surface began to soften and the furnace was deslagged through this door appropriately.

(Flux addition will vary depending on the slag ring build-up in the uppercase. Slag removal needed.)
Pressure Pouring Channel Furnaces holding treated Ductile Iron / Severe Build-up occurring daily

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Insoluble build-up can cause:

- energy inefficiencies, diminished heat transfer
- poor temperature control
- superheating in restricted inductor channel
- increased metal saturation within the Inductor
- reduced rate of filling/pouring of furnace
Examples of a Clogged throat and Saturated Inductor

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Severe Build-up Consequences
occurring daily in Pressure Pouring
Channel Furnaces holding treated Ductile Iron

Restricted Access
in Fill Spout

Inductor Runout

Uppercase Build-Up

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Severe Throat Build-Up in 3 TON Pressure Pour Furnace Holding/Pouring Treated Ductile Iron

Continuous Addition of 0.5 lbs per ton of molten metal

Manual Scraping of Receiver every 4 hours

Once a week, 1-3 lbs flux per ton of molten metal (low heel) through small cover.

High power on inductor for 2-4 HRS. Monitor temp.

Rod out channels / Fill furnace and Deslag. Repeat treatment next 2 days.

Courtesies of ABP Induction Corp

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Severe Throat Build-Up in 15 ton Pressure Pour Channel Furnace Holding/Pouring Ductile Iron

Treated Ductile Iron at 1426°C (2600°F)

0.8 Kg FLUX per 1 ton per each ladle metal entering the Furnace

Mechanical Rodding of Fill and Pour Siphons ONCE EVERY 8 HRS

Deslagged twice a week through small cover

Courtesy of Inductotherm Corp.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C. Canada – May 12-13, 2010
Severe Throat Build-Up in 15 ton Pressure Pour Channel Furnace Holding/Pouring Ductile Iron

No negative effect on Uppercase, Floor, Throat, Inductor Refractories

Lining Life extended from 4-6 months to 9-12 months

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Throat and Uppercase Build-Up Maintenance
15 ton Pressure Pour Channel Furnace
Holding/Pouring Ductile Iron

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Throat AND Uppercase Build-Up Maintenance
15 ton Pressure Pour Channel Furnace
Holding/Pouring Ductile Iron

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Throat AND Uppercase Build-Up Maintenance
15 ton Pressure Pour Channel Furnace
Holding/Pouring Ductile Iron

Weekly Maintenance of Fluxing and Mechanical
Slag removal allows this Press Pour to continue
To operate 5-6 days a week, for 1 year campaign

No sudden interruptions midweek for downtime
Due to build-up from holding treated ductile iron

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Method 3: Periodic Flux Plunging into Throat and Inductor Channels of Press Pour faces

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Method 3: Periodic Flux Plunging into Throat and Inductor Channels

Periodic Treatment as determined by Inductor Electrical readings.

Prolonged operation of Press Pour furnace with Minimal interruption of production.
Safety before Fluxing

Consider the Flux to be used.
Read Material Safety Data Sheet for gas generation and personal protective equipment recommendations.

Consider the Method of Application
There is a good deal of flair / flame off when using this methodology to remove slag. When you think that the amount of PPE is enough, put on some more. Employees should be dressed in full “silver leathers”, dark heat reflective face shield with fiberglass helmet, canister type respirator & hot mitts as a minimum requirement.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Safety Considerations when Plunging

A chimney type device is utilized to redirect the flare and smoke above & away from the team member.

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The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Safety Considerations when Plunging

The chimney is clamped to the furnace hatch & ceramic blanket material is used a compression gasket between the chimney base plate & fce lid.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure for Channel Inductors and Throats

Flux Plunging Wand (an example is shown below)

<table>
<thead>
<tr>
<th>18&quot; - 24&quot;</th>
<th>30&quot; - 32&quot;</th>
<th>10'-0&quot;</th>
</tr>
</thead>
</table>

Think small when determining the actual size that you will need for your application. One limitation is the size of the chimney and proper venting of the off-gases!!

_Ductile Iron Society_  
_The Guildford Sheraton_  
_Surrey, B.C Canada – May 12-13, 2010_
Method 3: Flux Plunging Procedure for Channel Inductors and Throats

A Mild Fluoride-free Flux, Redux EF40, is packed into the Flux Tube (either a round pipe or square tube can be used). Whether pellets/briquettes or bricks are used, each must be pulverized first before filling the tubes.

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The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Construction Guidelines for the Flux Plunger

Flux is packed into the Flux Tube (either a round pipe or square tube can be used). The “Feeler Gauge” is attached to the tube.

Prior to filling the tube you must cut slots or drill holes throughout the flux chamber.

This will allow for OFF-gassing when submerged below the molten metal.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure

The solid steel bar Feeler gauge” is attached to end of Flux Pipe. A solid steel bar handle welded on the other end of reaction chamber.

The tube is wrapped with duct tape to keep the flux in the tube.

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The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure

Remove existing slag from the molten metal bath. Record the electrical readings

Lower the bath level to minimum heel level and turn off the power on the inductor & lock out the disconnect. Do not leave the power off for more than 30 minutes maximum.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure for Channel Inductors and Throats

Lower the first flux plunger using the “Feeler gauge” to locate the channel opening.

Immediately plunge the flux perforated tube/pipe so that the entire length of the pipe is immersed below the molten metal, into the channel opening.

The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure for Channel Inductors and Throats

Hold this plunger in place until the flux has completely reacted. The vigorous boiling is similar to “green poling” often used in the past to mechanically disrupt build-up. With Flux Plunging, one can expect a flaring up and must be prepared to take precautions to prevent it reaching the operator such as a chimney.

After the reaction has been completed, there will be more slag generated. This should be removed immediately.

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Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure for Channel Inductors and Throats

It may be necessary to repeat the plunging with a new flux plunger depending on the severity of the build-up. This application used 1 - 2 plungers. It is not recommend exceed this number in a single treatment episode.

Fill the furnace back to the normal “hold iron” level.

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Flux Plunging Procedure
for Channel Inductors and Throats

Seal any openings of the furnace to prevent any air from entering into the furnace.

Leave the furnace in a holding cycle mode from low Hold to High Hold as needed to maintain the normal hold temperature.

Record all electrical readings of the inductor and compare to previous clogged condition.
Fluxing in Treatment Ladles for Ductile Iron

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Treatment Ladles for Ductile Iron

IRON CAPACITY 600 TO 20,000 POUNDS

CONTROLLED FILLING FOR MAXIMUM RECOVERY
CONTROLLED VENTING THROUGH COVER
SEAL SWING COVER

LOW ALLOY EMISSIONS ELIMINATE NEED FOR DUST COLLECTION EQUIPMENT
COVERED LADLE RETAINS 99% OF ALLOY VAPOR FOR HIGH ALLOY RECOVERY
LOW OXYGEN LEVEL IN CLOSED LADLE INCREASES FABRIC TIME
HEAT RETENTION OF COVERED LADLE ALLOWS UP TO 160° LOWER TAP TEMPERATURES
COMPUTER CALCULATED BALANCE POINTS

NO SLUG BUILD-UP

THOROUGH MIXING OF ALLOY ASSURED
NO POCKETS OR SLOTS OF UNTREATED METAL

REMOVABLE BOTTOM FOR QUICK & EASY MAINTENANCE
NO COVER STEEL REQUIRED

Courtesy of D&E Ladles

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Treatment Ladles for Ductile Iron

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C Canada – May 12-13, 2010
Treatment Ladles for Ductile Iron

Fluxing 1 ton Treatment Ladle w/ 5 “Wash Heats” one Lb (0.4Kg) Pack /Ladle

Loss of pocket capacity due to Insoluble Build-Up. After 5 separate Wash heats

After the 5 individual treatments, pocket capacity was restored as shown.
Treatment Ladles for Ductile Iron

Before Treatment | After Treatment

This was achieved with minimal scraping, strictly the addition of Flux to 5 different “wash heats.” This treatment allowed for 72 hours of service versus 16 hours of service.
Pure Magnesium additions lead to MgO and MgS depositing along the sidewalls.

Rock Salt flux is recommended in the chamber, and an 1 lb addition of a mild flux per ton of metal was used inside the body.
Fluxing has been proven beneficial for many Ferrous applications. The three general methods are

**Method 1:**
Continuous or Semi-Continuous Additions

**Method 2:**
2-Day Additions, Low Metal Heel Superheat;
Inductor Max Power

**Method 3:**
Periodic Flux Plunging into Throat and Inductor Channels

Any information whether visual or written that is presented, is intended for education purposes only. These represent general suggestions of what foundries have found to be useful for their own operation. It may or may not work for you. This presentation must not be used as a reference for your Maintenance program unless written permission has been given by its author.

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*Ductile Iron Society*
*The Guildford Sheraton*
*Surrey, B.C  Canada – May 12-13, 2010*
Other Flux Applications in Ferrous Foundries

Transfer Ladles for Grey, Ductile, Alloyed Iron

Steel Coreless Melting

Cupola Coke Cleansing, Increasing Slag fluidity

Reduction of Sulfur in Furnace Melts
We would like to acknowledge the contribution of Mr Dom Bonacci from Grede St Cloud for his assistance in providing the parameters and safety aspects on Flux Plunging.

Thank you

Any Questions?

