The Ductile Iron Society Spring 2012 Annual Meeting was held at the Holiday Inn-Muskegon Harbor on June 6-8, 2012. On the Wednesday the normal committee meetings were held and concluded with the Board of Directors meeting at 3pm. The activities of the research Committee can be found later in this publication under the Annual Meeting remarks by the DIS President, Scott Gledhill of Waupaca Foundry. For the next fiscal year 2012/13 the Board of Directors approved the funding of two new research projects. They are project #48 – Evaluation of Normalizing Heat Treatment to Develop Improved Properties in Heavy Section Pearlitic Iron and project #49 - Analysis of Pearlitic Ductile Iron with Enhanced Mechanical Properties. The cost for both projects is $38,000 and it was awarded to Element Material Technology in Wixom, MI. The estimated time for completion is 12 months.

On Thursday June 7th, the group received 10 excellent technical presentations. You can find more information about those presentations by clicking on the left side under each author. At lunch, Scott Gledhill, the DIS President delivered the Annual Members Meeting summary.

Here are the notes from Scott’s presentation;

AT THIS TIME I WILL RECAP THE SOCIETY’S ACTIVITIES DURING THIS PAST YEAR BEFORE PROCEEDING WITH THE ANNUAL BUSINESS MEETING AND THE ELECTION OF NEW OFFICERS.

THE PAST YEAR HAS BEEN ONE WHERE THE FOUNDRY INDUSTRY SEEMS TO BE AT CAPACITY, WHERE THE US ECONOMY IS SHOWING A MUCH SLOWER GROWTH RATE. YOUR SOCIETY HAS HAD A FEW FIRSTS IN MANY YEARS. THE DUCTILE IRON MARKETING GROUP COMMITTEE PURCHASED OUR FIRST EVER DISPLAY BOOTH AND EXHIBITED AT THE 2011 RAILWAY SHOW BACK IN SEPTEMBER 2011 IN MINNEAPOLIS, MINNESOTA. THEN IN MAY 2012 THE DIMG EXHIBITED AT THE AGRICULTURAL MACHINERY CONFERENCE IN WATERLOO, IA. BOTH SHOWS WERE A GREAT SUCCESS AND WE WERE ABLE TO CONNECT WITH DESIGN ENGINEERS AS WELL AS HELP OUT SOME CONSUMERS OF DUCTILE IRON CASTINGS FIND A PRODUCER. THANKS GO OUT TO JOHN LEWENSKY ALONG WITH HIS COMMITTEE MEMBERS AND VOLUNTEERS WHO WORKED THE BOOTH AT BOTH EXPOS.

IN ADDITION, THE MEMBER SERVICES COMMITTEE PURCHASED A TABLE TOP BOOTH AND WAS ABLE TO BE DISPLAYED AT THE 2012 AFS CASTING CONGRESS. WHAT A GREAT SUCCESS THAT WAS. EVEN THE NEIGHBORS AROUND OUR BOOTH WERE COMMENTING ON THE TRAFFIC AT THE DIS BOOTH. THANKS GO OUT TO JEFF HALL
ALONG WITH HIS COMMITTEE MEMBERS AND VOLUNTEERS.

IN THE LAST FEW MONTHS WE FINALLY MOVED THE ENTIRE LIBRARY BOOKS FROM STORAGE TO A NEW OFFICE SPACE ON THE SAME FLOOR AS THE CURRENT HEAD OFFICE. WE ARE STRIVING TO MAKE THIS LIBRARY AVAILABLE TO THE MEMBERS THROUGH THE WEBSITE. MORE NEWS WILL BE AVAILABLE AS THE CHANGES ARE MADE. THESE BOOKS WERE A COLLECTION OF ART SPANGLER, LYLE JENKINS, P. H. MANI AND KEITH MILLIS.

THIS PAST FISCAL YEAR WE GAINED A FEW NEW MEMBERS.

DONSCO (FOUNDRY)
GREDE HOLDING, LLC (FOUNDRY)
MID-CITY FOUNDRY (FOUNDRY)
ALLIED MINERAL PRODUCTS (ASSOCIATE)
MRO RESOURCES LLC (ASSOCIATE)
S&B INDUSTRIAL MINERALS (ASSOCIATE)
CAPITAL REFRACTORIES (ASSOCIATE)
FAIRMOUNT MINERALS (ASSOCIATE)
BORCHERT ASSOCIATES (ASSOCIATE)
GREEN PACKAGING (ASSOCIATE)

DURING THIS PAST YEAR WE HELD TWO GENERAL MEETINGS. THE FIRST ONE WAS OUR ANNUAL MEETING HELD IN DALLAS, TEXAS IN CONJUNCTION WITH A TOUR OF OIL CITY IRON WORKS IN CORSICANA, TEXAS, WITH 98 ATTENDING INCLUDING 9 SPOUSES AND GUESTS. THE SECOND MEETING HELD LAST FALL, WAS IN GETTYSBURG, PA IN CONJUNCTION WITH TOUR OF TB WOODS IN CHAMBERSBURG, PA. THE ATTENDANCE FOR THAT MEETING WAS 130.

THE DUCTILE IRON SOCIETY HELD A PRODUCTION SEMINAR BACK ON FEBRUARY 21 & 22, 2012 IN ROLLING MEADOWS, ILLINOIS. THE ATTENDANCE WAS A RECORD 52 FOR THIS SEMINAR. WE WERE VERY DELIGHTED TO SEE SO MANY REGISTER FOR THE SEMINAR. THANKS GO OUT TO OUR VERY SPECIAL INSTRUCTORS, KATHY HAYRYNEN OF APPLIED PROCESS, FRED LINEBARGER OF MILLER & COMPANY, GENE MURATORE OF RIO TINTO AND DON CRAIG OF SELEE CORPORATION. DON WAS OUR NEWEST INSTRUCTOR AS THIS YEAR WE ADDED A DEFECT ANALYSIS SESSION.

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 2011 COLLEGE INDUSTRY CONFERENCE HELD ON NOVEMBER 17 & 18, 2011 AT THE WESTIN HOTEL IN CHICAGO. I WOULD LIKE TO THANK JOHN KEOUGH OF APPLIED PROCESS AND GARY GIGANTE OF TK WAUPACA FOR SELECTING THIS YEAR’S STUDENTS. THEY WERE ERICA HILL OF NORTHERN IOWA UNIVERSITY, JOSEPH GRAY OF WEST MICHIGAN UNIVERSITY,
RYAN BRATTRUD OF NORTHERN IOWA UNIVERSITY, AND KANE ROHRIG OF PITTSBURG STATE UNIVERSITY. EACH STUDENT RECEIVED $2000.

YOUR DIS BOARD HAS AGREED ONCE AGAIN THIS YEAR TO MAKE UP WHATEVER SHORT FALL AMOUNT SO THAT WE CAN CONTINUE TO HAND OUT $8000.00 IN SCHOLARSHIPS AT THE NEXT FEF CIC CONFERENCE IN NOVEMBER 2012.

YOUR SOCIETY CONTINUES TO MAKE A DONATION TO THE KEITH MILLIS SCHOLARSHIP FUND EVERY YEAR SO IT WILL CONTINUE TO GROW. THIS PAST YEAR WE MADE A ONE TIME DONATION OF $25,000 AND REACHED A GOAL OF CHROMIUM IN DONATIONS TO THE KEITH MILLIS FUND.

JIM WOOD ATTENDED THIS PAST YEAR’S CONFERENCE. WE ALSO HAD A BOOTH FOR THE INDUSTRY INFORMATION SESSION WHERE WE DISTRIBUTED THE “STRETCH THE POSSIBILITIES” T-SHIRTS. THEY WERE A VERY POPULAR HANDOUT DURING THIS SESSION AS YOU WOULD WELL UNDERSTAND. THANKS GO OUT TO KATHY HAYRYNEN OF APPLIED PROCESS AND ERIC MEYERS OF OIL CITY IRON WORKS WHO DONATED THEIR TIME TO HELP OUT IN THE BOOTH.

ONCE AGAIN THANKS TO THE MEMBERS THAT SPONSORED THESE T-SHIRTS. THEY ARE ASK CHEMICALS, APPLIED PROCESS, BUCK COMPANY, BLUEWATER THERMAL, BENTON FOUNDRY, BREMEN CASTINGS, BLACKHAWK DE MEXICO, ELYRIA FOUNDRY, ELKEM, FARRAR CORPORATION, FOSECO, FUNDICION AGUILAS MEXICO, FERRO PEM, GREDE HOLDINGS, HODGE FOUNDRY, HICKMAN WILLIAMS, HITACHI METALS AUTOMOTIVE, PRIMETRADE, PURE POWER, SINTO, AND THYSSENKRUPP WAUPACA. ALSO I SHOULD MENTION THE HARD WORK BY YOUR UNIVERSITY RELATIONS COMMITTEE MEMBERS. THANKS GO OUT TO BILL SORESEN AND PAM LECHNER FOR THEIR INVITATION TO ATTEND THIS IMPORTANT CONFERENCE.

THE RESEARCH COMMITTEE MET THREE TIMES DURING THE PAST YEAR. WE COMPLETED ONE BIG PROJECT IN 2011-2012. TWO YEARS AGO YOUR BOARD OF DIRECTORS APPROVED THE FUNDING OF $47,000 TO BE SPENT OVER 2 YEARS ON A DIS PROJECT NUMBER #46. WE WERE 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 WAS $155,000.

WE WILL NOW PROCEED WITH THE ANNUAL BUSINESS MEETING.

WE HAVE 2 FOUNDRY MEMBERS RETIRING FROM THE BOARD OF DIRECTORS AS OF JUNE 30TH. THEY ARE J. B. BROWN OF BREMEN CASTINGS, AND DAVE KNAPP OF GLIDEWELL SPECIALTIES FOUNDRY COMPANY. WE ALSO HAVE 1 ASSOCIATE BOARD MEMBER RETIRING THIS YEAR. HE IS DAN SALAK OF ASK CHEMICALS WHO COMPLETED JOHN CAMELI’S OF TECPRO’S TERM. WE WOULD LIKE TO THANK ALL THREE BOARD MEMBERS FOR THEIR PARTICIPATION AND DEDICATION TO THE SOCIETY OVER THE
PAST 3 YEARS.

ALONG WITH THESE BOARD MEMBERS, OUR SCOTT GLEDHILL, PRESIDENT OF THE DIS WILL RETIRE AS OF JUNE 30TH.

TO REPLACE THOSE RETIRING BOARD MEMBERS, THE NOMINATING COMMITTEE RECOMMENDS THE FOLLOWING SLATE TO SERVE ON THE BOARD OF DIRECTORS FOR A 3 YEAR TERM EFFECTIVE JULY 1, 2012;

KIRK MCCULLOUGH (FOUNDRY MEMBER) OF SENECA FOUNDRY
MIKE RIABOV (FOUNDRY MEMBER) OF NEENAH FOUNDRY
DAN SALAK (ASSOCIATE MEMBER) TO SERVE HIS OWN TERM UNDER ASK CHEMICALS

ALONG WITH THESE BOARD MEMBERS, THE NOMINATING COMMITTEE AND BOARD OF DIRECTORS HAVE ELECTED ROBERT O’ROURKE TO FILL THE VACANT POSITION OF VICE PRESIDENT FOR THE NEXT 2 YEARS. PATRICIO GIL OF BLACKHAWK FOUNDRY de MEXICO, THE CURRENT VP WILL FILL THE POSITION OF PRESIDENT FOR THE NEXT 2 YEARS.

THE ATTENDEES WERE ASKED TO APPROVE THE SLATE. THERE WAS TOTAL APPROVAL AND NO OBJECTIONS. THE SLATE PASSED.

SCOTT ASKED THE AUDIENCE IF THERE WERE ANY FURTHER QUESTIONS AND THERE WERE NONE.

WITH THAT, HE DECLARED THAT THE ANNUAL MEETING WAS ADJOURNED.

********

The day ended with an awesome reception and banquet. The master of ceremonies for the banquet was the DIS President Scott Gledhill of Waupaca foundry. First Scott introduced our guests who attended the meeting. They were;

Srikanth Sivaraman from Snam Alloys in India
Lenny Basaj and David Kesse from MTI Ravenna
Matt Sharifi from Ariel Corporation
David Blandford of Padnos
Sandeep Deshpande & Greg Alexander of Intat
Vicente Sanchez from the Consul, Mexican Consulate Detroit
Marie Galindo from the Asociacion de Profesionistas Mexicanos en Michigan- Society of Mexican Professionals in Michigan.