David C Williams

Ductile Iron Society
The Guildford Sheraton
Surrey, B.C  Canada – May 12-13, 2010
BOB GRADUATED FROM THE UNIVERSITY OF MINNESOTA IN 1959 WITH A BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING. BOB IS CURRENTLY WORKING FOR MAGNAFLUX QUASAR. THEY CONTINUE TO DEVELOP ADVANCED RESONANT TESTING METHODS FOR DUCTILE IRON, AS WELL AS OTHER CASTING AND METAL FORMING METHODS INCLUDING AEROSPACE AND CERAMICS. BOB WAS ONE OF THE FOUNDERS OF QUASAR INTERNATIONAL IN 1992. IN EARLY 2007 QUASAR WAS PURCHASED BY THE MAGNAFLUX DIVISION OF ILLINOIS TOOL WORKS. BOB WORKED FOR CATERPILLAR FOR 20 YEARS UNTIL 1980. HE WAS RESPONSIBLE FOR NEW PRODUCT DEVELOPMENT, INTERNATIONAL MARKETING MANAGEMENT AND SALES MANAGEMENT. AFTER THAT HE WAS THE DEPUTY ASSISTANT SECRETARY OF COMMERCE IN BOTH THE CARTER AND REAGAN ADMINISTRATION. RESPONSIBLE FOR TRADE WITH EASTERN EUROPE, SOVIET UNION AND CHINA. AFTER THIS SERVICE HE WENT ON TO BE THE VICE PRESIDENT OF ATLANTIC RICHFIELD COMPANY (ARCO) WITH RESPONSIBILITIES IN PHOTOVOLTAIC (SOLAR CELLS) AND OTHER NEW TECHNOLOGIES.
Magnaflux Quasar

Process Compensated Resonant Testing for Ductile Iron

12 May 2010
Vancouver BC Canada
Quasar Rejects Ferrous Castings with Significant Structural Defects

- Low Nodularity
- Excessive Carbidity (even when only in thin sections)
- Cracks
- Inclusions, alloy films, carbon films
- Cold Shuts, misruns (even when very tight and “invisible”)
- Cold Spatter
- Sand chunk inclusions (not surface sand)
- Missed or wrong heat treatment (thermal history)
- Blow Holes
- Shrink Porosity
- Wrong grain structure or alloy
- Missing Features
- Non-fill or short pour
- Dimensions
- Broken or shifted cores
Some Quasar Applications

• Ductile Iron suspension castings at Hitachi (HMAC)
  – Automated, 8 different parts now, 4 more in planning

• Steel investment cast rocker arms for GM and Chrysler
  – 21 million per year for GM (originally, now reduced)
  – Major quality improvement and cost reduction
  – 5 years of production testing, only 1 GM rocker failed

• DI Brake calipers, anchors, suspension components

• Crankshafts
GM Steel Rocker Arms

- The Most Rigorously Proven Quasar Application
  - Billions of fatigue cycles plus force breaking
    - Performance correlation criteria met
    - Quasar predicted those rocker arms that would fail early
  - Hundreds of laboratory correlations for grain structure
  - Critically reviewed by top GM metallurgists, quality statisticians, engine designers, production process engineers and purchasing execs
- Greatest percent testing cost savings
  - Previous NDT: 50% film X-ray, Mag Particle, 5 visuals
- Most valuable warranty cost reduction results
- Greatest reduction of scrap loss
  - >6% to 0.5% scrap
**Immediate Benefits**

- NDT that rejects parts based on probability of failure in operation, rather than “indications”
  - Better performance than conventional NDT
  - Eliminates wasted processing & machining
- Significant reduction in NDT & visual inspection cost.
- Lower Risk
  - *Proper use has eliminated containment for Magnaflux Quasar users*
  - *Part return is virtually ZERO!*
- Process easily automated
  - Computer decision & control
  - Inherent Error Proofing
Magnaflux Quasar NDT System

Dual Test Heads
Control Module
Monitor
Transceiver Access
Keyboard Access
Work Station
Test Station
Shock Isolation
(VIEWED FROM OPERATOR SIDE)

NEST 2
(SLAVE)

NEST 1
(MASTER)

VIBRATION DAMPENING

VIBRATION DAMPENING

QUASAR DUAL-NEST INSPECTION SYSTEM

(ELEVATION)
NEST(S) CONTROL

QUASAR DUAL-NEST INSPECTION SYSTEM

(PLAN VIEW)
Sources of Errors

• Human error in process control and NDT

• Visual estimate of % nodularity is human dependent particularly below 90% nodularity

• NDT methods are too easily “adjusted to accept”

• Velocity measurements not sensitive to carbide

• Velocity measurements should be compensated for Section dimensions and temperature

• 40 degrees F changes velocity about 0.30% or about 10% difference in nodularity
Application Example - Nodularity

Data Source: Emerson – British Cast Iron Research Assoc. - 1974

Sensitivity: Frequency shift vs. Nodularity

<table>
<thead>
<tr>
<th></th>
<th>Nodularity Detection Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncompensated</td>
<td>&lt; 60%</td>
</tr>
<tr>
<td>Compensated</td>
<td>&lt; 90%</td>
</tr>
</tbody>
</table>

Ductile Iron Brake Anchors
Defective = Average nodularity 70%

R² = 0.9274

Uncompensated Process Noise Threshold = 1.3%
Compensated Process Noise Threshold = 0.3%
**Application Example - Nodularity**

**Sensitivity example:**
- Change in Nodularity = 5%
- Change in Frequency = 0.5%
- Uncompensated sensitivity ~ 1.5%
- Compensated sensitivity ~ 0.3%

VIPR Sort – 2 bands

166 Brake Anchors

Defect – Average Nodularity of “bad” anchors is 70%

Because Nodularity of all “bad” anchors is so low, <70%, all bad parts fail MTS

Rejecting higher % nodularity, say below 80% requires Bias test and more bands to compensate
Quasar Score vs. Velocity

Note: 10 additional Bad parts were statistical outliers
**RI Masking Effect**

- Acceptable Production Variations in dimensions and material properties produce frequency shifts that mask defects – the batch problem

- Frequency shifts correlated to defect size

Ferrous Castings Variation +/- 2%

Result – Uncompensated Resonant Inspection limited to detecting large defects or requires “batch adjustment”
Marc King, Hiler Industries

MARC GRADUATED FROM MICHIGAN TECHNOLOGY UNIVERSITY IN 1996 WITH A BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. MARC IS CURRENTLY THE METALLURGIST FOR HILER INDUSTRIES. HE HAS SERVED IN THE METALLURGICAL POSITION WITH SEVERAL FOUNDRIES IN HIS WORKING CAREER. HILER INDUSTRIES IS A SHELL MOLDING FOUNDRY THAT POURS DUCTILE IRON, GRAY IRON, WHITE IRON, NI HARD, GRAY NI RESIST, DUCTILE NIRESIST, CARBIDIC DUCTILE IRON, AND VARIOUS BRASS AND BRONZE ALLOYS.

View Ductile Iron Related Publications

Located in Strongsville, Ohio, USA
15400 Pearl Road, Suite 234; Strongsville, Ohio 44136
Billing Address: 2802 Fisher Road, Columbus, Ohio 43204
Phone (440) 665-3686; Fax (440) 878-0070
email:jwood@ductile.org
Carbidic Ductile Iron

Marc King
Metallurgist
Hiler Industries
LaPorte, IN
Why would anybody in their right mind want to add carbides to ductile iron?
Ductile Iron is a great engineering material:

- Great Strength
- Good Elongation
- Excellent Castability
- Excellent Machinability
- Heat Treatable
- Highly Adaptable
Unfortunately its wear properties ultimately needed some improvement!
Where to begin?

How do you make normal ductile iron into a highly abrasion resistant material?
Let's take a look at traditional abrasion resistant cast irons:

White Iron

Ni-Hard Iron
ASTM A532 15% Cr-Mo White Iron

Etched, 1000X

Precipitation Carbides

Chemical Specifications
- C: 2.00 - 3.30%
- Mn: 2.0 Max
- Si: 1.5% Max
- Ni: 2.5% Max
- Cr: 14 - 18%
- Mo: 3.0% Max
- Cu: 1.2% Max
- S: 0.06% Max

Complex Chromium Carbides

Martensitic Matrix after heat treatment.

Hardness Spec: 59 R_c Min.
ASTM A532 15% Cr-Mo White Iron

Good Properties:
1) Extremely Wear Resistant

Bad Properties:
1) Brittle
2) Difficult to cast in thin sections and complex shapes.
3) Shrink Prone.
4) Expensive alloys with limited availability and volatile pricing.
ASTM A532 1D Ni-Hard Iron

Etched, 1000X

Chemical Specifications:
- C: 2.7 - 3.20%
- Si: 1.60 - 1.70%
- Mn: 0.50 - 0.70%
- Cr: 7.0 - 11.0%
- Mo: 0.00 - 1.50%
- Ni: 4.50 - 4.90%

Hardness Specification: 500 BHN Min.

Austenite

Complex Chromium Carbide

Martensite
ASTM A532 1D Ni-Hard Iron

**Good Properties:**
1) Wear Resistant
2) Impact Resistant

**Bad Properties:**
1) Brittle
2) Difficult to cast in thin sections and complex shapes.
3) Shrink Prone
4) Expensive Alloys with limited availability and volatile pricing.
What do wear resistant irons have that traditional ductile iron doesn’t?
Carbides!
What is Carbidic Ductile Iron?

1) Carbidic Ductile Iron has no ASTM designation.

2) A normal carbide specification is 10 - 30 % of the matrix.

3) Nodularity is a minimum of 70%. This specification is loose due to the lack of nucleation needed to stabilize carbides, and carbide formation causing poor nodule formation.

4) The grades that Hiler Industries produces are austempered to increase matrix hardness and the toughness of the metal. Final Hardness is 444-555 BHN. This produces a metal with similar physical properties to Ni-Hard alloys.
So how do we get carbides into the iron when we have spent our whole career getting them out?

Happy Metallurgist

Unhappy Metallurgist
Thought process behind making Carbidic Ductile Iron:

1) This iron is basically a compromise between making a Ductile Iron Alloy and a “White Iron” or Ni-hard Alloy.

2) My thought was that you have to make normal Ductile Iron, but modify your process to stabilize the desired % carbides without completely sacrificing nodule formation and nodule count.

3) The starting point, in the beginning, was a normal ductile base iron. The charge materials and chemistry were not changed.

4) Magnesium treatment method does not change, because good nodularity is required to give the metal impact toughness.
Thought process behind making Carbidic Ductile Iron:

5) Carbide stabilizing alloys are added.

6) Inoculation is reduced to maximize carbide stabilization and while providing some potential for nodule formation.
Carbide Stabilizing Alloys in Carbidic Ductile Iron

Elements:

Chromium
Molybdenum
Manganese
Copper (Minor Effect)

Use the most cost effective carbide stabilizers.

Do not overcomplicate the interpretation of the results by using too many alloys. It is best to simplify alloy additions.

The level of carbide stabilizing alloy will be proportional to the % Carbides formed.

The level of carbide stabilizer may have to be increased for thicker sectioned castings.
Inoculation of Carbidic Ductile Iron

The addition of carbide stabilizers will cause thin sections to become almost completely carbidic.

Inoculation is reduced to maximize carbide stabilization.

A small inoculation must be added to maintain graphite nucleation potential in the thin sections.

The elimination of inoculation causes carbidic ductile iron to be extremely brittle in sections under 1/4 inch thickness due to a combination of poor nodule count and high % carbide formation.

Inoculation promotes graphite sphere roundness in carbidic ductile iron.

Low levels of inoculation promotes growth of nodules in the thin sections to prevent stress cracking that can occur during austempering heat treatment if the nodule count is insufficient.
Graphite Structure of Carbidic Ductile Iron

Unetched, 100X Magnification

Nodularity: 90%
NC: 100 Nod/mm²
% Graphite: 6%

Fully spherical graphite formation is difficult to achieve in carbidic ductile iron. This is not due to the effects of magnesiuim treatment.
Graphite Structure of Carbidic Ductile Iron

Etched, 500X Magnification

Etching the sample reveals that particles of carbide intersect the graphite spheres. This gives the appearance that the graphite spheres are deteriorated in an unetched view.
Graphite Structure of Carbidic Ductile Iron

% Nodularity less than 90% is common due to carbide formation impairing the graphite nucleation. The carbide formation cuts into the graphite nodules as they are nucleating causing graphite that appears to be deteriorating.

% Nodularity is a secondary criteria. The customer specifications often stress wear properties and carbide formation over % Nodularity as being a passing criteria.
Carbide is stabilized through the addition of carbide stabilizers combined with a low % inoculation.

Note: Complex intercellular carbide formation.
As-Cast Matrix Microstructure of Carbidic Ductile Iron

Etched, 500X

The use of carbide stabilizers causes the stabilization of fine pearlite lamella in the matrix.

It is common in Carbidic Ductile Iron for carbide formations to intersect graphite nodules, and to see intercellular carbide surrounding graphite nodules.
The use of carbide stabilizers causes the stabilization of fine pearlite lamella in the matrix.

**Etched, 1000X**

Graphite Nodule intersected Complex Intercellular Carbides during nucleation and growth.

**Matrix:** Fine sized pearlite with minimal stabilized ferrite.
Thick vs. Thin Sections in Carbidic Ductile Iron

Carbide Formation and Nodule Formation vary according to section thickness.

The thicker section in the photo is the critical wear resistant section of the part.
Thick vs. Thin Sections in Carbidic Ductile Iron: Graphite Nucleation

There is higher Nodule Count in the thin section.

Both contained 6% Graphite

Thick: Unetched, 100X

90% Nodularity

100 Nodules/mm²

Thin: Unetched, 100X

93% Nodularity

175 Nodules/mm²
Thick vs. Thin Sections in Carbidic Ductile Iron: Carbide Formation

Both contained 6% Graphite

Thinner sections have higher % Carbide formation.

25% Carbide Formation

40% Carbide Formation
Thin Sections in Carbidic Ductile Iron

Section thickness affects the formation of iron carbide. There is always an area in these castings where the % Carbides in the matrix has to be maintained to give the material wear resistant properties.

Many parts that we cast have thin sections, <1/4 inch thick, that are not critical areas for wear resistance. Thin sections will have greater than the maximum allowed % carbides.

Graphite nucleation is promoted in thin sections by adding a small post inoculant addition.

Increasing inoculation (% Silicon) will decrease the amount of carbides throughout the casting.

Inoculate enough to promote some graphite nucleation in the thin sections, but not enough to decrease the carbides in the critical sections to the point where the wear resistant properties are compromised.
Cracking in Carbidic Ductile Iron Due to Lack of Inoculation

The cracks in these castings were the result of early experimentation using no post inoculation combined with a carbide stabilizing alloy to form carbides during solidification.
Cracking in Carbidic Ductile Iron Due to Lack of Inoculation

- Thin Section Cracking
- Less Than 1/4 inch Thick Section
- Oxidized Fracture Surface
- Paint
- Transition between thick and thin section.

The crack occurred during austempering heat treatment.
Cracking in Carbidic Ductile Iron Due to Lack of Inoculation

Unetched, 100X

Graphite: 80% Nodularity, 70 Nodules/mm²

Etched, 100X

Matrix: 40% Carbides, Austempered

Poor Nodule Shape and Count combined with High % Carbides.

Nodule Count and Shape is better in casting thin sections that receive a small post inoculation.
Cracking in Carbidic Ductile Iron Due to Lack of Inoculation

Stress Riser Cracking

The crack occurred during austempering heat treatment.

Edge transition between two thick sections at a cast corner.

The cracks in these castings were the result of early experimentation using no post inoculation combined with a carbide stabilizing alloy to form carbides during solidification.
Cracking in Carbidic Ductile Iron Due to Lack of Inoculation

Etched, 500X

Note the directional carbide growth in the uninoculated casting.

Directional growth of the carbide in uninoculated carbidic ductile iron makes the material more prone to brittle fracture.

35% Carbides
Austempered Matrix

Small inoculant additions help to produce more random directional carbide growth. This makes the material tougher and reduces stress cracking.
Wear Properties

Example of a casting microstructure displaying poor wear properties.

Etched, 200X

10% Carbides in a fully austempered matrix.

Poor carbide formation decreases the wear resistance of the casting.

Low carbide stabilizer additions and high % Silicon cause poor carbide formation.

Nodule shape is much better with lower % carbide formation.
Wear Properties

Example of a casting microstructure displaying poor wear properties.

Graphite Structure

Unetched, 100X

95% Nodularity
NC: 100 Nodules/mm²

Nodule shape improves with lower % carbide formation.

Decreased Resistance to wear.
Matrix Microstructure of Carbidic Austempered Ductile Iron

Austempering is the most common means of creating a hardened, wear resistant matrix microstructure allowing Carbidic Ductile Iron to compete with Ni Hard Irons.

Carbidic Austempered Ductile Iron exceeds Ni-Hard in applications where both impact resistance and wear resistance are desired properties.
The final material is a Carbidic Ductile Iron with Modified ASTM A897, Grade 230-185-01 Austemper Heat Treatment. BHN Range: 444-555.

Microstructure of Carbidic Austempered Ductile Iron (CADI)

Etched, 1000X

Graphite Nodule  Carbide  Acicular Ferrite in a matrix of Austenite.
Points to consider concerning austempering:

The iron will grow during austempering. Stress cracking can occur in uninoculated, over-carbidic iron during austempering heat treatment in both thin sections and at sharp corners where changes in plane geometry cause a stress riser to occur.

Carbides may dissolve into solid solution during the austenitizing step of the austempering heat treatment. Take this into account when developing your process to produce Carbidic Ductile Iron. Minimal carbide will cause premature wear of the parts in field service.
Conclusions:

Normal ductile iron can be easily modified to produce wear resistant Austempered Carbidic Ductile Iron that can compete with physical properties of the Ni-Hard class of alloys.

The wear resistant properties are achieved by producing as-cast carbides within the matrix microstructure by carbide stabilizing alloy additions combined with reduced inoculation. The matrix is further modified through an austemper heat treatment. This hardens the matrix and makes a tougher, more impact resistant.

Carbidic Iron is lower cost to produce than Ni-Hard and is not subject to the volatility of alloy prices.
Thank You for your attention!

Any Questions?
To promote the production and application of ductile iron castings

DUCTILE IRON SOCIETY

2010 ANNUAL MEETING

MAY 11-13, 2010
SURREY, BC

SAFETY ON THE MELT DECK

Robert C. (Chuck) Cushing
Manager of Technical Services
EMSCO, Incorporated
Safety on the Melt Deck

Number of Fatal Workplace Injuries, 1995-2008

Safety on the Melt Deck

Total Number of Workplace Fatalities 1992-2008 =

101,014

U. S. Battle Deaths Vietnam War: 58,226

95,166
Safety on the Melt Deck

Total Non-Fatal Workplace Injuries, 2008 =

3,700,000
Safety on the Melt Deck

Total Estimated Cost to the U.S. Economy =

$170 Billion
### Injury Rate, U. S. Foundries (2006)

*Days Lost per 100 Employees Per Year*

<table>
<thead>
<tr>
<th>Employee Size</th>
<th>U.S. Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ALL SIZES</td>
<td>7.2</td>
</tr>
<tr>
<td>1-10 Employees</td>
<td>2.3</td>
</tr>
<tr>
<td>11-49</td>
<td>6.5</td>
</tr>
<tr>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>50-249</td>
<td>9.1</td>
</tr>
<tr>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>250-999</td>
<td>6.5</td>
</tr>
<tr>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>1,000+</td>
<td>5.6</td>
</tr>
<tr>
<td>2.5</td>
<td></td>
</tr>
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</table>


---

2010 Annual Meeting · May 11-13, 2010 · Surrey, BC
## Injury Rate by Foundry Process (2006)

*Days Lost per 100 Employees Per Year*

<table>
<thead>
<tr>
<th>Foundry Process</th>
<th>Days Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Investment</td>
<td>4.9</td>
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<tr>
<td>Steel Sand</td>
<td>6.4</td>
</tr>
<tr>
<td>Aluminum Die Cast</td>
<td>5.5</td>
</tr>
<tr>
<td>Aluminum Sand</td>
<td>7.3</td>
</tr>
<tr>
<td>All Copper-Based</td>
<td>5.9</td>
</tr>
<tr>
<td>Other Non-Ferrous</td>
<td>4.5</td>
</tr>
<tr>
<td>All Iron</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Safety on the Melt Deck

What should you expect?

• Renewed emphasis
• Vigorous Enforcement
• Tougher Penalties
• Increased criminal sanctions
• Announced plans for 450 new inspectors nationwide
“The Labor Department is back in business. … I think you can rest assured that there is a new sheriff in town.”

Hilda M. Solis
U.S. Secretary of Labor
March 2009
Safety on the Melt Deck

Year-to-Date 2010

Six Foundries in SIC 3321 have been inspected by OSHA
Safety on the Melt Deck

Recognized Foundry Hazards

1. Heat
2. Airborne Contaminants
3. Noise
4. Molten Metal
5. Plant Machinery
6. Electricity

Source: Occupational Health & Safety Administration, U. S. Dept. of Labor
Safety on the Melt Deck

Airborne Contaminants

Crystalline Silica

The #1 airborne contaminant in the foundry environment; subject to an ongoing OSHA Special Emphasis Project
Crystalline Silica Facts

In the United States, from 1968 through 1990 the total number of deaths where silicosis was reported anywhere on the death certificate was 13,744. Of these, approximately 6,322 listed silicosis as the underlying cause of the death. In this study, deaths in the United States due to silicosis was primarily concentrated in 12 states (California, Colorado, Florida, Illinois, Michigan, New Jersey, New York, Ohio, Pennsylvania, Virginia, West Virginia, and Wisconsin.) The silica-related deaths in these 12 states accounted for 68% of the total silica related deaths in the United States.

Safety on the Melt Deck

Silica in the Foundry

Installation & Removal of Furnace Linings
Safety on the Melt Deck

Silica in the Foundry

Cleaning Room
Safety on the Melt Deck

Silica in the Foundry

CFR 1910.134

Respirator Selection

Appropriate & Designed for Identified Hazard?
Silica in the Foundry

CFR 1910.134

• Proper Training

• Fit Testing Protocols
Safety on the Melt Deck

Airborne Contaminants in the Foundry

Shakeout & Cooling

- Benzenes
- Formaldehydes
Safety on the Melt Deck

Molten Metal Hazards

What is wrong with THIS picture?
Molten Metal Hazards

The primary hazard zone extends from the edge of an induction melting furnace in which molten metal is present and to which power is being applied to a distance of twenty feet OR a distance equal to five times the ID of the coil diameter, whichever distance is greater.