Scott then presented the New Members certificates to the following companies and representing member who was attending and receiving the certificates;
Next, we asked Gene Muratore and Kathy Hayrynen, the morning and afternoon technical directors to come to the front of the room for the speaker’s gift presentations.
Scott then asked the retiring directors to come to the front and receive their Directors Service certificates. The following gentlemen have retired from 3 years’ service on the Board of Directors.
From left, Jim Wood, Dave Knapp of Glidewell Specialties & Scott Gledhill

Also Dan Salak of ASK Chemicals. Dan finished out the service commitment for John Cameli who retired early from Tecpro. The Society thanks these gentlemen for their service on the board for the last 3 years. The new directors who were voted in by the Board and including Dan are; Kirk McCullough of Seneca Foundry and Mike Riabov of Neenah Foundry. Since this is Scott’s last meeting as President, and Patricio Gil of Blackhawk de Mexico will be taking over, the Board elected Robert O’Rourke of Wells Durabar as the new Vice President for the next 2 years. Congratulations to these 4 gentlemen for their new appointments.

Jim Csonka of Hickman Williams then announced to the group the winning slogan for this year’s University Relations Committee t-shirt that will be handed out to the students who attend the FEF Conference in Chicago in November. The slogan is “Flakes Are For Cereals Not Ductile Materials”.

This year’s Ductile Iron Society’s Member of the Year is John Lewensky of Pure Power Technologies Metalcasting Group (Formerly Navistar). John was first introduced by his good friend Gene Muratore of Rio Tinto.
John Lewensky (Pure Power) & Gene Muratore

John Lewensky Acceptance Speech

John is relatively new to the DIS but when he was asked to take over the Ductile Iron Marketing Group, the feet hit the ground and he is still running. John took this large group of volunteers and now has the DIS exhibiting at least twice a year. Congratulations John!

Next the Ductile Iron Society handed out the first ever “DIS Lifetime Achievement Award”. This year’s recipient was Prem Mohla, retired Hickman Williams, after 40 years plus of service to the foundry business and the Ductile Iron Society.

Jim Wood (DIS) Introducing Prem
Prem Mohla Acceptance Speech

Prem started his education by graduating in India with his Masters in Metallurgy, then moved to England and received his PhD in Metallurgy. After graduating, his working career started by returning to India and working for Tata Automotive. He then moved to the US and went to work at Ford Motor Company in Detroit. After working for Ford for a number of years he then moved on to Intermet, then Globe Metallurgical and finished his working career at Hickman Williams & Company where he retired December 31, 2012. Congratulations Prem!!

Next, the DIS new President, Patricio Gil of Blackhawk de Mexico presented the Past President Award to Scott Gledhill.

From left Jim Wood, Scott Gledhill & Patricio Gil

The DIS wished to thank again Scott for his past 4 years of dedicated service to the Society.

Patricio then asked Vicente Sanchez and Marie Galindo to speak for a few minutes about the achievements of Patricio Gil as our new President but also the DIS first President from Mexico. Thanks to both Vicente and Marie for driving over from the Detroit area to witness Patricio taking over as the President of the DIS from Scott.
The evening concluded by Patricio inviting Jim Heethuis, Vice President and General Manager of CWC Textron to make a short presentation about CWC and what the tour attendees would see the next day.

Patricio then concluded the evening by making a great presentation about the foundry industry and where he wants to take the DIS over the next 2 years and beyond.

On Friday, June 8th the group then went on a tour of CWC Textron in Muskegon, MI. The DIS wishes to thank Jim, Phil Johnson and the rest of the group of tour guides for this awesome visit.
After the CWC tour the group went down the street to take a tour of Anderson Global Innovative Tooling Solutions. The DIS wishes to thank Betsy and John McIntyre for arranging a tour of their great facility. We also wish to thank the tour guides for looking after our group.
**Anderson Global Plant in Muskegon, MI**

This concluded the Spring Annual Meeting in Muskegon and the DIS hopes to see everyone at the fall in Peoria, IL with a tour of Caterpillar’s Foundry in Mapleton, IL.

Jim Wood  
DIS Executive Director

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<tr>
<td>Phone (440) 665-3686, Fax (440) 878-0070</td>
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<tr>
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June 7, Morning Session

SPEAKER BIO’S

GENE MURATORE - SESSION CHAIR

DAVID GILSON

DAVID GRADUATED FROM THE UNIVERSITY OF WISCONSIN-MADISON WITH HIS BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. HE STARTED HIS CAREER IN THE FOUNDRY INDUSTRY AT MOTOR CASTINGS COMPANY IN MILWAUKEE, WISCONSIN FOR 3 YEARS. HE THEN RETURNED TO SCHOOL TO OBTAIN HIS MASTERS OF BUSINESS ADMINISTRATION DEGREE FROM THE UNIVERSITY OF WISCONSIN-MILWAUKEE. HE THEN JOINED ASHLAND CHEMICAL’S FOUNDRY PRODUCTS DIVISION AFTER GRADUATE SCHOOL. DAVID STARTED IN THE TECHNICAL SERVICE GROUP EVENTUALLY BECOMING THE TECHNICAL SERVICE MANAGER PRIOR TO RELOCATING TO MONTERREY TO LEAD ASHLAND’S FOUNDRY BUSINESS IN MEXICO. AFTER 3 YEARS, HE RETURNED TO THE US TO BECOME THE GLOBAL MARKETING MANAGER. IN 15 YEARS AT ASHLAND, HE AUTHORED MANY ARTICLES FOR PUBLICATION IN THE AFS TRANSACTIONS AND OTHER TECHNICAL JOURNALS, GAVE INTERNATIONAL, NATIONAL AND REGIONAL PRESENTATIONS, AND WAS PART OF A TEAM THAT GAINED A PATENT ON RISER SLEEVE TECHNOLOGY. HE THEN JOINED REXNORD INDUSTRIES IN 2008 IN MILWAUKEE IN AN EXECUTIVE MARKETING POSITION TO WORK IN THE POWER TRANSMISSION AND WIND ENERGY MARKETS. IN 2011, HE CAME BACK TO THE FOUNDRY INDUSTRY TO LEAD SINTERCAST’S GLOBAL COMMERCIAL GROUP.

THE DIS WELCOMES DAVID WHO IS HERE TO TALK ABOUT “MARKET ADVANCES IN COMPACTED GRAPHITE IRON”
MARK ADAMOVITS

MARK GRADUATED FROM JOHN CARROLL UNIVERSITY IN CLEVELAND, OHIO WITH HIS BACHELOR OF SCIENCE DEGREE IN CHEMISTRY. HE THEN CONTINUED HIS EDUCATION BY OBTAINING HIS EXECUTIVE EDUCATION MARKETING PROGRAM FROM NORTHWESTERN KELLOGG SCHOOL OF BUSINESS AND HIS EXECUTIVE EDUCATION FINANCE PROGRAM FROM INDIANA KELLEY SCHOOL OF BUSINESS. HE STARTED HIS WORKING CAREER AT FAIRMOUNT MINERALS LTD - WEDRON SILICA AND TECHNISAND RESIN COATED SAND OPERATIONS, IN VARIOUS PRODUCT MANAGERS, QUALITY, AND R&D POSITIONS. HE WAS THERE FOR 5 YEARS. MARK THEN MOVED OVER TO ASHLAND CHEMICAL NOW KNOW AS ASK CHEMICALS L.P. IN VARIOUS PRODUCT MANAGER POSITIONS, TECHNICAL SERVICE, QUALITY, MANUFACTURING, BUSINESS DEVELOPMENT, AND COMMERCIAL POSITIONS. HE IS CURRENTLY THE SENIOR PRODUCT MANAGER AND HAS BEEN AT ASK CHEMICALS FOR OVER 20 YEARS. MARK IS ALSO A MEMBER OF THE PENN STATE METAL-CASTING ADVISORY COMMITTEE.


THE DIS WELCOMES MARK WHO IS HERE TO TALK ABOUT “PATRIOT – THE NEW BENCHMARK FOR LARGE DUCTILE IRON NO-BAKE MOLDING OPERATIONS”
KEVIN PILON


THE DIS WELCOMES KEVIN WHO IS HERE TO TALK ABOUT “EVALUATING ALTERNATIVE CHARGE MATERIALS FOR MELTING: CHEMISTRY AND COST”

*******
DOUG GRADUATED FROM McMaster University in Hamilton, Ontario, Canada in 1970 with his Bachelor of Science Degree in Metallurgy. Doug is currently the Technical Services Manager for Elkem Foundry Products. After a brief period at the Steel Company of Canada R&D department, he joined Crouse Hinds of Canada, a gray iron and aluminum foundry, serving as a Metallurgist to set up the melt and pour cycle of a new coreless induction furnace line. In 1974, he joined Union Carbide Canada Ltd., Metals Division. This business was later purchased by Elkem and became Elkem Metal Canada Inc. In addition to Canada, Doug has held positions with Elkem in Oslo, Norway, Antibes, France, Pittsburgh, PA and Ashtabula, OH. His activities have involved foundry technical service for gray and nodular iron manufacture, design and manufacture of nodulizers and inoculants, and desulfurization technology. Doug has written numerous papers, held technical seminars, and made many foundry visits in Canada, Europe, SE Asia, Australia and the United States. Doug served as president of the Ontario Chapter of AFS from 1981 to 1982, and currently serves on the DIS Research Committee.

THE DIS WELCOMES DOUG BACK AGAIN TO TALK ABOUT “HOW TO MINIMIZE RARE EARTH USAGE IN DUCTILE IRON”
RICHARD GUNDLACH


THE DIS WELCOMES RICK BACK AGAIN TO TALK TO US ABOUT “A SUMMARY OF THE ELEMENTS EFFECTS ON DUCTILE IRON”
June 7 Afternoon Session

Speaker Bios

Kathy Hayrynen - Session Chair

MEGHAN OAKS

MEGHAN GRADUATED FROM MICHIGAN TECHNOLOGICAL UNIVERSITY IN 2009 WITH A BACHELOR OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING. THE FOLLOWING SEMESTER, SHE STARTED GRADUATE SCHOOL WORKING UNDER PAUL SANDERS. SHE GRADUATED IN 2011, ALSO FROM MICHIGAN TECH, WITH A MASTERS OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING. HER THESIS TITLE WAS “EFFECTS OF SILICON CONTENT AND COOLING RATE ON THE MECHANICAL PROPERTIES OF HEAVY SECTION DUCTILE CAST IRON”. MEGHAN IS CURRENTLY WORKING AS AN R&D ENGINEER FOR APPLIED PROCESS, IN LIVONIA, MI. SHE WAS OUR GUEST STUDENT DURING THE DIS HEAVY SECTION CONFERENCE HELD IN OCTOBER 2010 IN CLEVELAND, OHIO. SHE IS ALSO A MEMBER OF THE AFS 5R CAST IRON RESEARCH COMMITTEE, DIS RESEARCH COMMITTEE AND THE MICHIGAN TECH FOUNDRY ADVISORY BOARD.

THE DIS WELCOMES MEGHAN WHO IS HERE TO TALK ABOUT “LETTING MR. CHARPY DIE: EVALUATING THE USEFULNESS OF CHARPY IMPACT TESTING ON DUCTILE IRON”

**********
TOM PRUCHA


THE DIS WELCOMES TOM WHO IS HERE TO TALK ABOUT “THE NEW AFS GUIDE TO DUCTILE MICROSTRUCTURES”

********
CUPOLA OPERATIONS PANEL

MARK BIDOLI


THE DIS WELCOMES MARK WHO IS HERE TO TALK ABOUT “US FOUNDRY COKE SUPPLY…AND FACTORS THAT DRIVE THE MARKET”

SCOTT GLEDHILL/RICK ERICKSON

SCOTT GRADUATED FROM THE UNIVERSITY OF ALABAMA WITH B.S. IN METALLURGICAL ENGINEERING. WHILE AT SCHOOL HE CO-OPED AT STOCKHAM VALVES AND FITTINGS IN BIRMINGHAM SPENDING TIME IN THE BRONZE, GREY IRON, MALLEABLE IRON AND METALLURGICAL AREAS.

IN 1985, SCOTT STARTED AT GM CENTRAL FOUNDRY IN DEFIANCE
OHIO.

IN 1992 SCOTT JOINED THYSSENKRUPP WAUPACA AT THEIR MARINETTE PLANT AS PLANT METALLURGIST. DURING SCOTT’S 19 YEARS WITH THYSSENKRUPP HE HAS HELD VARIOUS POSITIONS INCLUDING METALLURGIST, QUALITY MANAGER, PLANT MANAGER, MANAGER OF RESEARCH AND IS CURRENTLY DIRECTOR NEW PRODUCT INTRODUCTION.

SCOTT HAS BEEN INVOLVED IN VARIOUS AFS AND DIS COMMITTEES INCLUDING MOLTEN METAL PROCESSING, MOLD-METAL INTERFACE, DIS RESEARCH AND IS CURRENTLY PRESIDENT OF THE DIS. HE IS ALSO CHAIRMAN OF THE INDUSTRIAL ADVISORY BOARD FOR THE METALLURGICAL DEPT. AT THE UNIVERSITY OF ALABAMA.

THE DIS WELCOMES SCOTT WHO IS HERE TO PRESENT FOR RICK ERICKSON AND TALK ABOUT “MATERIAL COST REDUCTION IDEA’S FOR TODAY’S FOUNDRY”

ROBERT BIGGE


THE DIS WELCOMES BACK BOB WHO IS HERE TO TALK ABOUT “IMPROVING CUPOLA EFFICIENCY”

*******

PETE SATRE

PETE GRADUATED FROM OHIO STATE UNIVERSITY IN 1994 WITH HIS
BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. PETE STARTED HIS CAREER WITH FORD MOTOR COMPANY IN CLEVELAND, OHIO AS PROCESS ENGINEER, REFRACTORY SUPERVISOR, AND MAINTENANCE PLANNING SPECIALIST. PETE WAS THERE FOR A TOTAL OF 10 YEARS IN THE MELTING DEPARTMENT OF THIS CAPTIVE GRAY AND DUCTILE IRON FOUNDRY. HE THEN MOVED TO COLUMBUS, OHIO AND BEGAN HIS NEW CAREER WITH ALLIED MINERAL PRODUCTS AS A PRODUCT SERVICES ENGINEER. HE IS CURRENTLY THE MANAGER OF ENGINEERING, WHICH INCLUDES PRODUCT APPLICATION AND ENGINEERING RESPONSIBILITIES WORLDWIDE. PETE IS A MEMBER OF THE AFS AND PAST CHAIRMAN OF THE MELTING METHODS AND MATERIALS AND PAST CHAIRMAN OF THE CUPOLA COMMITTEE.

THE DIS WELCOMES BACK PETE WHO IS HERE TO TALK ABOUT “REFRACTORY ALTERNATIVES FOR COMBATING ELEPHANT’S FOOT erosion AND TOP CAP WEAR IN CORELESS FURNACES”
DAVID GILSON

DAVID GRADUATED FROM THE UNIVERSITY OF WISCONSIN-MADISON WITH HIS BACHELOR OF SCIENCE IN METAL-LURGICAL ENGINEERING. HE STARTED HIS CAREER IN THE FOUNDRY INDUSTRY AT MOTOR CASTINGS COMPANY IN MILWAUKEE, WISCONSIN FOR 3 YEARS. HE THEN RETURNED TO SCHOOL TO OBTAIN HIS MASTERS OF BUSINESS ADMINISTRATION DEGREE FROM THE UNIVERSITY OF WISCONSIN-MILWAUKEE. HE THEN JOINED ASHLAND CHEMICAL'S FOUNDRY PRODUCTS DIVISION AFTER GRADUATE SCHOOL. DAVID STARTED IN THE TECHNICAL SERVICE GROUP EVENTUALLY BECOMING THE TECHNICAL SERVICE MANAGER PRIOR TO RELOCATING TO MONTERREY TO LEAD ASHLAND'S FOUNDRY BUSINESS IN MEXICO. AFTER 3 YEARS, HE RETURNED TO THE US TO BECOME THE GLOBAL MARKETING MANAGER. IN 15 YEARS AT ASHLAND, HE AUTHORED MANY ARTICLES FOR PUBLICATION IN THE AFS TRANSACTIONS AND OTHER TECHNICAL JOURNALS, GAVE INTERNATIONAL, NATIONAL AND REGIONAL PRESENTATIONS, AND WAS PART OF A TEAM THAT GAINED A PATENT ON RISER SLEEVE TECHNOLOGY. HE THEN JOINED REXNORD INDUSTRIES IN 2008 IN MILWAUKEE IN AN EXECUTIVE MARKETING POSITION TO WORK IN THE POWER TRANSMISSION AND WIND ENERGY MARKETS. IN 2011, HE CAME BACK TO THE FOUNDRY INDUSTRY TO LEAD SINTERCAST'S GLOBAL COMERCIAL GROUP.

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THE DIS WELCOMES MARK WHO IS HERE TO TALK ABOUT “PATRIOT – THE NEW BENCHMARK FOR LARGE DUCTILE IRON NO-BAKE MOLDING OPERATIONS”
Patriot – The New Benchmark for Large Ductile Iron No-Bake Molding

Mark Adamovits
Sr. Product Manager
ASK Chemicals L.P.

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Don’t Ride The Roller Coaster ! .... At Least Not The Financial One.
Furan No-Bake = Inherent Volatility

Furfuryl Alcohol Volatility
Baseline Price = 2008 - CQ3

NOTES: Upward Trend
60% Volatility

Market Reaction: Phenolic Modification & Reduction in Performance Properties

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Furan No-Bake Volatility Drivers

Increased Industrial & Consumer Demand

Governmental Policy / Material Resources

Regulation & Tariff Inequalities

Climate Change

Limited Agricultural Resources

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Phenolic Urethane No-Bake Volatility

NOTES: Upward Trend
< 40% Volatility

Market Reaction: Improved Product Performance @ Lower Cost
Dynamic Shift: PUNB is Now The Lowest Cost Technology Platform

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Phenolic Urethane No-Bake Drivers

- Increased Usage of Bio-Based Materials
- Abundant Gas & Oil / Decreased Demand
- Consolidation of Multiple Operations
- Improved Manufacturing Efficiencies
- Short & Efficient Supply Chain

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
# Flake Skin Graphite & Sulfur Defects

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<th>Molding Process = Acid Cured Furan</th>
<th>Molding Process = Phenolic Urethane</th>
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<tr>
<td>1.00% Binder Level BOS</td>
<td>1.00% Binder Level BOS</td>
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<tr>
<td>30% TSA Based Catalyst BOR</td>
<td>6% Catalyst BOPI</td>
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<tr>
<td>Common 65% TSA Catalyst</td>
<td>Common 15% Amine Catalyst</td>
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- 0.03- 0.04% Sulfur @ Mold : Metal Interface
- 3X That Value With Mechanical Reclaim Sand
- Flake Skin Graphite & Sulfur Related Defects
- 0.00% Sulfur @ Mold : Metal Interface
- Elimination of 1° Sulfur Source in Reclaim Sand
- Elimination of Sulfur Related Defects

Dynamic Shift: Superior Process for Large & Safety Critical Ductile Iron Castings
No Sulfur = Opacity & Odor Reduction

OPACITY DEFINITION: “The amount of light which is blocked by a medium such as smoke or a film of tint on a window. It is a visual determination made by a trained & certified observer.”

APPLICABILITY: The US EPA supports opacity measurements because they believe that these measurements provide an indication of the concentration of pollutants leaving a smokestack or point source within a manufacturing facility.

NUISANCE ODORS: Nuisance odors have become a top 5 issue for most large no-bake molding operations in North America.

APPLICABILITY: Odor is a measureable and quantifiable property via ASTM Standard of Practice E679-91. This standard identifies (7) objective odor measuring techniques including the type of odor detected. Sulfur odors fall into the “Character Descriptor” category.

Environmental Shift: Low & No Sulfur Resin Technologies Improve Opacity & Odor Reduction.
Core & Mold Strength Comparison

Technology Shift: Equivalent or Better Core & Mold Strength Properties When Compared to Modified Furan Technology

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Mold-Making Productivity Band

Technology Shift: Superior Productivity Attributes (WT : ST Ratio) Resulting in Lower Costs to Produce Per Unit Molds & Castings

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Mold-Making Safety Margins

Real Work Time Safety Margin Profile
- PATRIOT vs. Furan Technologies
  - 100% Resin on 60 AFS/65 GRN Silica Sand
  - (66 Minute Cure Times)

CAUTION!

Technology Shift: Superior Safety Characteristics / Instantaneous Through Cure

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Summary: The New Benchmark

Minimize Price Volatility
- No Furfuryl Alcohol
- No Dependence on China / Tariffs
- No Climate Change / Agricultural Influence

Superior Operational Performance
- Higher Productivity
- Superior Safety Margins
- Reduced Opacity & Nuisance Odors

Superior Casting Attributes
- Elimination of Sulfur Related Defects
  - Flake Skin Graphite
  - Shrinkage

PATRIOT = “Made in America”
- R&D – Created in America
- Raw Materials Made in America
- Product Made in America

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Questions & Additional Information:

Name: Mark Adamovits
   Senior Product Manager

Address: ASK Chemicals L.P.
   5200 Blazer Parkway
   Dublin, OH 43017

Phone: (614) 790 - 6988

Fax: (614) 790 – 4359

E-mail: mark.adamovits@ask-chemicals.com

Web Site Address: www.ask-chemicals.com
Thank You
KEVIN PILON

KEVIN GRADUATED FROM THE UNIVERSITY OF WISCONSIN - MILWAUKEE IN 1985 WITH A BACHELOR OF SCIENCE DEGREE AND IN 1986 WITH A MASTER OF SCIENCE DEGREE IN MATERIALS ENGINEERING. UPON GRADUATION, KEVIN WENT TO WORK FOR NEENAH FOUNDRY COMPANY AS A MELTING SUPERVISOR AND THEN AS A SUPERINTENDENT. KEVIN LEFT NEENAH AND JOINED ELKEM METALS COMPANY AS A MARKET DEVELOPMENT ENGINEER IN LATE 1990. HE WORKED WITH VARIOUS CUSTOMERS PROVIDING TECHNICAL SUPPORT IN FERROALLOYS.


THE DIS WELCOMES KEVIN WHO IS HERE TO TALK ABOUT “EVALUATING ALTERNATIVE CHARGE MATERIALS FOR MELTING: CHEMISTRY AND COST”
Evaluating Alternative Charge Materials – Cost and Chemistry

Kevin L. Pilon
Carpenter Brothers, Inc.

Carpenter Brothers, Inc.

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Muskegon, Michigan
Misnomers

- Purchasing Agents – always buy the lowest cost material, scrap is scrap!
- Metallurgists – always want the highest cost, highest quality scrap!
- Scrap Dealers – are the devil in disguise!
What Materials to Use, or Choose?

- Depends on the desired chemistry or product being produced – safety part, wear part, fatigue application, weight, etc.
- Availability of raw material – sometimes you just take what you can get!
- Melting practice – electric or cupola.
- And as always, PRICE!
Chemistry

- What are you producing?
  - Gray Iron – wear part, counter weight, etc.
  - Ductile Iron – safety art with fatigue applications, wear part, etc.
  - Specialty Metals – is it to be alloyed, or even heat treated?
Availability of Material

• Good or desirable materials may not be available in abundant quantities.
• Less than desirable materials may be quite abundant.
• "Bleed" in less desirable materials to reduce overall melt costs – a couple of $ per ton quickly adds up on an annual basis.