*ASTM E2349, section 9.2.11.1*
Molten Metal Hazards

Within the primary hazard zone, employees are subject to PRIMARY exposure whenever the risk of significant exposure to molten substance splash, radiant heat, and flame sources are LIKELY to occur.

Within the primary hazard zone, employees are subject to SECONDARY exposure whenever the risk of intermittent exposure to molten substance splash, radiant heat, and flame sources are POSSIBLE.

ASTM F1002, section 3.1.1
Molten Metal Hazards

Primary Hazards Include:

- Charging
- Tapping
- Sampling

ASTM F1002, section 3.1.1
Safety on the Melt Deck

Molten Metal Hazards

Personal Protective Equipment

Primary Exposure
Safety on the Melt Deck

Molten Metal Hazards

Personal Protective Equipment

Secondary Exposure
Safety on the Melt Deck

Molten Metal Hazards

Metal splash took the life of the melt operator wearing this garment.
Safety on the Melt Deck

Molten Metal Hazards

The Primary Hazard Zone and recommended PPE are NOT defined or promulgated by OSHA.
Molten Metal Hazards

General Duty Clause

“Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.”

29 U.S.C. § 654, 5(a)1
Molten Metal Hazards

Proximity to Molten Metal is a Recognized Hazard!
Safety on the Melt Deck

Molten Metal Hazards

OSHA will issue citations under the General Duty Clause using the recognized ASTM standards
Molten Metal Hazards

Hazard Number One:

Molten Metal Explosion
Molten Metal Hazards

The most common reason for metal explosion is wet or damp charge materials.
Safety on the Melt Deck

Molten Metal Hazards

Charge Material Safety

The introduction of wet charge materials into a molten bath can have catastrophic results
Molten Metal Hazards

Here is what can happen
Safety on the Melt Deck

Molten Metal Hazards

One cubic inch of water is equivalent to 1,600 cubic inches of steam
Molten Metal Hazards

**Charge Material Safety**

- Ensure that charge materials are thoroughly dried
- Beware the introduction of baled or bundled scrap
- Inspect for sealed containers or other contaminants
Safety on the Melt Deck

Furnace Bridging

*The MOST dangerous condition that can exist in the foundry environment*
Safety on the Melt Deck

Furnace Bridging

A Furnace Bridge Waiting to Happen
Safety on the Melt Deck

Furnace Bridging

An accumulation of un-melted solids sealing the top of the molten bath
Furnace Bridging

Air gap prevents the molten bath from contacting the solid material.
Furnace Bridging

Gasses begin to emerge from the superheated bath increasing the pressure on the furnace vessel.
Furnace Bridging

Lining Destructs
Furnace Bridging

Refractory failure & a metal runout to the coil

The BEST case scenario!
Safety on the Melt Deck

Furnace Bridging

The worst case scenario
Furnace Bridging

What is the first action taken when the presence of a metal bridge is detected?

Answer:
Activate your Evacuation Plan
Safety on the Melt Deck

Furnace Bridging

Kill the Furnace Power
Furnace Bridging

Tilt the furnace only enough for the molten bath to displace the layer of air and contact the underside of the bridge.
Furnace Bridging

A Summary...

- The molten metal will superheat very rapidly
- Refractory failure is imminent
- A steam/metal explosion is likely
- Power should be turned OFF immediately
- Tilt the furnace slightly to put molten bath into contact with bridge
- Evacuate the work area
Safety on the Melt Deck

Furnace Bridging

What NOT to do...

Do NOT permit anyone to stand in front of the furnace (or anywhere near it for that matter)

Do NOT attempt to cut through the bridge with an oxygen lance, drill, or anything else
Safety on the Melt Deck

Electrical Safety
Safety on the Melt Deck

Electrical Safety

**Principle Electrical Hazards on the Melt Deck**

- Coming into contact with energized components
- Overriding or bypassing safety interlock switches
- Malfunctioning or disconnected ground fault systems
Safety on the Melt Deck

Electrical Safety

Electrical shock is the passage of amperes through the human body.
Safety on the Melt Deck

Electrical Safety

Nominal electrical resistance ($R$) of the human body

<table>
<thead>
<tr>
<th>Condition</th>
<th>Resistance (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRY SKIN</td>
<td>600,000</td>
</tr>
<tr>
<td>NORMAL SKIN</td>
<td>6,000</td>
</tr>
<tr>
<td>WET SKIN</td>
<td>1,000</td>
</tr>
<tr>
<td>INTERNAL BODY (HAND TO FOOT)</td>
<td>500</td>
</tr>
<tr>
<td>EAR TO EAR</td>
<td>100</td>
</tr>
</tbody>
</table>
Safety on the Melt Deck

Electrical Safety

**Shock Hazard**

- DRY
  - 80 Volts / 600,000 Ohms = .0001 Amps
  - NORMAL
  - 80 Volts / 6,000 Ohms = .013 Amps
  - WET
  - 80 Volts / 1,000 Ohms = .08 Amps

*Hint: Amps = Volts/Ohms (Ohm’s Law)*

**Shock Effects**

- .2 amps — SEVERE BURNS - HEART CLAMPED
- .1 amps — HEART FIBRILLATION
- .05 amps — MUSCULAR CONTROL LOST
- .02 amps — PAINFUL SHOCK
- .01 amps — MILD SHOCK
- .005 amps — NO SHOCK

5 Milliamp
Safety on the Melt Deck

Electrical Safety

![Diagram showing 3,000 VOLT BUS and typical calculations: 3,000 VOLTS / 6,000 Ohms = .5 Amps]
Safety on the Melt Deck

Electrical Safety

Lock Out/Tag Out
Safety on the Melt Deck

Electrical Safety

Even after a circuit is locked out…..

Capacitors are designed to STORE energy that is NOT dissipated when power is turned off
Safety on the Melt Deck

Electrical Safety

Ground Fault Protection
Safety on the Melt Deck

Ground Fault Protection

The MOST Important Safety Feature on the System

- Protects People
- Protects Equipment
- Can easily be the most annoying feature on the system
- Must be properly working at ALL times!
Safety on the Melt Deck

Ground Fault Protection

*If the bath contacts the power coil, the bath will energize at the same voltage as the power coil*
Safety on the Melt Deck

Ground Fault Protection

![Ground Resistance Meter](image1)

![Ground Leakage Meter](image2)
Ground Fault Protection

GROUND RESISTANCE MONITOR (GRM)

60 VOLT D.C. POWER

Fault

.1 Amps SENSITIVITY
Safety on the Melt Deck

Ground Fault Protection
Safety on the Melt Deck

Ground Fault Protection

The wires MUST be in contact with the molten bath
Safety on the Melt Deck

Ground Fault Protection

**What can happen**

1. Contact is broken
2. Metal impingement – bath energized
3. Power is on
4. An employee makes contact with the bath (slagging, temp check, etc.)
Safety on the Melt Deck

Ground Fault Protection

What can happen

The current flowing through a direct short to ground is likely to be as much as 3 times line current

Bath should NEVER be slagged or otherwise contacted unless furnace power is reduced to zero
Ground Fault Protection

Ground fault monitoring system should be independently checked on a daily basis.
Some Conclusions Regarding Safety

Studies prove that accidents are rarely the result of one discreet action...but rather the “perfect” accumulation of a host of factors.
Some Conclusions Regarding Safety

Accidents are not always the result of doing “dumb” things

...although there ARE exceptions.
Safety on the Melt Deck

Some Conclusions Regarding Safety

The easy way is not always the best way!
Some Conclusions Regarding Safety

Teamwork alone does not make a safe workplace
Some Conclusions Regarding Safety

Accidents happen when people become comfortable
Some Conclusions Regarding Safety

A measure of fear is NOT a bad thing on the furnace deck!
Safety on the Melt Deck
Chris DeRosa, Washington Mills

Ductile Iron Slag Management in Coreless Furnaces

Chris DeRosa
Market Manager Metallurgical Products
Washington Mills Hennepin

Ductile Iron Society Annual Meeting May 11-13, 2010 Surrey BC
Ductile Iron Slag Management in Coreless Furnaces

- Slag Generation and Handling Options
- Discussion of Analytical Testing and Results
- Tips on Minimizing Slag Generation
Slag Generation

Influential Factors

- Charge materials
- Alloy addition
- Preheat
- Fines removal
Charge Materials

Steel / Plate / Shred

• Sizing and flowability

• Surface area to weight ratio

• Coated or galvanized steel

• Be aware of micro contaminants

Ductile Iron Society Annual Meeting May 11-13, 2010 Surrey BC
Charge Materials

Remelt / Shop Scrap

- Blasted vs unblasted
- Flowability
- Filters
Charge Materials

Pig Iron
- Great surface area : weight
- Use magnetic handling

Alloy Addition
- Use high quality
- Proper sizing
- Early but not first

Pre Heat / Fines
- Ensure fines removal
- Avoid excessive preheat

Ductile Iron Society Annual Meeting May 11-13, 2010 Surrey BC
Slag Removal

• Raking
• Twirl
• Scoop
• Clam Shell
Slag Removal

- Paddles
- Rakes
- Spoons
- Refractory coatings
- Clam shells
- Slag coagulant
Slag Testing and Sampling

- Analysis with XRD/XRF
- Small Sample Size for Analysis
- Gathering Sample Critical
  - Gather 10-20 lbs
  - Crush large chunks
  - Pull out contaminants
  - Submit 3-5 lbs
Slag Testing and Sampling

- Don’t use slag coagulant
- Use proper tools
- Collect sample at the same time during melt cycle
- Collect sample at the same temperatures

- Establish baseline
- Sample frequency
Slag Testing and Sampling

- Ideas to Consider
  - Establish melt slag baseline
  - Take samples from holders
  - Take samples from ladles
  - Consider primary vs secondary slags

- Track charge condition
- Track charge changes
- Monitor alloy changes
- Note any defect trends
## Slag Analysis

### Typical Analysis

<table>
<thead>
<tr>
<th></th>
<th>Gray (%)</th>
<th>Ductile (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>65%</td>
<td>55%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>MgO</td>
<td>2%</td>
<td>10%</td>
</tr>
<tr>
<td>CaO</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>MnO</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>FeO</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Tramp Elements

<table>
<thead>
<tr>
<th></th>
<th>Gray/Ductile (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₂O₅</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td>K₂O</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>&lt;1.0%</td>
</tr>
<tr>
<td>V₂O₅</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>&lt;0.2%</td>
</tr>
</tbody>
</table>
# Slag Analysis

<table>
<thead>
<tr>
<th>P₂O₅</th>
<th>B₂O₃</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>ZrO₂</th>
<th>FeO</th>
<th>PbO</th>
<th>CuO</th>
<th>Na₂O</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
</tr>
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<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**ACIDIC**  