Sometimes you have to use what you can get, and then use the best available at the best price.
Melting Practice

• Electric Melt
  – Type of furnace – medium frequency vs. line frequency – are you emptying the furnace, or tapping small amounts and replenishing?
  – Preheat, or no preheat
  – Furnace size

• Cupola Melt
  – Cupola diameter
  – Limitations to charging system
Melting – Available Methods

- Arc Furnace
- Cupola
- Electric
  - Channel Induction
  - Coreless Induction
Melting – Available Methods

Arc Furnace

Cupola

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Melting – Available Methods

Coreless Induction

Channel Induction
Melting – Coreless/Induction

- Disadvantages
  - Delicate lining
  - Lining wear
  - Limited raw material selection
  - Limited melt capacity
  - Iron more difficult to inoculate

- Advantages
  - Good mixing
  - Low sulfur heats for DI
  - Temperature control
  - Chemistry control
Melting - Cupola

- Disadvantages
  - Chemistry control
  - Downtime for repair/maintenance
  - Need to desulfurize for DI

- Advantages
  - Iron more receptive to inoculation
  - Low cost
  - Higher melt rates
  - Greater variety of raw materials
Melting – Raw Materials Selection

- Steel Scrap – slitter, busheling, shredded, rail
- Cast Scrap – purchased cast, GI returns, DI returns
- Pig Iron – foundry pig, GI pig, DI pig
- Carbon – pet coke, graphitized carbon, high/low sulfur content, blended...
- Silicon Carbide
- FeSi – 50% silicon content, 75% silicon content
- Other Alloys – P, Mn, Cr, ... depending on the type of iron you are making
Melting – Critical Elements

- Carbon (C) – typically picked up from returns, pig iron, SiC and carbon
- Silicon (Si) – typically picked up from returns, SiC, FeSi
- Manganese (Mn) – typically picked up from steel cast scrap, returns, and remelt
- Copper (Cu) – typically picked up from steel, cast scrap, and returns
- Sulfur (S) – typically picked up from carbon raisers
Melting – Critical Elements

- Chromium (Cr), Molybdenum (Mo), Vanadium (V) – typically picked up in steel scrap
- Titanium (Ti) – typically present in ferroalloys and pig iron
- Lead (Pb) – typically present in non-ferrous material in steel scrap
- Phosphorous (P) – typically present in cast scrap, pig iron, and steel scrap
- Tellurium (Te) – present in thermal analysis cups
- Boron (B) – typically present in steel scrap
Melting – Gray Iron

- Typical GI Grades & Chemistries
  - GI35 – C-3.20%, Si-1.90%
  - GI25 – C-3.40%, Si-2.20%
  - Other grades, GI18, GI30, GI40

- GI Defined – GI35 (35,000 psi tensile), GI25 (25,000 psi tensile), all have less than 1% elongation
Melting – Ductile Iron

• Typical DI Grades & Chemistries
  – DI60-40-18 – C-3.65%, Si-2.60%, Mg-0.042%, Cu-less than 0.1%
  – DI80-55-06 – C-3.65%, Si-2.60%, Mg-0.042%, Cu-0.20-1.00% (depending on section thickness)
  – Mn, Sn, Sb, Ni can act similar to Cu
  – Other grades-65-45-12, 100-70-03, 120-90-02
• DI Defined – DI65-45-12 (65,000 psi tensile strength, 45,000 psi yield strength, 12% elongation)
Raw Materials Evaluation

- Visit your scrap supplier
- Invite our scrap supplier into our facility
- Least cost charge programs
- Similar, less, and not so similar, sheets
- Sometimes you can run the numbers in a rough ram or sheet before actually melting any material
Visit Your Scrap Supplier

- Review your current materials
- How are your materials brought in?
- Where are they brought in from?
- How are materials shipped out?
- How are materials stored?
- What alternatives do they have that don’t quite meet your specifications?

And ask ... “What’s in that pile over there?”
Invite Your Scrap Supplier Into Your Facility

- Introduce them to your charging / melting department and its restrictions
- Show them your lab where you not only test their material, but the product made from it
- Finally, show them what you are making, the final product going out the door – they may be using your parts and not even know it
Least Cost Charge Programs

- Cost money, but can save money in the long run
- Sometimes, but not always, cumbersome to use - user friendly?
- Limited in what they can do
Simple, and Not So Simple Spreadsheets

- How are your capabilities in Excel?
- Tailor to your operation
- Evaluate any material you want
- Track any element you want
- Make it as simple, or as complicated as you want, or need

Start simple, and build from there!
A Simple Spreadsheet Could Include

- Different Materials Used
- Material Costs
- Material Chemistries
- Losses / Recoveries
- Alloying / Treatment / Inoculation
- Total Material Cost
- Final Chemistry
- A workbook for ductile, gray, electric melt, or cupola melt
- ?
### Spreadsheet Breakdown

**Materials Used and Costs**

| Raw Material/Commodity | Cost | % of Change | Cost | % of Total Cost | Si | % Si | Mn | % Mn | Cu | % Cu | Fe | % Fe | C | % C | P | % P | O | % O | Cr | % Cr | Mo | % Mo | V | % V |
|------------------------|------|-------------|------|-----------------|----|------|----|------|----|------|----|------|----|------|----|------|----|------|----|------|----|------|----|------|----|------|
| Alumina Sierso | $570.00 | 12.0% | $475.05 | 22.9% | 1.25 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Slag | $464.00 | 10.0% | $314.12 | 12.8% | 1.25 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Silicon Carbide | $265.00 | 5.0% | $178.52 | 25.0% | 1.25 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Carbon | $174.00 | 3.0% | $121.42 | 11.0% | 1.25 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

<table>
<thead>
<tr>
<th>Total Org Wt</th>
<th>1,000</th>
<th>Total Charge Cost/Ton</th>
<th>$1,376.47</th>
<th>Total Org Wt</th>
<th>2,000</th>
<th>Total Charge Cost/Ton</th>
<th>$1,376.47</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>3.71%</td>
<td>1.00</td>
<td>3.71%</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Alloy Trim Addition to Ladle**

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (Lbs)</th>
<th>% Mg</th>
<th>% Si</th>
<th>% C</th>
<th>% P</th>
<th>% O</th>
<th>% Cr</th>
<th>% Mo</th>
<th>% V</th>
<th>Total Wt</th>
<th>Treatment Size (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgS 1</td>
<td>1.00%</td>
<td>20.0%</td>
<td>0.95%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>10.00%</td>
<td>10.00</td>
</tr>
<tr>
<td>MgS 2</td>
<td>1.00%</td>
<td>20.0%</td>
<td>0.95%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>10.00%</td>
<td>10.00</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.10%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>10.00%</td>
<td>10.00</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>10.00%</td>
<td>10.00</td>
</tr>
<tr>
<td>Inco (Kiln)</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>0.00%</td>
<td>10.00%</td>
<td>10.00</td>
</tr>
</tbody>
</table>

**Total Charge Costs:**
- Total Charge Cost/Ton: $585.53
- Total Alloying Cost/Ton: $585.53

**Total Cost/Ton, Metals Only:**
- $536.10

**Final Chemistry:**
- Mg: 0.04%
- Si: 0.61%
- C: 3.71%
- P: 0.00%
- O: 0.00%
- Cr: 0.00%
- Mo: 0.00%
- V: 0.00%

**Recovery Lab:**
- Carbon from Ingot billets: 95%
- Silicon from Ingot billets: 95%
- Alum from Ingot billets: 95%
- Wt from Ingot billets: 95%
- All other recoveries are total.
Materials Used & Costs

Electric Melt

- Raw Material or Commodity
- Cost/ton
- Amount used in charge
- % of total charge
- Total charge weight
- For cupola melt, include coke, limestone, and even desulfurization costs

### Electric Melt

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matl. Cost/Ton</th>
<th>Weight (lbs.)</th>
<th>% of Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slitter/Busheling</td>
<td>$650.00</td>
<td>1895</td>
<td>37.9%</td>
</tr>
<tr>
<td>Shredded</td>
<td>$431.00</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Returns</td>
<td>$500.00</td>
<td>2250</td>
<td>45.0%</td>
</tr>
<tr>
<td>Pig Iron</td>
<td>$550.00</td>
<td>750</td>
<td>15.0%</td>
</tr>
<tr>
<td>FeSi</td>
<td>$2,320.00</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>$1,450.00</td>
<td>35</td>
<td>0.7%</td>
</tr>
<tr>
<td>Carbon</td>
<td>$1,122.00</td>
<td>70</td>
<td>1.4%</td>
</tr>
<tr>
<td><strong>Total Chg. Wt.</strong></td>
<td><strong>5000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cupola Melt

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matl. Cost/Ton</th>
<th>Weight (lbs.)</th>
<th>% of Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slitter/Busheling</td>
<td>$570.00</td>
<td>1918</td>
<td>38.4%</td>
</tr>
<tr>
<td>Shredded</td>
<td>$430.00</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>R I m</td>
<td>$500.00</td>
<td>2250</td>
<td>4%</td>
</tr>
<tr>
<td>Pig Iron</td>
<td>$550.00</td>
<td>750</td>
<td>15.0%</td>
</tr>
<tr>
<td>FeSi</td>
<td>$2,320.00</td>
<td>12</td>
<td>0.2%</td>
</tr>
<tr>
<td>Silicon Carbide Briquettes</td>
<td>$1,450.00</td>
<td>70</td>
<td>1.4%</td>
</tr>
<tr>
<td>Coke</td>
<td>$350.00</td>
<td>600</td>
<td>12.0%</td>
</tr>
<tr>
<td>Limestone</td>
<td>$11.00</td>
<td>125</td>
<td>2.5%</td>
</tr>
<tr>
<td>CaC2</td>
<td>$540.00</td>
<td>35</td>
<td>0.7%</td>
</tr>
<tr>
<td><strong>Total Chg. Wt.</strong></td>
<td><strong>5000</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Material Cost Breakdown

#### Charge Calculation - Electric Melt - DI

<table>
<thead>
<tr>
<th>Raw Material / Commodity</th>
<th>Mass Cost/Ton</th>
<th>Weight (Lbs)</th>
<th>% of Charge</th>
<th>Mass Cost/Lb</th>
<th>Total Mass Cost</th>
<th>% of Total Cost</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% O</th>
<th>% S</th>
<th>% Mo</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>427.20</td>
<td>1.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00%</td>
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<tr>
<td>Tin</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>1.272</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
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<td>0.2%</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.272</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
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</tr>
</tbody>
</table>

**Total Org Wt:** 5000 lbs

**Total Charge Cost:** $1,376.47

### Alloying Addition to Ladle

<table>
<thead>
<tr>
<th>Alloying Addition to Ladle</th>
<th>Mass Quality</th>
<th>Weight</th>
<th>Additions (Lbs)</th>
<th>Charge (Lb)</th>
<th>% Mg</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% O</th>
<th>% S</th>
<th>% Mo</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Copper</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Incidental (aluminum alloying)</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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</tr>
</tbody>
</table>

**Total Alloying Cost:** $58.53

**Total Cost/Ton, Metals Only:** $236.10

**Total Cost/Ton:** $274.63

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**DIS Annual Meeting, June 7, 2012**  
**Muskegon, Michigan**
Material Cost Breakdown

- Material cost per lb.
- Total material in charge
- % of total charge cost
- Determine the greatest cost contributor

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matl. Cost/lb.</th>
<th>Total Matl. Cost</th>
<th>% of Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slitter/Bushing</td>
<td>$0.285</td>
<td>$540.08</td>
<td>39.2%</td>
</tr>
<tr>
<td>Shredded</td>
<td>$0.216</td>
<td>$0.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>Returns</td>
<td>$0.250</td>
<td>$562.50</td>
<td>40.9%</td>
</tr>
<tr>
<td>Pig Iron</td>
<td>$0.279</td>
<td>$209.25</td>
<td>15.2%</td>
</tr>
<tr>
<td>FeSi</td>
<td>$1.160</td>
<td>$0.00</td>
<td>0.0%</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>$0.725</td>
<td>$25.38</td>
<td>1.8%</td>
</tr>
<tr>
<td>Carbon</td>
<td>$0.561</td>
<td>$39.27</td>
<td>2.9%</td>
</tr>
<tr>
<td><strong>Tot. Chg. Cost</strong></td>
<td></td>
<td><strong>$1,376.47</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Tot. Chg. Cost/Ton</strong></td>
<td></td>
<td><strong>$579.57</strong></td>
<td></td>
</tr>
</tbody>
</table>
Spreadsheet Breakdown

Chemistry Contribution

Charge Calculation - Electric Melt - DI

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matt Cost/1000</th>
<th>Weight</th>
<th>% of Change</th>
<th>Matt Cost/lbs</th>
<th>Total Matt Cost</th>
<th>% of Total Cost</th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% O</th>
<th>% S</th>
<th>% N</th>
<th>% V</th>
<th>Fe V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Carbide</td>
<td>$6,500</td>
<td>0.00</td>
<td>100.00</td>
<td>$0.00</td>
<td>$650.00</td>
<td>0.00</td>
<td>0.65</td>
<td>3.60</td>
<td>0.30</td>
<td>5.40</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Tungsten</td>
<td>$2,720</td>
<td>0.00</td>
<td>100.00</td>
<td>$0.00</td>
<td>$272.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.30</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Boron</td>
<td>$2,000</td>
<td>0.00</td>
<td>100.00</td>
<td>$0.00</td>
<td>$200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
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</tr>
<tr>
<td>Titanium</td>
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<td>100.00</td>
<td>$0.00</td>
<td>$272.00</td>
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<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Total</td>
<td>$1,220</td>
<td>0.00</td>
<td>100.00</td>
<td>$0.00</td>
<td>$122.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>$6,500</td>
<td>0.00</td>
<td>100.00</td>
<td>$0.00</td>
<td>$650.00</td>
<td>0.00</td>
<td>0.65</td>
<td>3.60</td>
<td>0.30</td>
<td>5.40</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Org Wt: 0.000
Total Charg. Cost/1000: $1,378.47

Alloy Trim Addition to Ladle

<table>
<thead>
<tr>
<th>Metal</th>
<th>Weight</th>
<th>Additions</th>
<th>Ladle</th>
<th>% Mg</th>
<th>% P</th>
<th>% Si</th>
<th>% S</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% O</th>
<th>% S</th>
<th>% N</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg Cast</td>
<td>0.00</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Copper Block</td>
<td>0.00</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>0.00</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Copper Hose</td>
<td>1.2%</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Ingot Oil</td>
<td>0.00</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Trim Wt</td>
<td>0.00</td>
<td>1.2%</td>
<td>132.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Total Alloying Cost/1000: $56.53

Final Chemistry

<table>
<thead>
<tr>
<th>Element</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.00%</td>
</tr>
<tr>
<td>Si</td>
<td>0.00%</td>
</tr>
<tr>
<td>Mn</td>
<td>0.00%</td>
</tr>
<tr>
<td>Cu</td>
<td>0.00%</td>
</tr>
<tr>
<td>P</td>
<td>0.00%</td>
</tr>
<tr>
<td>O</td>
<td>0.00%</td>
</tr>
<tr>
<td>S</td>
<td>0.00%</td>
</tr>
<tr>
<td>N</td>
<td>0.00%</td>
</tr>
<tr>
<td>V</td>
<td>0.25%</td>
</tr>
</tbody>
</table>

Recovery Labs

- Carbon from Integrated Nickel, etc.: 0%
- Carbon from Graphite: 0%
- Silicon from Steel: 0%
- Silicon from pig iron: 0%
- Silicon from spent carbon: 0%
- Manganese from spent carbon: 0%
- Manganese from steel: 0%
- All other recoveries are total

**DIS Annual Meeting, June 7, 2012**
**Muskegon, Michigan**
Chemistry Contribution

- Track only what you want, or what you feel is important
- Determine the total chemical contribution from each commodity used
### Spreadsheet Breakdown

**Charge Calculation - Electric Melt - DI**

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matt. Cost/Ton</th>
<th>Weight (lbs)</th>
<th>% of Change</th>
<th>Matt. Cost/lb</th>
<th>Total Matt. Cost</th>
<th>% of Total Cost</th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% Cr</th>
<th>% Mo</th>
<th>% V</th>
<th>% N</th>
<th>% O</th>
<th>% Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon/Casting</td>
<td>$120.00</td>
<td>160</td>
<td>32%</td>
<td>$0.75</td>
<td>$46.48</td>
<td>12.9%</td>
<td>5.4%</td>
<td>0.5%</td>
<td>3.6%</td>
<td>0.0%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Spreader</td>
<td>$220.00</td>
<td>60</td>
<td>0.0%</td>
<td>$3.70</td>
<td>$22.20</td>
<td>6.0%</td>
<td>0.0%</td>
<td>3.9%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Return</td>
<td>$90.00</td>
<td>250</td>
<td>33%</td>
<td>$0.36</td>
<td>$90.00</td>
<td>22.5%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Pig Iron</td>
<td>$270.00</td>
<td>150</td>
<td>48%</td>
<td>$1.80</td>
<td>$54.00</td>
<td>14.7%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1,520.00</td>
<td>600</td>
<td>9.2%</td>
<td>$13.12</td>
<td>$1,059.47</td>
<td>28.9%</td>
<td>0.0%</td>
<td>3.1%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Silicon/Casting</td>
<td>$120.00</td>
<td>160</td>
<td>32%</td>
<td>$0.75</td>
<td>$46.48</td>
<td>12.9%</td>
<td>5.4%</td>
<td>0.5%</td>
<td>3.6%</td>
<td>0.0%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>$90.00</td>
<td>250</td>
<td>33%</td>
<td>$0.36</td>
<td>$90.00</td>
<td>22.5%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$210.00</td>
<td>410</td>
<td>8.4%</td>
<td>$1.41</td>
<td>$328.07</td>
<td>8.6%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

**Contributions from Alloy Additions or Treatment Process**

**DIS Annual Meeting, June 7, 2012**

**Muskegon, Michigan**
Contribution from Alloy Additions or Treatment Process

- Track alloy additions/adjustments, inoculation, and treatment process
- Add to previous contribution from charge

<table>
<thead>
<tr>
<th>Alloy/Trim Addition to Ladle</th>
<th>Mat., Cost/lb</th>
<th>Weight</th>
<th>Addition Rate</th>
<th>Cost/ton Iron</th>
<th>% Mg</th>
<th>% Si</th>
<th>% C</th>
<th>% Cu</th>
<th>% Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgFeSi</td>
<td>$1.500</td>
<td>35.0</td>
<td>1.17%</td>
<td>$37.25</td>
<td>5.50%</td>
<td>1.35</td>
<td>45.00%</td>
<td>14.96</td>
<td>0.00%</td>
</tr>
<tr>
<td>Cover Steel</td>
<td>$0.300</td>
<td>30.0</td>
<td>1.00%</td>
<td>$7.63</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.20%</td>
<td>0.06</td>
<td>0.08%</td>
</tr>
<tr>
<td>Carbon</td>
<td>$0.500</td>
<td>0.0</td>
<td>0.00%</td>
<td>$0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>98.00%</td>
</tr>
<tr>
<td>FeSi Cover/Trim</td>
<td>$1.160</td>
<td>0.0</td>
<td>0.00%</td>
<td>$0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>75.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Copper Chops</td>
<td>$4.000</td>
<td>0.0</td>
<td>0.00%</td>
<td>$0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>Inoculant (Stream or Ladle)</td>
<td>$1.160</td>
<td>15.0</td>
<td>0.50%</td>
<td>$11.65</td>
<td>0.00%</td>
<td>0.00</td>
<td>75.00%</td>
<td>10.69</td>
<td>0.00%</td>
</tr>
<tr>
<td>Trim WL</td>
<td>80.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment Size, lbs.</td>
<td>3000</td>
<td></td>
<td></td>
<td>$56.53</td>
<td>0.045%</td>
<td>2.47%</td>
<td>3.71%</td>
<td>0.06%</td>
<td></td>
</tr>
</tbody>
</table>

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
## Spreadsheet Breakdown

### Charge Calculation - Electric Melt - DI

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Matt. Cost/Ton</th>
<th>Weight (Ton)</th>
<th>% of Charge</th>
<th>Matt. Cost/lb</th>
<th>Total Matt. Cost</th>
<th>% of Total Cost</th>
<th>% C</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% O</th>
<th>% Cr</th>
<th>% Fe</th>
<th>% Mo</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Shavings</td>
<td>$2.75</td>
<td>1000</td>
<td>32%</td>
<td>$0.03</td>
<td>$637,000</td>
<td>29.2%</td>
<td>0.2%</td>
<td>0.4%</td>
<td>0.3%</td>
<td>5.5%</td>
<td>0.3%</td>
<td>0.5%</td>
<td>0.0%</td>
<td>1.6%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Scrap Motor</td>
<td>$472.00</td>
<td>1000</td>
<td>0.0%</td>
<td>$0.47</td>
<td>$472,000</td>
<td>24.9%</td>
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<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Return</td>
<td>$500.00</td>
<td>703</td>
<td>22%</td>
<td>$0.07</td>
<td>$201,970</td>
<td>9.8%</td>
<td>3.5%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Pig Iron</td>
<td>$237.00</td>
<td>250</td>
<td>48%</td>
<td>$0.94</td>
<td>$592,470</td>
<td>28.3%</td>
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<td>0.1%</td>
<td>0.0%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>0.1%</td>
<td>3.1%</td>
<td>1.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>$1,325.00</td>
<td>2000</td>
<td>100%</td>
<td>$1.33</td>
<td>$1,325,000</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Silicon Coating</td>
<td>$4.50</td>
<td>1000</td>
<td>0.2%</td>
<td>$0.45</td>
<td>$450,890</td>
<td>18.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Carbon</td>
<td>$1.12</td>
<td>1000</td>
<td>1.4%</td>
<td>$0.11</td>
<td>$114,260</td>
<td>4.7%</td>
<td>0.1%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

| Total Org Wt. 290,000 | $1,325,000   | $327,063     |

### Alloying Addition to Ladle

<table>
<thead>
<tr>
<th>Alloy/Trim Addition to Ladle</th>
<th>Weight</th>
<th>Addition Rate</th>
<th>% Mg</th>
<th>% Si</th>
<th>% Cu</th>
<th>% Cr</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>0.1%</td>
<td>0.7%</td>
<td>0.10%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Silicon Midnight</td>
<td>0.6%</td>
<td>0.1%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Copper Chlorides</td>
<td>0.1%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Copper Chlorides</td>
<td>0.1%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total Alloying Addition Ladle</td>
<td>8.6%</td>
<td>0.6%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

| Trim Wt. 290,000 | $54,530 |

| Total Charge Cost/Ton | $578,530 |
| Total Alloying Cost/Ton | $58,530 |
| Total Cost/Ton, Materials Only | $530,000 |

### Final Chemistry

<table>
<thead>
<tr>
<th>% Mg</th>
<th>% Si</th>
<th>% Cu</th>
<th>% Cr</th>
<th>% V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6%</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

### Recovery Table

- Carbon from steel returns, coke, etc. 60%
- Silicon from slag, returns, etc. 50%
- Oxygen from gases, etc. 50%
- Sulfur from gases, etc. 50%
- Phosphorus from metal, etc. 50%
- Nitrogen from metal, etc. 50%
- All other losses are 50%

---

**DIS Annual Meeting, June 7, 2012**

**Muskegon, Michigan**
Final Results

- Display final results of costs and chemistries
- Setup recovery table which impacts all of the above results
- Recoveries can vary from one material to the next for a given element being tracked

<table>
<thead>
<tr>
<th>Total Charge Cost/Ton</th>
<th>Final Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>$579.57</td>
<td>% Mg = 0.045%</td>
</tr>
<tr>
<td></td>
<td>% C = 3.71%</td>
</tr>
<tr>
<td></td>
<td>% Si = 2.47%</td>
</tr>
<tr>
<td></td>
<td>% Mn = 0.22%</td>
</tr>
<tr>
<td></td>
<td>% Cu = 0.06%</td>
</tr>
<tr>
<td></td>
<td>% P = 0.019%</td>
</tr>
<tr>
<td></td>
<td>% Cr = 0.029%</td>
</tr>
<tr>
<td></td>
<td>% V = 0.029%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Alloying Cost/Ton</th>
<th>Total Cost/Ton, Metallics Only</th>
<th>$56.53</th>
<th>$836.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Table</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon from steel, returns, pig iron, etc.</td>
<td>95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon from graphite additions</td>
<td>90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon from SiC</td>
<td>90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon from steel, returns, pig iron, etc.</td>
<td>95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon from FeSi additions</td>
<td>95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon from SiC</td>
<td>90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium from treatment process</td>
<td>70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>95%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*all other recoveries are fixed
Evaluation Examples