**BASIC**

V Ratio is

\[
\text{V Ratio} = \frac{\text{Sum of Basic Components}}{\text{Sum of Acid & Neutral Components}}
\]

- V Ratio > 1, Slag is Basic
- V Ratio = 1, Slag is Neutral
- V Ratio < 1, Slag is Acidic
Monitoring Slag Chemistry

Slag Chemistry Control

- Most coreless operations have SiO₂ refractory systems
- SiO₂ refractories require acidic slag
- Importance of SiO₂ in charge

Sources of SiO₂
- Sand on remelt
- SiC addition
- Dirt
- Alloy loss
- Refractory wear
Monitoring Slag Chemistry

Sources of SiO₂

- Example Foundry “A”
  - Weigh remelt: 292.96 lbs
  - Blast remelt
  - Re weigh remelt: 291.92
  - Weight of sand on remelt: 1.04 lbs
  - % of sand on remelt: 0.355%

- They found that there will be 7.1 lbs of SiO₂ per ton of remelt
Monitoring Slag Chemistry

Sources of SiO₂

- Example Foundry “A”
  - Adds 6000lbs remelt in a 12000lb charge
  - 6000lbs x 0.355% = 21 lbs sand/charge
  - Slag weight is 79.74 lbs/12000lb charge
  - SiO₂ addition from remelt will be 26.7% of slag weight
Monitoring Slag Chemistry

Sources of SiO₂

• SiO₂ from SiC
  • 50 lbs SiC addition
  • 7% SiO₂ in SiC
  • 3.5 lbs SiO₂ from SiC
  • SiO₂ addition from SiC will be 4.4% of slag weight

• SiO₂ from Remelt (21 lbs) 26.7%
• SiO₂ from SiC (3.5 lbs) 4.4%
• Total SiO₂ intentionally added (24.5 lbs) 31.1%
Monitoring Slag Chemistry

- Analyzed SiO$_2$ 53.8%
- Added SiO$_2$ 31.1%
- Difference 22.7%

- Slag weight 79.74 lbs
- Missing 18 lbs of SiO$_2$

<table>
<thead>
<tr>
<th>Slag Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MgO</td>
<td>9.81</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>20.29</td>
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<tr>
<td>SiO$_2$</td>
<td>53.8</td>
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<tr>
<td>S</td>
<td>0.05</td>
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<tr>
<td>K$_2$O</td>
<td>0.24</td>
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<tr>
<td>CaO</td>
<td>3.58</td>
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<tr>
<td>TiO$_2$</td>
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<tr>
<td>V$_2$O$_5$</td>
<td>0.06</td>
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<tr>
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<tr>
<td>MnO</td>
<td>5.57</td>
</tr>
<tr>
<td>FeO</td>
<td>5.05</td>
</tr>
</tbody>
</table>

Ductile Iron Society Annual Meeting May 11-13, 2010 Surrey BC
Minimizing Slag Generation

- Evaluate charge materials thoroughly
- Proper selection & addition of alloys
- Use of SiC
- Avoid excessive preheat

- Fines removal system
- Iron level in the furnace
- Lid use & condition
- Slag coagulant
- Right tools for the job
Charles Fink, Inductotherm

CHARLIE STARTED AT INDUCTOTHERM 47 YEARS AGO, WORKING FIRST IN INDUCTOTHERM’S SHOP, BUILDING FURNACES AND POWER SUPPLIES, AND LATER IN SERVICE, INSTALLING AND MAINTAINING THIS SAME EQUIPMENT. CHARLIE’S MOST RECENT THREE DECADES HAVE BEEN SPENT SERVING FOUNDRIES IN PENNSYLVANIA, NEW YORK, NEW ENGLAND AND THE MIDDLE AND SOUTHEASTERN UNITED STATES AS THE DISTRICT MANAGER AND AT TIMES IN THE SURROUNDING STATES AS A KEY MEMBER OF THE SALES DEPARTMENT. HE PLAYED A PIVOTAL ROLE IN CREATING INDUCTOTHERM’S LARGEST CORELESS MELTING INSTALLATION, THREE 70 TON STEEL SHELL FURNACES AT ALLEGHENY LUDLUM STEEL NEAR PITTSBURG. BEFORE FEDERAL EXPRESS CAME ON THE SCENE OFFERING OVERNIGHT PACKAGE DELIVERY, CHARLIE A PILOT, WOULD DELIVER CRUCIAL PARTS TO CUSTOMERS IN HIS SMALL PIPER CHEROKEE AIRPLANE.

TODAY, CHARLIE’S PILOTING TAKES PLACE ABOARD HIS BOAT, WHERE HE CAN BE FOUND MOST SUMMER WEEKENDS CRUISING THE DELAWARE BAY, CHESAPEAKE BAY AND OFFSHORE. HE IS ACTIVE IN THE AFS, AND HAS GIVEN MANY PRESENTATIONS AT VARIOUS AFS MEETINGS AND REGIONAL CONFERENCES. CHARLIE LIVES IN MOUNT LAUREL, NJ AND IS MARRIED WITH THREE GROWN CHILDREN. CHARLIE IS A PAST MEMBER OF THE INDUCTOTHERM’S CORPORATION BOARD OF DIRECTORS.
INNOVATIONS OF MEDIUM FREQUENCY INDUCTION MELTING
BY
C H FINK JR
INDUCTOTHERM CORP
INDUCTOTHERM HEADQUARTERS
MEDIUM FREQUENCY MELTING
MELT SHOP IN THE NEW MILLENNIUM
WHAT IS INDUCTION FURNACE?

- AN INDUCTION FURNACE IS AN ELECTRICAL FURNACE IN WHICH HEAT IS APPLIED BY INDUCTION HEATING OF A CONDUCTIVE MEDIUM (METAL) IN A CRUCIBLE PLACED IN A WATER COOLED ALTERNATING CURRENT SOLENOID COIL.
TWO TYPES OF INDUCTION MELTING FURNACES

- CORELESS FURNACE
- CHANNEL OR CORE TYPE FURNACE
TWO TYPES OF INDUCTION MELTING FURNACES

- CORELESS
- CHANNEL OR CORE
EARLY CORELESS INDUCTION MELT SYSTEMS IN 1950’S

- WERE POWERED BY HIGH FREQUENCY MOTOR GENERATORS
- WERE POWERED BY 60 HERTZ (MAINS) POWER SUPPLIES
- WERE NOT VERY FLEXIBLE AND REQUIRED A LOT OF OPERATOR ATTENTION
- THE OPERATOR HAD TO BE A OCTUPUS TO KEEP UP WITH THE CHANGES OF CAPACITOR AND TRANSFORMER TAPS
666 KW 1 KC MG SET WITH 1000 HP MOTOR 1950
MAINS FREQUENCY 60 HZ UNIT

TYPICAL THREE PHASE POWER CIRCUIT DIAGRAM

- POWER FUSES
- MAIN CONTACTOR
- SOFT START CONTACTOR AND SOFT START RESISTOR
- PRIMARY TAPPED POWER TRANSFORMER
- PHASE BALANCING
- SWITCHABLE CAPACITOR BANK
- FIXED CAPACITOR BANK
- FURNACE COIL
60 HERTZ AIR COOLED CAPACITOR RACK
WHAT DOES FREQUENCY MEAN?

- FREQUENCY: THE NUMBER OF PERIODS OF A REPETITIVE FUNCTION PER UNIT OF TIME
- FURNACE FREQUENCY: THE NUMBER OF TIMES PER SECOND THAT AN ALTERNATING CURRENT CHANGES FROM A POSITIVE SIGNAL TO A NEGATIVE SIGNAL.
- CALLED CYCLES PER SECOND OR HERTZ
WHAT IS MEDIUM FREQUENCY?

- OPERATING FREQUENCIES ABOVE 60 HERTZ BUT BELOW 1 KC
  - EXAMPLES:
    - 100/150 Hertz
    - 200/300 Hertz
    - 300/400 Hertz
    - 500/700 Hertz
WHAT DOES KW MEAN?

- KILOWATTS - A UNIT OF POWER OR ELECTRICAL ENERGY
- ONE KW EQUALS 1000 WATTS OF ENERGY
- ONE WATT = ONE AMPERE TIMES ONE VOLT
- INDUCTION FURNACES ARE RATING IN KW OR MEGAWATTS
- ONE KW = ABOUT 1.34 HP
RANGES OF INDUCTION SYSTEMS TO DATE

- 15 KW TO 23,000 KW MELTING
- 15 KW TO 42,000 KW HEATING
- 5 LBS TO 250 TONS CAPACITY
RANGE OF CORELESS INDUCTION COILS
50 POUND HAND POUR FURNACE
70 TON FURNACE POWERED BY 23 MEGAWATTS
The two purposes of the induction coil:
- To create a concentrated magnetic field
- To contain and rigidly support the refractory lining.
A VARYING MAGNETIC FIELD INDUCES CURRENT IN THE CHARGE
EDDY CURRENTS

INDUCED CURRENTS

SECONDARY CURRENTS ARE INDUCED INTO THE CHARGE.

POINT OF HIGH RESISTANCE CAUSES ADDITIONAL HEATING

A CURRENT IS INDUCED INTO EACH SEPARATE PIECE OF CHARGE MATERIAL.
... in a coreless induction furnace is caused by magnetic forces acting on the molten metal bath which result from the interaction of the electrical currents flowing in the induction coil and in the molten bath itself. These forces are strongest at the mid-point of the coil. The metal is forced toward the center of the bath, where it is diverted upward and downward. The upward movement of metal in the center causes the characteristic "swirl" of the coreless furnace.

... is affected by the power and frequency applied; the size and shape of the induction coil and molten bath; as well as the density and viscosity of the molten metal. The effects on stirring by the three most common variable factors are:

- Power
- Frequency
- Furnace size
STIRRING VS FURNACE SIZE
KW AND FREQUENCY

EFFECTS OF INCREASING FREQUENCY

INCREASE FREQUENCY

50 Hz
1000 Kw 4 Tonne

100 Hz
1000 Kw 4 Tonne

200 Hz
1000 Kw 4 Tonne

500 Hz
1000 Kw 4 Tonne

1000 Hz
1000 Kw 4 Tonne

INCREASE FURNACE

1000 Kw 3 Tonne

1000 Kw 2 Tonne

1000 Kw 1.5 Tonne

1000 Kw 1 Tonne

MORE POWER

1250 Kw 4 Tonne

2000 Kw 4 Tonne

3000 Kw 4 Tonne

4000 Kw 4 Tonne
MEDIUM FREQUENCY FURNACES VS MAINS

- Does not require starter blocks as does mains frequency
- Can melt scrap with smaller cross section
- Can be used as batch melters or low heel melters
- Furnace size is smaller for the same KW applied
- Can be emptied at the end of the day or week depending on size
- Requires less refractory because the furnace size is typically smaller
- Can be easily emptied and restarted with different analysis iron in batch melt mode
- Furnace components are smaller thus lower cost
- Lower holding power due to smaller furnace
- Shorter time required to reline
MELTING WITH MEDIUM FREQUENCY IS NOT NEW!