- GI – high chrome raw material
- DI – using more pig iron, but maintaining the same chemistry
Melting – GI, Typical Charge, Cupola Melt

### Charge Calculation - Cupola Melt - GI

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Mass (lbs)</th>
<th>Weight (lbs)</th>
<th>% of Charge</th>
<th>Mass Cost</th>
<th>Total Mass Cost</th>
<th>% of Total Cost</th>
<th>% C</th>
<th>% Si</th>
<th>% P</th>
<th>% Mn</th>
<th>% Mo</th>
<th>% Cr</th>
<th>% Ni</th>
<th>% Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingot/Foundry</td>
<td>100</td>
<td>1500</td>
<td>3.5%</td>
<td>100</td>
<td>85.35</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Abrasive Mill</td>
<td>100</td>
<td>2500</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Recycled</td>
<td>100</td>
<td>2500</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Pig iron</td>
<td>100</td>
<td>5000</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Rails/Bar</td>
<td>100</td>
<td>5000</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Silicon Carbon Composite</td>
<td>100</td>
<td>5000</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>5000</td>
<td>0.0%</td>
<td>0</td>
<td>0.00</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

### Typical Charge: Shredded steel, rail, gray iron returns, pig iron, SiC, carbon, FeSi

**DIS Annual Meeting, June 7, 2012**  
**Muskegon, Michigan**
Melting – GI, High Cr
Alternative Material, 0.20%

Typical GI Charge, $547.18/ton

<table>
<thead>
<tr>
<th>Total Charge Cost/Ton</th>
<th>$531.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Alloying Cost/Ton</td>
<td>$16.05</td>
</tr>
<tr>
<td>Total Cost/Ton, Metallics Only</td>
<td>$547.18</td>
</tr>
</tbody>
</table>

Final Chemistry

| % C    | 2.59% |
| % Si   | 1.97% |
| % Mn   | 0.67% |
| % P    | 0.075% |
| % Cr   | 0.030% |
| % Mo   | 0.010% |
| % Cu   | 0.03% |

Chromium increases from 0.030% to 0.047%, depending on what you are pouring, is this significant?

Same Chemistry, high Cr alternative at 10% of charge displacing some shredded, $543.18/ton

<table>
<thead>
<tr>
<th>Total Charge Cost/Ton</th>
<th>$527.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Alloying Cost/Ton</td>
<td>$16.05</td>
</tr>
<tr>
<td>Total Cost/Ton, Metallics Only</td>
<td>$543.18</td>
</tr>
</tbody>
</table>

Final Chemistry

| % C    | 2.59% |
| % Si   | 1.97% |
| % Mn   | 0.67% |
| % P    | 0.075% |
| % Cr   | 0.047% |
| % Mo   | 0.010% |
| % Cu   | 0.03% |

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
### Something to Watch For!

<table>
<thead>
<tr>
<th>Description</th>
<th>Cr</th>
<th>Cu</th>
<th>Mn</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI Electric Melt, 10/5, Recycled Returns 1</td>
<td>0.046/0.054</td>
<td>0.11/0.12</td>
<td>0.28/0.29</td>
<td>0.025/0.027</td>
</tr>
<tr>
<td>DI Electric Melt, 10/5, Recycled Returns 2</td>
<td>0.054/0.057</td>
<td>0.12/0.13</td>
<td>0.29/0.29</td>
<td>0.027/0.028</td>
</tr>
<tr>
<td>DI Electric Melt, 10/5, Recycled Returns 3</td>
<td>0.057/0.058</td>
<td>0.13/0.13</td>
<td>0.29/0.29</td>
<td>0.028/0.028</td>
</tr>
<tr>
<td>DI Electric Melt, 10/5, Recycled Returns 4</td>
<td>0.058/0.059</td>
<td>0.13/0.13</td>
<td>0.29/0.29</td>
<td>0.028/0.028</td>
</tr>
<tr>
<td>DI Electric Melt, 10/5, Recycled Returns 5</td>
<td>0.059/0.059</td>
<td>0.13/0.13</td>
<td>0.29/0.29</td>
<td>0.028/0.028</td>
</tr>
</tbody>
</table>

**DIS Annual Meeting, June 7, 2012**  
**Muskegon, Michigan**
Analysis of Charges

- Overall cost is down, while chromium increase is not that significant.
- Can monitor chilling tendency differences between charges using conventional equipment – thermal analysis, chill wedges.
Melting – DI, Typical Charge, Electric Melt

Charge Calculation - Electric Melt - DI

<table>
<thead>
<tr>
<th>Raw Material/Commodity</th>
<th>Net Weight (lbs)</th>
<th>% of</th>
<th>Net</th>
<th>Total Melt Cost</th>
<th>$/lb</th>
<th>$/s Thi</th>
<th>% S</th>
<th>% Si</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% P</th>
<th>% Cr</th>
<th>% Mo</th>
<th>% V</th>
<th>#s V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shredded</td>
<td>1058</td>
<td>37.9%</td>
<td>39.2%</td>
<td>648.08</td>
<td>3.60</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
</tr>
<tr>
<td>Pig Iron</td>
<td>320</td>
<td>18.0%</td>
<td>40.9%</td>
<td>562.50</td>
<td>3.15</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
</tr>
<tr>
<td>Steel Scrap</td>
<td>320</td>
<td>18.0%</td>
<td>40.9%</td>
<td>562.50</td>
<td>3.15</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
</tr>
<tr>
<td>Silicon Carbide</td>
<td>255</td>
<td>9.1%</td>
<td>36.0%</td>
<td>92.63</td>
<td>3.60</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
</tr>
<tr>
<td>Carbon</td>
<td>112</td>
<td>4.2%</td>
<td>2.9%</td>
<td>31.97</td>
<td>0.97</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
<td>0.10%</td>
<td>0.80</td>
</tr>
</tbody>
</table>

**Total Charge Weight:** 6,500 lbs

**Total Charge Cost:** $1,378.47

Typical Charge: Slitter or busheling, ductile iron returns, pig iron, SiC, carbon, FeSi

---

**DIS Annual Meeting, June 7, 2012**

**Muskegon, Michigan**
Melting – DI, High Pig Use

Typical Charge, 15% pig iron, $636.10/ton

<table>
<thead>
<tr>
<th>Total Charge Cost/Ton</th>
<th>$579.57</th>
</tr>
</thead>
</table>
| Total Alloying Cost/Ton | $56.53 | Final Chemistry
| % Mg = 0.045%          |         |
| % C = 3.71%            |         |
| % Si = 2.47%           |         |
| % Mn = 0.22%           |         |
| % Cu = 0.06%           |         |
| % P = 0.019%           |         |
| % Cr = 0.029%          |         |
| % Mo = 0.010%          |         |
| % V = 0.029%           |         |

Total Cost/Ton, Metallics Only $636.10

Cost Difference, $4.96/ton

Same Chemistry, 30% pig iron, $641.06/ton

<table>
<thead>
<tr>
<th>Total Charge Cost/Ton</th>
<th>$584.53</th>
</tr>
</thead>
</table>
| Total Alloying Cost/Ton | $56.53 | Final Chemistry
| % Mg = 0.045%          |         |
| % C = 3.70%            |         |
| % Si = 2.47%           |         |
| % Mn = 0.18%           |         |
| % Cu = 0.05%           |         |
| % P = 0.020%           |         |
| % Cr = 0.029%          |         |
| % Mo = 0.010%          |         |
| % V = 0.029%           |         |

Total Cost/Ton, Metallics Only $641.06

At 30,000 tons melted per year, this has an annual cost impact of $148,800
Analysis of Charges

• While the chemistry is still the same, a 15% to 30% increase in pig iron usage has increased overall melt cost significantly.

• While ferritic iron looks good, if returns are used for pearlitic iron, costs could go up even more because of additional alloying.
Closing Comments

- Identical chemistries are not always the same cost
- A normally unacceptable material may have some hidden benefits – alloying elements
- Charges should be evaluated on a regular basis
QUESTIONS?
For additional information, please contact:

- Kevin Pilon
- Waterford, MI
- Cell (231) 740-2558
- Fax (248) 681-5194
- E-mail k.pilon@carpenterbrothersinc.com
- Website carpenterbrothersinc.com
DOUG WHITE

DOUG GRADUATED FROM McMASTER UNIVERSITY IN HAMILTON, ONTARIO, CANADA IN 1970 WITH HIS BACHELOR OF SCIENCE DEGREE IN METALLURGY. DOUG IS CURRENTLY THE TECHNICAL SERVICES MANAGER FOR ELKEM FOUNDRY PRODUCTS. AFTER A BRIEF PERIOD AT THE STEEL COMPANY OF CANADA R&D DEPARTMENT, HE JOINED CROUSE HINDS HINDS OF CANADA, A GRAY IRON AND ALUMINUM FOUNDRY, SERVING AS A METALLURGIST TO SET UP THE MELT AND POUR CYCLE OF A NEW CORELESS INDUCTION FURNACE LINE. IN 1974, HE JOINED UNION CARBIDE CANADA LTD., METALS DIVISION. THIS BUSINESS WAS LATER PURCHASED BY ELKEM AND BECAME ELKEM METAL CANADA INC. IN ADDITION TO CANADA, DOUG HAS HELD POSITIONS WITH ELKEM IN OSLO, NORWAY, ANTIBES, FRANCE, PITTSBURG, PA AND ASHTABULA, OH. HIS ACTIVITIES HAVE INVOLVED FOUNDRY TECHNICAL SERVICE FOR GRAY AND NODULAR IRON MANUFACTURE, DESIGN AND MANUFACTURE OF NODULIZERS AND INOCULANTS, AND DESULFURIZATION TECHNOLOGY. DOUG HAS WRITTEN NUMEROUS PAPERS, HELD TECHNICAL SEMINARS, AND MADE MANY FOUNDRY VISITS IN CANADA, EUROPE, SE ASIA, AUSTRALIA AND THE UNITED STATES. DOUG SERVED AS PRESIDENT OF THE ONTARIO CHAPTER OF AFS FROM 1981 TO 1982, AND CURRENTLY SERVES ON THE DIS RESEARCH COMMITTEE.

THE DIS WELCOMES DOUG WHO IS HERE TO TALK ABOUT “HOW TO MINIMIZE RE USAGE IN DUCTILE IRON”
Rare Earths in Ductile Cast Iron
Minimizing Usage of These Metals For Cost Reductions and to Prepare for Reduced Supply

D. S. White, Technical Service Manager
Initial price increase Aug-Sept. 2010: $10 to $40 / kg. FOB China
Ce: 130 $/kg – La: 123 $/kg – Misch: 121 $/kg
RE Price Development 2009 - 2012

Source: metal-pages.com
Global Production REO

Source: USGS
Rare Earth Metals

Periodic Table of the Elements

* Lanthanide Series
+ Actinide Series

Source: library.thinkquest.org
# Change in Chinese Export Quotas of REM

<table>
<thead>
<tr>
<th>Year</th>
<th>REM [tons]</th>
<th>Change [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>65.609</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>61.821</td>
<td>-6</td>
</tr>
<tr>
<td>2007</td>
<td>59.643</td>
<td>-4</td>
</tr>
<tr>
<td>2008</td>
<td>56.939</td>
<td>-5</td>
</tr>
<tr>
<td>2009</td>
<td>50.145</td>
<td>-12</td>
</tr>
<tr>
<td>2010</td>
<td>30.258</td>
<td>-40</td>
</tr>
<tr>
<td>2011</td>
<td>30.184</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>~30.000</td>
<td>-</td>
</tr>
</tbody>
</table>

54% reduction of export quota on REM from 2005 to 2010

40% reduction of export quota on REM from 2009 to 2010
World Demand of RE (tons/year)

Demand from World
Available from World
Demand from China
Available from China

Source: sgu.se
Effect of Rare Earths in Cast Iron

Possible Pros:

- Strong deoxidizing and desulphurizing elements: effective nodularizers.
- Forms stable nuclei that are less prone to fading.
- High boiling points: less violent reaction than Mg.
- With the correct RE addition, nodule count is higher than without RE.
- With the correct RE type and addition, nodule size distribution can be manipulated to reduce shrinkage.
- Neutralises subversive elements like Pb, Sb, Bi, As. There are no known substitutes for RE for this effect.
Effect of Rare Earths in Cast Iron

Possible Cons:
• Strong carbide promoters: Increases chill tendency if added in excess
• Deteriorated graphite morphologies (graphite flotation, exploded and chunky graphite) in case of unbalanced levels with tramp elements.
• Tolerance level of ductile iron to rare earths decreases with increasing casting thickness.
Effect of REM in ductile iron

Inoculation effect: increased nodule count.