- FIRST 180 Hertz system built in 1961 using toroidal triplers
- FIRST 540 Hertz system built in 1965 also using triplers
- The largest 180 Hertz tripler system was rated at 3600 kW with 20 ton furnace in 1972 using triplers
180 HERTZ MELT SYSTEM 1972
600 KW AND 3000 LB FURNACE
EARLY SOLID STATE POWER SUPPLIES

- INTRODUCED TO THE FOUNDRY INDUSTRY IN 1967
- USED STUD MOUNTED TYPE SCRS
- USED MANY CONTROL BOARDS
- VERY COMPLEX FOR UNITS IN THE 500 KW RANGE
STUD MOUNTED SCR -- SILICON CONTROLLED RECTIFIER IN 1967 RATED 125 AMPS
HOCKEY PUCK SCR TODAY
TYPICAL HOCKEY PUCK RATINGS

- 53 MM SCR  2000 AMPS
- 77 MM SCR  4000 AMPS
- 100 MM SCR 5500 AMPS
THE CONTINUED DEVELOPMENT OF MORE POWERFUL HOCKEY PUCK SCRSHAS MADE IT POSSIBLE TO PROVIDE MELTING SYSTEMS ABLE TO APPLY 1000 KW PER METRIC TON OF FURNACE SIZE IN THE 100 TO 300 HERTZ RANGE.
SCR ASSEMBLY
1500 KW 200 HERTZ POWER SUPPLY SCR INVERTER SECTION
1500 KW 200 HERTZ POWER SUPPLY SCR RECTIFIER SECTION
MEDIUM FREQUENCY CAPACITORS

- In 1970 180 Hz capacitors were rated at 300 kVAR.
- Today medium frequency capacitors are rated as high as 5500 kVAR or higher.
- Require much less space and less water cooling.
AC WATER COOLED CAPACITORS
1500 KW 200 HZ POWER SUPPLY CAPACITOR SECTION
CONTROL BOARDS REDUCED TO ONE
SOLID STATE POWER SUPPLY
RATED 10,000 KW 200 HZ
SIMPLIFIED CONTROLS
BATCH MELTING VS HEEL MELTING

![Graph showing efficiency over time for Batch Melter and Heel Melter](image)
SINGLE POWER SUPPLY WITH SWITCHES
DUAL OUTPUT SYSTEM - 1991
TYPICAL LARGE VIP DUAL-TRAK WITH STEEL SHELL FURNACES.
TRIPLE OUTPUT SYSTEM - 1997

[Diagram showing a triple output system with 5,000 kW ACI, connected to three 5,000 kW inverters, each powering a 9 T Furnace]
20,000 KW TRIPLE OUTPUT SYSTEM

Diagram showing a 20,000 KW ACI system with three 10,000 KW inverters and capacitor banks, each associated with a 12.5 MT steel shell furnace.
FUTURE MULTIPLE OUTPUT SYSTEM FOR 100 TONS/HR

Diagram of a 50 MW Multiple-Output 100 Ton/Hour System with control and monitoring modules.
COMPUTER CONTROLS
FURNACE WEIGHING LOAD CELLS
DIGITAL CONTROLS NETWORKS

Diagram showing the flow of operations management, control room, digital melt shop control and data network, induction power supply, remote station, and furnaces.
CLOSE CAPTURE FUME COLLECTION AND BACK SLAGGING
10 METRIC TON FURNACE AND TRANSVERSE INDEXING CHARGE CAR
AUTOMATED CHARGE CONVEYORS WITH ACOUSTIC ENCLOSURES
PUSHOUT LINING REMOVAL SYSTEM
PUSHOUT LINING REMOVAL SYSTEM
LINING INSTALLATION UNITS
BOTTOM VIBRATOR
SAVEWAY LINING MONITOR SYSTEM

Diagram:
- Normal wear
- Coil
- Coil grout
- Electrode panel
- Refractory material
- Vertical crack
- Intensive erosion
- Metal fin
SAVEWAY ELECTRODE PANEL
INSTALLATION
SAVEWAY OPERATIONAL DISPLAY
ARMS SYSTEM - AUTOMATED ROBOTIC MELT SHOP
ARMS-AUTOMATED ROBOTIC MELT SHOP
MELT SHOP SAFETY!

- Working with molten metals has always been a dangerous job. Today's high efficiency induction furnaces have improved working conditions by making foundries cooler, cleaner and generally less hostile for the operators. They have not however eliminated the dangers inherent in working with molten metals!
THE INDUCTION FOUNDRY
SAFETY TRAINING KIT
"That's all Folks!"

Cartoon Songs From
MERRIE MELODIES & LOONEY TUNES
THANK YOU !
QUESTIONS ?
### FEATURES

- 2010 Spring Meeting Summary
- 2010 SPRING MEETING SPEAKER BIOS AND SELECTED PRESENTATIONS
- Refractory Concerns for Melting, Treating & Pouring Ductile Iron - Pete Satre
- Fluxing in Ductile Iron Melting and Pouring - Dave Williams
- Process Compensated Resonant Testing for Ductile Iron - Bob Nath
- Carbidic Ductile Iron - Marc King
- Melt Deck Safety - Chuck Cushing
- Ductile Iron Slag Management in Coreless Furnaces - Chris DeRosa
- Innovations in Medium Frequency Induction Melting - Charles Fink
- Front End Nodularity Determination Using Standard Coupons - Matt Meyer
- A.R.M.S. - Automatic Robotic Melt System - Paul Webber
- Studies of Nuclei in Ductile Iron - Why Is This Important For Foundrymen - Rob Logan

### DEPARTMENTS

- News Briefs
- Advertisers
- Back Issues
- DIS Home Page

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**Presentation Link:** (Presentation not Available)

Matt Meyer, Bremen Castings

MATT GRADUATED FROM MICHIGAN TECHNOLOGY UNIVERSITY IN HOUGHTON, MI WITH A BACHELOR OF SCIENCE IN METALLURGICAL AND MATERIALS ENGINEERING. MATT IS CURRENTLY THE TECHNICAL DIRECTOR AT BREMEN CASTINGS, INC. IN BREMEN, IN. HIS FOUNDRY CAREER STARTED WITH HICKMAN WILLIAMS & COMPANY IN THE DETROIT OFFICE AS A QUALITY ENGINEER AND WAS QUICKLY FOLLOWED UP BY HIS APPOINTMENT AS THE PLANT METALLURGIST AT GREDE IRON MOUNTAIN. MATT COMPLETED GRADUATE STUDIES AT THE UNIVERSITY OF WISCONSIN AT MADISON EARNING TWO MASTER’S DEGREES: ONE IN ENVIRONMENTAL CHEMISTRY AND TECHNOLOGY AND THE OTHER IN CIVIL AND ENVIRONMENTAL ENGINEERING. HE RETURNED TO GREDE AS THE TECHNICAL PROCESS ENGINEER AT THE REEDSBURG FOUNDRY BEFORE BEING PROMOTED TO TECHNICAL DIRECTOR AT GREDE ST. CLOUD IN 2006.

MATT AND HIS WIFE JENNIFER HAVE THREE DAUGHTERS, TWINS MEGAN & KIERSTEN, AND THEIR YOUNGEST ERIN. THEY ARE EXPECTING THEIR FOURTH CHILD AND MAYBE A SON THIS TIME? IN OCTOBER 2010.
Link to Presentation: [A.R.M.S. Automated Robotic Melt System](#)

![Paul Webber, Inductotherm](image)

**PAUL GRADUATED FROM THE UNIVERSITY OF WATERLOO IN WATERLOO, ONTARIO, CANADA WITH A BACHELOR OF SCIENCE IN CIVIL ENGINEERING. PAUL IS CURRENTLY THE MANAGING DIRECTOR FOR INDUCTOTHERM GROUP CANADA LTD. WHICH IS LOCATED IN TORONTO, CANADA. THIS DIVISION OF INDUCTOTHERM IS PRIMARILY RESPONSIBLE FOR EQUIPMENT SALES, REPAIRS, PARTS AND SERVICE THROUGHOUT CANADA. PAUL HAS SPENT HIS ENTIRE CAREER WORKING FOR SEVERAL FURNACE MANUFACTURERS IN CANADA. THE FIRST 10 YEARS AFTER GRADUATION HE WAS PRIMARILY INVOLVED WITH CONVENTIONAL FUEL FIRED FURANCES, INCLUDING THE DEVELOPMENT OF A RATHER REVOLUTIONARY NEW HEATING PROCESS, FOLLOWED BY THE LAST 25 YEARS IN THE INDUCTION INDUSTRY. IN PAUL’S OFF HOURS HE IS A MEMBER OF HIS LOCAL CURLING CLUB, ACTIVE IN THE LOCAL CHAMBER OF COMMERCE AND ASSIST IN COACHING MINOR GIRLS HOCKEY. IN ADDITION HE HAS BEEN A MEMBER OF THE AFS FOR OVER 20 YEARS.**
ARMS® SYSTEMS: AUTOMATED ROBOTIC MELT SHOP

Presented to the Ductile Iron Society

By: Paul Webber

INDUCTOTHERM
Automation in Manufacturing

• Maximum Production
• Maximum Safety
• Minimal Cost
Computer Automation on the Melt-Deck
Since 1988
**LAST SAMPLE TEMP.**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Value</th>
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<tbody>
<tr>
<td>665</td>
<td>TO HOLD POWER</td>
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<tr>
<td>1350</td>
<td>SAMPLE TEMP.</td>
</tr>
<tr>
<td>1400</td>
<td>POUR TEMP.</td>
</tr>
</tbody>
</table>

0.02 V. (0.4%) CONTROL SIGNAL

---

Ofen #1: 35 KW <- VIP #1
Status: AT POUR TEMP.
Info: 1500 KG, 1403 C

Messages: (2) (SIM) (SUPV)
At POUR TEMP. - Ofen #2

MELTMINDER 100, V4.00, SYSTEM 130  12:43:08  21/1/94  COMM OFF
Exposure to Fume
Manual Slagging Work is:
Hot
Heavy
& Dangerous
Manual Slagging
Causes of Splashing

• Addition of Trim Materials
• Dropping of Large pieces of Scrap
Causes of Explosions

- Wet Scrap Material
- Bridging of Unmelted Scrap
- Water System Failure
- Refractory Failure
## Injuries in Foundries - USA

### METAL CASTING INDUSTRY

**Incidence Rates of Nonfatal Occupational Injuries & Illnesses per 100 Full Time Workers**

<table>
<thead>
<tr>
<th>NAICS Code(1)</th>
<th>OSHA RECORDABLE INJURY &amp; ILLNESS CASES</th>
<th>CASES with Days Away, Restricted or Transferred (DART)</th>
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<tbody>
<tr>
<td></td>
<td>2003</td>
<td>2004</td>
</tr>
<tr>
<td>All Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Metal Manufacturing</td>
<td>331</td>
<td>9.6</td>
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<tr>
<td>Foundries (All)</td>
<td>3315</td>
<td>13.1</td>
</tr>
<tr>
<td>Ferrous Metal Foundries</td>
<td>33151</td>
<td>15.2</td>
</tr>
<tr>
<td>(Iron &amp; Steel Foundries)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron Foundries</td>
<td>33151</td>
<td>16.0</td>
</tr>
<tr>
<td>(Ductile, Gray, Malleable)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Investment Foundries</td>
<td>33152</td>
<td>10.6</td>
</tr>
<tr>
<td>Steel Foundries (Except Investment)</td>
<td>33153</td>
<td>15.2</td>
</tr>
<tr>
<td>Nonferrous Metal Foundries</td>
<td>33152</td>
<td>10.4</td>
</tr>
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<td>Aluminum Die-Casting Foundries</td>
<td>331521</td>
<td>11.7</td>
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<tr>
<td>Aluminum Foundries (Except Die-Casting)</td>
<td>331524</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Foundries as shown above

Have 2 - $2^{1/2}$ times more injuries
The Need for ARMS®

• Improve worker safety by relocating the furnace operator away from the most dangerous areas.
Benton Foundry
The First Installation of Automatic Robotic Melt Shop (ARMS®)

Benton Foundry has two 10 tonne back tilting furnaces including:

• Close Capture Fume Extraction Hoods
• Vibratory Scrap Metal Feeders
John Deere
Was the second installation of
Automatic Robotic Melt Shop
(ARMS®)

John Deere has numerous furnaces in the 20MT range. Including:
• Close Capture Fume Extraction Hoods
• Vibratory Scrap Metal Feeders
• Individual ARMS ® Systems
Robot’s Duties

- Charging the Furnace
- Removing Slag
- Taking Temperature Measurement
- Taking a Sample
- Adjusting Chemistry
- Molten Bath Ground Testing
Scrap Metal Feeder
Robot Training Without it’s High Temperature Safety Gear
Robot with Protective Suit
Tool Rack
Tool Rack
Robot Slagging Off Screen
Robot Slagging with Back Tilt
Robot Slagging with Clam Shell
Checking Bath Temperature
HMI Temperature Screen
Ground Check
HMI Bath Grounding Screen
HMI Trim Materials Screen
Adding Trim Material
Energy Savings

• Robot is fast pace with no delays
• Meaning minimal lid opening
• Resulting in energy savings
Automated furnace operations provide a variety of important advantages:

- Automated processes are precisely repeatable, ensuring consistency and improved productivity melt-after-melt.
- Fewer workers may be needed for melt deck tasks.
- Enhanced safety that may reduce worker compensation claims.
- Better working conditions, with the most dangerous tasks performed by the robot and other automated equipment, make it easier to recruit and retain foundry workers.

The primary benefit provided by the robotic equipment is greatly enhanced worker safety. The robot enables foundry management to remove the furnace operator from the most dangerous area - close to the furnace.
Presentation Link: Studies of Nuclei in Ductile Iron-Why Is This Important for Foundrymen

Rob Logan, Elkem Metals, Inc.

ROB GRADUATED FROM MCMASTER UNIVERSITY WITH A BACHELOR OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING AND ALSO HIS MBA. ROB IS CURRENTLY THE NATIONAL ACCOUNT MANAGER FOR ELKEM METALS INC., FOUNDRY DIVISION IN CANADA. ROB STARTED HIS CAREER AT DOFASCO IN 1988 IN HAMILTON, ONTARIO, CANADA IN VARIOUS PROCESS AND PRODUCT DEVELOPMENT ROLES. ROB THEN JOINED WESCAB INDUSTRIES IN 1994 AND WORKED IN A VARIETY OF MANUFACTURING POSITIONS INCLUDING METALLURGICAL, QUALITY AND ENGINEERING MANAGEMENT ROLES. IN 2001 HE MOVED INTO THE WESCAB PRODUCT DESIGN AND R&D GROUP AS PRODUCT DEVELOPMENT LEADER AND SOON BECAME THE CORPORATE R&D LEADER. ROB HAS BEEN WORKING IN THE IRON FOUNDRY AND STEEL BUSINESS FOR 22 YEARS. ROB HAS PUBLISHED AND PRESENTED SEVERAL PAPERS AT SAE, DIS AND MANY OTHER INDUSTRY FUNCTIONS IN NORTH AMERICA AND EUROPE. HE CURRENTLY RESIDES IN BRANTFORD, ONTARIO, CANADA.
DIS Conference – Vancouver 2010

Studies of Nuclei in Ductile Iron - Why is this important for Foundrymen?

Presented by Rob Logan, National Account Manager, Elkem Metals Inc.
Originally Prepared by D.S. White, Manager of Research and Technical Service, Elkem Metals Inc.
“A Model for Graphite Formation in Ductile Cast Iron”

Skaland conducted extensive studies of particles under several different conditions:

- in the iron matrix as well as within nodules,
- inoculated and not inoculated ductile irons
- particles were extracted and studied using SEM and TEM.
Classification of Micro-particles (Skaland)

Type A: 60%
Mg, Ca, S and Si

Type B: 20%
Mg and Si

Type C: 20%
Mg and P
Particles - nodularizing & inoculation (Skaland)

**Mg-treatment**

- Major constituent phases:
  - Shell: MgO $\text{SiO}_2$
  - $2\text{MgO} \cdot 2\text{SiO}_2$
  - Core: MgS
  - CaS

**Inoculation**

- Core: MgS
  - CaS
- Shell: MgO $\text{SiO}_2$
  - $2\text{MgO} \cdot 2\text{SiO}_2$
- X = Ca, Sr or Ba

Where $X = \text{Ca, Sr or Ba}$

- $X \text{SiO}_2$ or
- $X \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$

**Carbidic**

**Graphitic**
Fading of Inoculation (Skaland)

![Graph showing the relationship between inclusion number and holding time.](image-url)
What is Important for Foundrymen?

- Inoculants activate nuclei that are made during the MgFeSi treatment.
- The MgFeSi treatment is therefore the first step to controlling inoculation by providing sulfide and oxide particles.
- Inoculants can only activate what the MgFeSi treatment provided that remains after time. Therefore base iron S and O are key process parameters.
- The number of nuclei declines rapidly after these treatments, as they become coarser, so time is a key parameter.
Dr. Morten Onsoien’s PhD Thesis in 1997

Onsoien further studied the “Microstructure Evolution in Ductile Iron Containing Rare Earths”:

- Used a similar approach and Methodology to Skaland.
- If the MgFeSi is so important to nucleation, what happens with different contents and types of RE in the MgFeSi alloy.
An Improved Experimental Method (Onsoien)

Figure 1. Sketch of the experimental set-up for directional solidification of ductile iron.
## Effective Nuclei at various RE Input Levels (Onsoien)

| Table 3. Grouping of particles found in experimental cast irons. |
|---------------------|---------------------|---------------------|
| Casting             | Main elements in particles | Particle classification |
| 1/Reference         | Ca, Mg, Si, S, O       | Type A               |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 2/Low Ce            | Ca, Mg, Si, S, O, Ce   | Type A+Ce            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 3/Medium Ce         | Ca, Mg, Si, S, O, Ce   | Type A+Ce            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 4/High Ce           | Ca, Mg, Si, S, O, Ce   | Type A+Ce            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 5/Very High Ce      | Ca, Mg, Si, S, O, Ce   | Type A+Ce            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 6/Low La            | Ca, Mg, Si, S, O, La   | Type A+La            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 7/Medium La         | Ca, Mg, Si, S, O, La   | Type A+La            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 8/High La           | Ca, Mg, Si, S, O, La   | Type A+La            |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 9/Low Misch-metal   | Ca, S, Mg, Si, Ce, La  | Type A+Ce+La         |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |
| 10/High Misch-metal | Ca, S, Mg, Si, Ce, La  | Type A+Ce+La         |
|                     | Mg, Si                | Type B               |
|                     | Mg/Ce, P              | Type C               |

* Present (+), not present (-).
Nodule Count Peaks for Pure Ce or Pure La Alloyed MgFeSi alloys (Onsoien)

Figure 9. Effect of cerium and lanthanum on the graphite formation in ductile iron; (a) Normalised nodule count vs. Ce content, (b) Normalised nodule count vs. La content. Corresponding data from Kanetkar et al. are included for comparison.
What is Important for Foundrymen?

- Foundrymen should consider testing MgFeSi alloys with different RE contents and different types of RE.
- It takes far less La to get the optimum nodule count, than any of the other RE elements.
- Avoid chunky and exploded, with less RE, by considering a more powerful RE, such as La?
Professor Solberg and Onsoien 2001

Wrote a paper titled “Nuclei for Heterogeneous Formation of Graphite in Ductile Cast Irons”

- Type A particles are magnesium silicon aluminum nitrides, not magnesium silicates.
- \( \text{Mg}_{2.5}\text{Si}_{2.5}\text{AlN}_6 \) (aluminum nitride type hexagonal structure)
- Still ineffective for graphite growth due to crystal spacing differences
Nakae and Igarashi (2002) - Influence of Sulfur on Heterogeneous Nucleus of Spheroidal Graphite

<table>
<thead>
<tr>
<th></th>
<th>0.00035 S</th>
<th>0.0029 S</th>
<th>0.014 S</th>
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<td>cooling rate: 25K/s</td>
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<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Fig. 2 Optical microstructure of graphite for these samples.

Nodule Count Increases as Base S Increases
Nuclei convert from Nitrides to Sulfides as Base S Increases above 0.005% (Nagae and Igarashi)

Fig. 4 SEM observation of graphite nucleus-like cores in Mg-treated iron for 0.0022 mass% S base melt.

Fig. 6 SEM observation of graphite nucleus-like cores in Mg-treated iron for 0.013 mass% S base melt.
Nuclei Types Detected at Different Base S Levels (Nakae and Igarashi)

Proposed that spherical particles may still be liquid when graphite starts to grow and may more readily grow at the interface.