0% TRE

1% TRE
Minimizing Rare Earth Usage

1. Optimize the treatment process.
2. Lower RE-content MgFeSi.
3. Replace standard RE in MgFeSi with pure La metal (optimum nodule count at lower usage)
4. Use a RE-containing inoculant with a low or RE free type MgFeSi
   I. 1.75% RE or 1.75%Ce metal (75% FeSi - Ca,Al)
   II. S and O coated versions also available
Increase MgFeSi Treatment Efficiency

- Control base S (C raiser selection or desulfurize)
- Use thermal efficiency techniques to tap colder and increase Mg recovery to reduce MgFeSi usage. Use insulating ceramic paper behind working face linings and use ladle covers. Keep ladles covered when empty.
- Use tall pockets with reduced area for a longer reaction time.
- Fill treatment ladles quickly to minimize or avoid the use of cover metal
- Add treatment alloys from a dispensing system that avoids segregation of sizes and delivers the alloy totally into the treatment pocket
- Add treatment alloys just before the treatment – not sooner.
- Keep pockets clean so that MgFeSi and cover metal are totally contained
Change Treatment Processes?

• Flow – through treatment boxes – MgFeSi - low Mg with high RE content?

• Very thin carbide prone ductile castings - treated quite hot. MgFeSi with low Mg and high RE or Ce metal content. (3.25% Mg and 2% Ce for example)

• Use a covered treatment ladle or perhaps treat in the pouring ladle with low Mg type MgFeSi and eliminate the treatment ladle and associated temperature loss.

• Historically the most common MgFeSi grades contained 1% TRE, made with mischmetal. This has been changing to 0.4% La because of a reduced shrinkage effect. Now it is also the more economical approach, since the amount to achieve optimum nodule count is so much lower.

• Inmold – 0.9% by weight of iron with MgFeSi containing 0.4% La
  – No dust collector to buy or operate.
  – Reduced autopour maintenance costs with un-treated iron
  – No stream inoculant equipment or alloy – no carbides.
Optimizing RE-level in MgFeSi-alloy

![Graph showing nodule count for different RE levels and inoculation statuses.](image)
Change to MgFeSi with Lower RE

- MgFeSi with 2% RE
- MgFeSi with 0.5% RE
- MgFeSi with 0.85% RE
- MgFeSi with 0.65% RE
Change to La-containing MgFeSi

Misch-based MgFeSi
0.5% RE

Lanthanum-based MgFeSi
0.5% La
RE Containing Inoculant Technology

- Example: Ca + Al + 1.75% Ce metal grade of 75% FeSi - developed for continuous stream inoculation in cooperation with Grede Reedsburg.
- Concept: Why waste expensive RE elements on deoxidation and desulfurization with the Mg treatment? Why not add them within stream inoculant after the Mg treatment?
- How much RE is needed? Alternate alloys were tested with different RE types and RE contents. 1.75% mischmetal was selected. The pure Ce version provided superior nucleation, but was considerably more expensive than mischmetal.
- The design was later changed to the use of pure Ce due to far stronger chill reduction.
- When coated with readily reduced sulfide and oxide compounds a new highly potent alloy results which also minimizes shrinkage tendency results.
RE Weight and Cost Ranges - per ton of iron treated @ $54/lb Ce $42/lb. La $33/lb. mischmetal (TRE)

- 2% by weight of alloy with 2% TRE – 0.8 lb. mischmetal ($26)
- 2% by weight of alloy with 0.4% La – 0.16 lb. La ($7)

- 1.5% by weight of alloy with 1% TRE – 0.3 lb. mischmetal ($10)
- 1.5% by weight of alloy with 0.4% La – 0.12 lb. La ($5)

- 1.1% by weight of alloy with 1% TRE – 0.22 lb mischmetal ($7)
- 1.1% by weight of alloy with 0.4% La – 0.09 lb. La ($4)

- 0.9% by weight of alloy with 0.4% La – 0.07 lb. La ($3)

- RE free MgFeSi and 0.1% stream inoculant with
  - 1.75% Ce – 0.035 lb. Ce ($2)
Reducing RE-level in MgFeSi

• Standard MgFeSi typically contains around 1% RE
• RE levels increased when steel scrap quality was poor.
• Pb, Sb and As are generally lower today.
• A RE level of less than 1% may be sufficient for many foundries. In fact it may be mandatory in low S iron with low levels of tramp elements, to avoid inferior graphite shapes
• CAUTION: There may be a reduction in nucleation when reducing RE content

<table>
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<tr>
<th>Element</th>
<th>1967 Range</th>
<th>1998 Range</th>
<th>Max</th>
<th>Average</th>
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<td>Sb ppm</td>
<td>2 – 90</td>
<td>80</td>
<td></td>
<td>31</td>
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<tr>
<td>As ppm</td>
<td>10 –380</td>
<td>160</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Pb ppm</td>
<td>– 50</td>
<td>43 ± 11</td>
<td>80</td>
<td>11</td>
</tr>
</tbody>
</table>

Lowering of Tramp Levels over time
Case study - RE reduction in MgFeSi

• A foundry in Denmark producing a range of different components for areas such as hydraulics, engineering, machines, trucks and busses, gears, pumps and valves, compressors, forest and agricultural machinery.

• The foundry has run trials where they changed from MgFeSi with 0.85% RE to 0.5% RE. Addition rate 1.4% The trial was successful and the foundry changed without any negative effects.
MgFeSi alloyed with Pure La Metal

• Sales of MgFeSi alloyed with small levels of pure La metal as the rare earth type have grown very rapidly in N. America.

• The initial growth in this type of MgFeSi was initially due to a reduction of shrinkage defects. Many foundries converted to this technology when La was far more expensive than mischmetal and the MgFeSi alloy cost more than traditional material. They switched because it was technically superior for them and reduced overall costs, not because it was cheaper per lb. to buy.

• The La-level is usually much lower than the typical mischmetal level in traditional MgFeSi. Also La metal prices have become more similar to mischmetal prices. Today this can allow a “purchased price” savings for MgFeSi due to the lower usage of La than mischmetal, in addition to the technical benefits.
Case Study

Objective:
Compare samples of ductile iron made by the “on-the-mould” process using:

1. Misch - MgFeSi
   - % Si: 47.0
   - % Mg: 4.5
   - % Ca: 0.3
   - % RE: 1.25
   - % Al: 0.8

2. La - MgFeSi
   - % Si: 46.0
   - % Mg: 5.5
   - % Ca: 0.5
   - % La: 0.35
   - % Al: 1.0

Both input 0.35% La
Graphite structure

Misch - MgFeSi

La - MgFeSi
Microstructure

<table>
<thead>
<tr>
<th></th>
<th>Nodule Count (N/mm²)</th>
<th>Nodularity (%)</th>
<th>Graphite (%)</th>
<th>Ferrite (%)</th>
<th>Perlite (%)</th>
<th>Nodule Diam ave (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>La-MgFeSi</td>
<td>258</td>
<td>82</td>
<td>8</td>
<td>75</td>
<td>17</td>
<td>15.7</td>
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<tr>
<td>La-MgFeSi</td>
<td>299</td>
<td>89</td>
<td>9</td>
<td>81</td>
<td>10</td>
<td>16.4</td>
</tr>
<tr>
<td>Misch-MgFeSi</td>
<td>167</td>
<td>80</td>
<td>9</td>
<td>77</td>
<td>14</td>
<td>21.8</td>
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<tr>
<td>Misch-MgFeSi</td>
<td>176</td>
<td>81</td>
<td>9</td>
<td>79</td>
<td>12</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Misch - MgFeSi  

La - MgFeSi
Shrinkage Tendency

Misch-MgFeSi

La-MgFeSi
Figure 2: Microstructure in 5 mm plate castings for the different nodularizer alloys. (a) RE-free, (b) 0.5%La, (c) 1.0%La, (d) 0.5%Ce, (e) 1.0%Ce, (f) 1.0%MM.
Microstructure in 5 mm plates

FREE

0.1LA

0.2LA

0.3LA

0.4LA

0.5LA

Un-inoculated samples
Microstructure in 5 mm plates

FREE

0.1LA

0.2LA

0.3LA

0.4LA

0.5LA

Inoculated samples
Reduction of overall RE-consumption through use of RE-containing inoculant

Ca, Al, 1.75% Ce - 75% FeSi

- Late stage addition for thick section D.I. for tight RE and tramp element balance, where the RE content in MgFeSi is being strongly reduced, or even eliminated.
- 0.2% addition with RE Free MgFeSi – replacing the RE in a 1.5% addition of MgFeSi containing 1% TRE

O and S coated version

- Similar attributes as the uncoated alloy, but even more efficient at very low addition rates.
- Improves and boosts nucleation state of iron and rejuvenates dead base iron.
- Excellent alternative for foundries with RE-free MgFeSi that need to boost the nucleation potential to avoid poor nodularity.
- Using 0.15% of the coated version with RE free Mg as an alternative to 1.5% by weight of MgFeSi containing 1% TRE
Case Study – Ce Containing Inoculant to Reduce RE Use

- A family owned old foundry in Germany producing about 10,000tpy finished castings grey iron and ductile iron. GI is produced in a cupola and DI in two 2 ton high frequent induction furnaces.
- The iron they make is very high in S (>0.1) but they do not wish to desulfurize.
- A test was conducted with RE-free Elmag® (2.1-2.2% addition rate) and Ce metal bearing inoculant.
- The result was higher quality ductile iron, with improved nodule count and nodularity.
O and S Coated Pure Ce Containing Inoculant – to Reduce RE Usage and Costs

• A foundry situated in Germany producing ductile castings for engineering and automotive industry.
• They have used MgFeSi containing 1% RE for a long time, but have been slowly replacing it with a RE free version.
• Trials have been run with a 0.3% addition of an O and S coated inoculant containing 1.75% Ce metal in combination with the RE-free MgFeSi
• The trials have been successful.
• The cost reduction from this change is very worthwhile.
Success factors in changing RE-level

Field experiences and case studies have shown us a few critical factors when changing the RE-level.

1. Do not change too many variables at once!
2. Using a normal and RE-free version of the same nodularizer and then slowly mixing in higher proportions of RE-free version is a proven method of finding the threshold for RE-content.
3. In some cases the change to lower mischmetal content MgFeSi alloy will require more powerful inoculants. This is not the case with La alloyed MgFeSi alloys.
4. Patience is key, as it takes time for the RE-level in the system to settle at a lower level due to returns and residual RE in linings etc. To confirm a test result, the process should be monitored with the new RE-level over several days. Variations in trace element levels in raw materials might also cause unexpected results.
Fading characteristics: Mg vs RE

- Mg has a higher fading rate than RE.
- Reduced RE input = reduce holding time for good nodularity.
- This may be offset by:
  - 1) operating with a slightly higher Mg level
  - 2) making smaller more frequent additions to an autopour
  - 3) stream inoculating with a RE bearing inoculant.

![Graph showing Mg Fade vs. Ce+La Fade with equations: y = -0.0022x + 0.0326 and y = -0.0008x + 0.0139.](image-url)
How much RE is needed to neutralize tramp Elements?

Extensive research has been done on finding the proper amount of RE to counteract the negative impact of tramp elements. Javaid and Loper Jr\(^5\) gave a rule of thumb 1:1 (or added 1:1.5), Larranaga et al\(^8\) found the ratio Sb/Ce should be at least 0.8 and Diao et al\(^9\) found the ratio to be 0.7.

- Javaid and Loper Jr\(^5\) also gave some expressions to calculate the amount needed. These expressions are based on their own research as well as data reported in literature. Their expressions are as follows:
  
  - Wt% RE = 1.1206Bi – 0.0029  \[\text{Equation 1}\]
    RE/Bi = 1.118
  - Wt% RE = 0.840Pb + 0.0045  \[\text{Equation 2}\]
    RE/Pb = 0.845
  - Wt% RE = 0.914Sb + 0.0042  \[\text{Equation 3}\]
    RE/Sb = 0.916
How Much RE When There are Multiple Tramp Elements?