<table>
<thead>
<tr>
<th>mass% S of BM*</th>
<th>Nucleus materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>shape of N**</td>
</tr>
<tr>
<td>0.0022</td>
<td>rectangle</td>
</tr>
<tr>
<td>0.0052</td>
<td>spherical</td>
</tr>
<tr>
<td>0.013</td>
<td>&quot;</td>
</tr>
<tr>
<td>0.050</td>
<td>&quot;</td>
</tr>
<tr>
<td>0.072</td>
<td>&quot;</td>
</tr>
<tr>
<td>0.083</td>
<td>&quot; / faceted</td>
</tr>
</tbody>
</table>

* base melt, ** nucleus, *** nucleus materials, **** other materials
What is Important for Foundrymen?

- Base S is a key variable due to conversion from nitride to sulfide type nuclei, when the base S is elevated above 0.005%.

- Nodule count increases as base S is raised further to 0.014%.

- Should base S be adjusted for the desired of nodule count?

- From a practical perspective, as S increases, so does Mg and MgFeSi addition rates required to desulfurize.

- Should the foundry optimum alloy design change due to different base S and different addition rates due to treatment efficiency improvements?
Skaland work on Inoculation Late 90’s to early 2000’s

- Can Inoculants Now add More Nuclei?
- O and S additions studied by Skaland.
- If we include O and S with inoculants what will this do to the nuclei structure?
Skaland - Test Pattern Design for experimental work

- 10 mm
- 20 mm
- 40 mm
- 5 mm

- Wedge
- Tensile
- Cross bars
Nodule count vs. section size

O & S bearing inoculant

Conventional

312
297

340
155

5 mm section

40 mm section
Soundness in crossbars

- O&S bearing inoculant: 353 Nodules/mm²
- Ba-FeSi: 221 Nodules/mm²
- Sr-FeSi: 219 Nodules/mm²
Thermal analysis of inoculation

Conventional

- \( T_{E_{\text{low}}} = 1139^\circ\text{C} \)
- Undercooling = 25^\circ\text{C}
- Recalescence = 6.2

O&S bearing inoculant

- \( T_{E_{\text{low}}} = 1145^\circ\text{C} \)
- Undercooling = 19^\circ\text{C}
- Recalescence = 2.3
Thermal Analysis Can Predict Shrinkage Tendency

- Curves that are rounded down during the second half of freezing correlate with increased shrinkage.
- Curves that stay flatter through the end of freezing correlate with even distribution of graphite precipitation through freezing. This leads to nodule size distributions with many small late forming nodules, and reduced shrinkage.
- Simply increasing nodule count may increase shrinkage, as can be seen with Bi containing inoculants.
Other studies completed on S and O in inoculants

- Riposan et al paper at 2003 Keith Mills DIS Paper “Contraction Curves to Identify the Influence of Inoculants on Shrinkage Behaviour of Ductile Iron”
  - Paper showed that O, S (Ca, Ce) bearing inoculant resulted in less shrinkage as a result of a wide distribution of nodule sizes, including late forming nodules

  - The results show that the wall thickness of ductile cast iron has very strong effect on the diameter of graphite spheroids.
  - O, S (Ca, Ce) bearing inoculant reduces the above effect.
RIPOSAN - Studies of Nuclei of O, S containing Inoculants

- Riposan conducted several studies of Nuclei using standard MgFeSi, combined with additions of standard Ca inoculant and inoculant containing S, O (Ce, Ce) bearing inoculants.
- Studied the difference in nuclei within large nodules and tiny late forming nodules.
RIPOSAN - Studies of Nuclei of O, S containing Inoculants

- Findings of Analysis of O,S bearing Inoculants:
  - Large nodules: high Mg, low O levels
  - Small nodules: higher Ca, O, and Si
  - Both Nodules: Have high levels of S
  - Ce present only in melts using Ce bearing inoculant
  - Al highest in med size nodules
- In summary the nuclei are different and it appears that different nuclei activate at different times during freezing.
What is Important for Foundrymen?

Late addition of O and S has several benefits

- Creates a skewed distribution of nodules by promoting new nucleation sites that form late in solidification.
- Increased nodule count and chill reduction
- Less shrink prone iron, particularly in thicker, long to freeze sections.
- Higher potency S and O bearing inoculant can allow a foundry to maintain a lower base S for reduced MgFeSi usage, since the late addition of S and O can compensate with a powerful late nucleation effect.
  - In studies up to only 1/3rd the amount of inoculant may be required.
Skaland in early 2000’s with La REM

Published paper “A new method of Shrinkage and Chill Control”

- Further studied optimizing RE Type and Content in MgFeSi
- Look at microstructures and shrinkage rating after MgFeSi treatment but before inoculation.
- Then looked at microstructure again after inoculation as well.
Skaland - Test Pattern Design for experimental work

Wedge

Tensile

Cross bars

10 mm
20 mm
40 mm
5 mm
Microstructure in 5 mm Plates – NOT INOCULATED – 1.5 % Addition rate of MgFeSi

FREE

(b) 595 N/mm

0.5% La

(c) 488 N/mm

1.0% La

(d) 164 N/mm

0.5% Ce

(e) 177 N/mm

1.0% Ce

(f) 418 N/mm

1.0% Mishmetal
Microstructure in 20 mm Plates – NOT INOCULATED – 1.5 % Addition rate of MgFeSi

(a) 112 N/mm
(b) 224 N/mm
(c) 188 N/mm
(d) 148 N/mm
(e) 149 N/mm
(f) 178 N/mm
Nodule Size Distribution in 20 mm Plates – Not Inoculated

(a) FREE
(b) 0.5La
(c) 1.0La
(d) 0.5Ce
(e) 1.0Ce
(f) 1.0MM
Shrinkage Porosity in Cross Bars

(a) FREE 8.3 %
(b) 0.5La 0.0 %
(c) 1.0La 0.0 %
(d) 0.5Ce 2.3 %
(e) 1.0Ce 2.0 %
(f) 1.0MM 38.2 %
Microstructure in 5 mm plates – NOT INOCULATED – 1.5 % Addition Rate

- FREE
- 0.1% La
- 0.2% La
- 0.3% La
- 0.4% La
- 0.5% La

(d) 200 N/mm  
(e) 320 N/mm  
(f) 250 N/mm
Microstructure in 5 mm plates - same irons as previous slide – INOCULATED – FeSi Ca Bearing.
RIPOSAN - Further Studies of Nuclei, La Containing MgFeSi

- La was present in most nuclei when La alloyed MgFeSi (either pure La or other containing La and RE) was used.

- Findings regarding the differences in chemistry of the nuclei of the large early forming nodules versus the tiny late forming nodules are similar for the La alloyed MgFeSi as for the S and O bearing inoculant. The late forming nodules contain CaO while the early forming ones are (Mg, Ca)S.

- More (medium amounts) of S was present in the nuclei containing La.
What is Important for Foundrymen?

La as the main form of RE in MgFeSi has several advantages:

- Creates a skewed distribution of nodules by promoting new nucleation sites that form late in solidification.
- Increased nodule count and chill reduction
- Less shrink prone iron can be produced.
Inoculation starts with the base iron and Mg treatment, as S, O, and N compounds form and suspend in the metal bath.

- Less violent treatments retain more valuable nuclei.

When the S increases above 0.005% the nucleus type changes from a nitride to a sulfide.

- This is a key parameter to increase nodule count and reduce carbide tendency.

Time after treatment is a key parameter as nuclei tend to grow and reduce in number with time.
Summary of What is Important for Foundrymen

- New nuclei can be added with a S and O coated inoculant.
  - Opportunity to reduce base S and MgFeSi additions in the process for a considerable economic advantage.
  - Less than half the addition rate compared to FG FeSi adds to that advantage.
- Small late forming nodules add a late expansion effect to reduce shrinkage porosity.
  - This is achieved with S and O coated inoculant and/or La alloyed MgFeSi.
  - La is the most effective type for minimal additions, optimized nodule counts, and shrinkage control.
THANK YOU

Questions?
MEETINGS

Heavy Section Ductile Iron Conference

The Ductile Iron Society Fall Meeting will be held October 27-29, 2010 at the Marriott Cleveland Downtown at Key Center Hotel in Cleveland, Ohio.

BUSINESS

Washington Mills Breaks Ground on a 10,000 Ton Silicon Carbide Expansion

Washington Mills has started construction to expand its silicon carbide furnace plant in Hennepin, Illinois. The new construction will add an additional 10,000 tons per annum of silicon carbide crude manufacturing capacity. This expansion will bring Washington Mills’ total silicon carbide crude capacity to 70,000 tons and is expected to be completed sometime in late 2010.

Washington Mills is expanding its silicon carbide crude production in order to take advantage of the growing demand for its CARBOREX® silicon carbide micro grits and powders. The best way to produce CARBOREX® silicon carbide powders to requested specifications is to control the manufacturing process from start to finish. Expanding its silicon carbide furnace plant gives Washington Mills control over the quality of the silicon carbide crude used as feedstock to produce high quality CARBOREX® microgrits. Increased production capacity will allow the company to continue supplying sales opportunities for CARBOREX® powders in the semiconductor, photovoltaic, and advanced ceramic industries as well as in standard abrasive applications.
This silicon carbide expansion is also aimed at continuing to supply a growing demand for a secure domestic source of metallurgical grade silicon carbide in North America. In addition to producing crystalline silicon carbide for the applications noted above, Washington Mills produces CARBOLON MA, a high quality metallurgical grade silicon carbide that is used as a source of carbon and silicon in the production of iron castings. CARBOLON MA is also a popular choice for the steel industry because its powerful, uniform deoxidizing properties can improve cost savings through effectively reducing slag and recovering valuable elements such as manganese and chromium.

The silicon carbide furnace expansion will feed into our patented SULFEROX environmental control system, which converts the additional off-gases into a solid state through an environmentally friendly process. Environmentally, Washington Mills’ Hennepin silicon carbide plant has one of the most advanced emission control systems in the world. Washington Mills’ sophisticated environmental control system contains the off-gases and particulate matter and then further processes the particulates and treats the gases in order to remove the sulphur.

Washington Mills’ reliable, high quality silicon carbide furnace operation puts the company in an excellent position to respond to customers’ needs. Washington Mills is the only silicon carbide furnace facility in the U.S, whereas much of the other silicon carbide production resides in developing countries. Washington Mills’ strategic U.S location makes it a dependable and stable source of silicon carbide. We’re expanding our furnace capacity at Hennepin because we believe in our future business opportunities for silicon carbide, and Hennepin is a competitive and environmentally sustainable facility that will be a reliable source of high quality silicon carbide for years to come.

Washington Mills, founded in 1868, is the largest electro-minerals producer in the U.S and serves customers around the world. Washington Mills has facilities in the U.S, Canada, Norway and the U.K.

Inquiries: awilliams@washingtonmills.com