• \[ RE = 0.5037(Bi+Pb+Sb) + 0.0037 \]

• \[ RE = (2.083 + 65.89P + 0.783Si - 39.09Mg - 1.963Ni - 0.176 \times \text{section size in inches} \times (Pb+Bi+Sb) \]
  (*For a 20 cm thick casting).*
THANK YOU
FEATURES

2012 ANNUAL MEETING HIGHLIGHTS

- Speaker Bios - Morning Session
- Speaker Bios - Afternoon Session
- Market Advances in Compacted Graphite Iron - Dave Gilson
- Patriot - The New Benchmark for Large Ductile Iron No-Bake Molding Operations - Mark Adamovits
- Evaluating Alternative Charge Materials: Cost and Chemistry - Kevin Pilon
- How to Minimize Rare Earth Usage in Ductile Iron - Doug White
- A Summary of the Elements Effects on Ductile Iron - Rick Gundlach
- Letting Mr. Charpy Die - Evaluating the Usefulness of Charpy Impact Testing on Ductile Iron - Meghan Oake
- The New AFS Guide to Ductile Microstructures - Tom Prucha
- Cupola Operations Panel - Mark Bidoli, Robert Bigge, Scott Gledhill
- Refractory Alternatives for Combating Elephant’s Foot Erosion and Top Cap Wear in Coreless Furnaces - Pete Satre

DEPARTMENTS

- News Briefs

Link to Presentation: A Summary of the Elements Effects on Ductile Iron

RICHARD GUNDLACH


THE DIS WELCOMES RICK BACK AGAIN TO TALK TO US ABOUT “A SUMMARY OF THE ELEMENTS EFFECTS ON DUCTILE IRON”
Summary of Element Effects in Ductile Iron

Rick Gundlach
Element Materials Technology Wixom

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Types of Alloying Elements

• Substitutional and Interstitial elements

• Each has a distinct and unique effect on the solidification structure and solid-state transformation products

  – Eutectic carbon content
  – Stability of graphite (versus carbide)
  – Eutectoid carbon content
  – Stability of austenite and ferrite phases
  – Hardenability, etc.
Iron-Carbon Phase Diagram

Temperature, °F
2600
2400
2200
2000
1800
1600
1400
1200

Carbon Content, Percent by Weight
1.0
2.0
3.0
4.0
5.0

Temperature, °C
1500
1400
1300
1200
1100
1000
900
800
700

Austenite
Austenite + Carbide
Eutectoid Temperature
Ferrite + Carbide
Melt
Eutectic Temperature

Austenite + Melt
Austenite
Austenite + Ferrite
Ferrite

A1
A3
Acm
Carbon Equivalent

- Many elements raise the chemical activity of carbon and, thus, they reduce the eutectic carbon content, such as Si, Al, Ni and Cu.
- Some elements reduce the chemical activity of carbon and, thus, they raise the eutectic carbon content, such as Cr and V.
- Another more comprehensive CE expression:

\[ CE = \%C + \%Si/3 + P/3 - Cr/6 + Ni/12 \]
Another Carbon Equivalent Formula

\[ \%C + \%\text{Si}/7 = 3.9 \]

- The formation of graphite compensates for the Liquid-Solid contraction that occurs during solidification.
- Chemical composition determines the amount of graphite that forms during solidification.
- Combinations of carbon and silicon influence the amount of graphite that forms and the type of solidification shrinkage.
- Values less than 3.9 generally exhibit draw-in or surface sinking.
- Values above 3.9 are subject to mold-wall movement and internal shrinkage porosity.
Temperature vs. Time Diagram

- γ Liquidus
- Graphite
- Eutectic
- Iron Carbide
- Eutectic
TEMPERATURE

GRAPHITE EUTECTIC

IRON CARBIDE EUTECTIC

CHILL

TIME

END OF SOLIDIFICATION
Fe-2%Si-C Phase Diagram
Ductile Iron Society

RESEARCH PROJECT NO. 22

THE EFFECTS OF ALLOYING ELEMENTS ON THE CRITICAL TEMPERATURES IN DUCTILE IRON

by

K. L. HAYRYNEN
J. R. KEOUGH
B. V. KOVACS

APPLIED PROCESS INC.
12238 NEWBURGH ROAD
LIVONIA, MI 48150
Calculating Critical Temperatures from Composition

\[
\text{UCT} = 1370^\circ F + 78(\%\text{Si}) - 32(\%\text{Mn}) - 20(\%\text{Ni}) - 53(\%\text{Cu}) + 4.6(\%\text{Mo}) - 160(\%\text{P})
\]

\[
\text{LCT} = 1324^\circ F + 38(\%\text{Si}) - 50(\%\text{Mn}) - 9.6(\%\text{Ni}) - 16(\%\text{Cu}) + 1.2(\%\text{Mo}) - 127(\%\text{P})
\]
Interstitial Elements

- Oxygen, Sulfur & Nitrogen

- These elements exhibit Surface Active behavior and influence the nucleation and growth of graphite
The Role of Magnesium

• Reduce the concentrations of the surface active elements S and O
• Promote high nodularity
How Much Mg is Needed?

- Too little Mg produces low nodularity
- Too much Mg leads to carbides
- The Mg requirement increases with decreasing freezing rate
- Various methods used for determining an adequate amount, including Mg:S ratio and Excess Mg
My Favorite Mg Calculation

\[ \text{Mg}_{\text{residual}} = 0.75\%S + 0.018\% \]

This calculation presumes that:

1. The level of soluble sulfur (and oxygen) must be reduced below a critical level to achieve a fully nodular structure, and

2. The reaction, \( \text{Mg} + \text{S} \rightarrow \text{MgS} \) does not go to completion – excess Mg is needed to drive the dissolved S down.
Solubility in Solutions

$$\text{Mg} + \text{S} \rightarrow \text{MgS}$$

$$K = \frac{(%\text{Mg}) \times (%\text{S})}{(%\text{MgS})}$$

$K = \text{Equilibrium Constant. It defines the limit of solubility of constituents in a solution}$
Solubility of Mg and S
(according to thermodynamic calculation)

\[ \Delta G^\circ = RT \ln K \]

where \( K = (\alpha_{Mg} \times \alpha_S) \), and
\( \alpha_{Mg} = \text{activity of Mg} \approx \text{wt-\% Mg} \)
\( \alpha_S = \text{activity of S} \approx \text{wt-\% S} \)

\[ \Delta G^\circ = RT \ln [(\%Mg \times \%S) \times C] \]
Gibb’s Free Energy for Sulfides

\[ \Delta G^0 = RT \log P_{\text{S}_2}, \text{kg cal.} \]

- \( \Delta G^0 = RT \log P_{\text{S}_2}, \text{kg cal.} \)
- Suggestedaccuracies:
  - \( \pm 1 \) kg cal.
  - \( \pm 3 \) kg cal.
  - \( \pm 10 \) kg cal.
  - \( \pm > 10 \) kg cal.

<table>
<thead>
<tr>
<th>Changes of State</th>
<th>Element</th>
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<tr>
<td>Melting Point</td>
<td>M</td>
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<tr>
<td>Boiling Point</td>
<td>B</td>
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<tr>
<td>Sublimation Pt.</td>
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<td>S</td>
</tr>
<tr>
<td>Transition Pt.</td>
<td>T</td>
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</tr>
</tbody>
</table>

Temperature °C
Solubility of MgS in Melt
Solubility of MgS in Melt
Rare Earth Elements

• RE aid in achieving high nodularity
• RE are strong deoxidizers
• RE are strong sulfide formers
• RE can increase nodule count
• RE react with tramp elements to form intermetallic compounds, and neutralize the damaging influence of tramp elements
Fig. 4-57. Flake films typical of magnesium-treated iron contaminated with lead (0.0086%) and antimony (0.0057%); unetched, x100.
Fig. 4-14. Crab graphite is shown at ×1000, unetched.
Relative Influence of Tramp Elements on Graphite Nodularity

One formula for rating the damaging influence:

\[ SG = 4.4Ti + 2As + 2.3Sn + 5Sb + 290Pb + 370Bi + 1.6Al \]

When \( SG < 1.0 \), SG graphite is possible,
When \( SG > 1.0 \) degenerate graphite is likely

- Ce and other RE elements can neutralize these tramp elements
- Amount needed to neutralize tramp elements not an exact science.
- Unlike S and O reactions, the RE reactions are not well known.
Tolerances for Tramp Elements

• Lead – 0.002%
• Antimony – 0.002%
• Tin – 0.002%
• Bismuth – 0.002%
• Tellurium – 0.02%
• Aluminum – 0.04%
• Titanium – 0.05%
• Zirconium – 0.01%
• Selenium – 0.01%
Fig. 4-40. Composite diagram illustrating the effects of low- and high-cerium, rare earth additions on the graphite nodule count.
Boron in Ductile Iron

- Boron is noted for promoting ferrite and, when present at elevated levels, more Cu is required to produce pearlitic grades.
- The boron effect essentially reduces the hardenability of ductile iron.
- Boron is insoluble in austenite and occupies the grain boundaries.
- In steels, boron is used to enhance hardenability, as long as nitrogen is tied up by Ti or Zr additions to the melt.
- Is it possible that boron nitride nucleates ferrite?
- Could the boron effect be neutralized by reducing the level of dissolved nitrogen?
Solubility of Boron Nitride

![Graph showing the solubility of Boron Nitride with data points for Nitrogen and Boron concentrations.](image)
Fig. 4-31. Influence of phosphorus on the mechanical properties of as-cast ductile iron.
Influence of silicon on the room temperature mechanical properties of ferritic Ductile Iron.
Fig. 4-52. The influence of copper additions on the mechanical properties of as-cast nodular iron are shown.
Elements Promote Pearlite

- Copper
- Manganese
- Chromium
- Tin
- Antimony
- Arsenic
Relative Influence of Alloying on Promoting Pearlite

- Manganese – strong
- Chromium – strong
- Copper – stronger
- Tin – 10 times stronger than Cu
- Sb & As – stronger than Sn
Relative Influence of Alloying on Promoting Pearlite

One formula for rating pearlitizing power:

Alloy Factor =

\[ \%Cu + \%Mn + \%Cr + \%Mo + \%V + 10\times\%Sn \]

For 80-55-06: AF must be 110 - 130
For 100-70-03: AF must be 140 - 160
TRANSFORMATION ON CONTINUOUS COOLING

Diagram showing the transformation of materials with temperature and log time axes. The diagram includes lines and labels for different phases such as $a_T$, $A_1$ (eutectoid), pearlite, and ferrite. Points labeled 'a' and 'b' are indicated on the graph.
INCREASED HARDENABLEITY WITH ALLOYING

DIAGRAM:
- TEMPERATURE vs. LOG TIME
- $a_T$
- $A_1$ (EUTECTOID)
- UNALLOYED
- ALLOYED
- a
- b
The influence of carbon and various alloying elements on the hardenability of Ductile Iron.
Fig. 4-48. Continuous-cooling transformation diagram showing the increases in hardenability obtained with a combined addition of copper and molybdenum to an unalloyed ductile iron.
Elements Influence Transformation to Martensite

Martensite Transformation occurs over a temperature range of 150°C

Martensite Transformation Start temperature is influenced by carbon and the alloying elements

$$Ms(\circ F) = 930 - 570C - 60Mn - 50Cr - 30Ni - 20Si - 20Mo - 20W$$
Interrupted Quench
Fig. 1-18. Schematic illustration of the progression of growth of the austenite-spheroidal graphite eutectic.$^{15}$
Segregation of Solute Elements During Solidification

• Alloying elements partition between the liquid and solid phases according to their effect on melting point temperature

• Some elements concentrate in the growing solid phase, others concentrate in the remaining liquid

• Ductile iron grows dendritically, and alloys that segregate to the liquid will concentrate in the interdendritic regions
Partitioning of Solute Element at Freezing Front

\[ \delta = \frac{D}{\nu} \]

\[ C_0 \]

\[ kC_0 \]

\[ C_s(z') \]

\[ \frac{C_0}{k} \]
Segregation of Solute Elements During Solidification

- Ductile iron grows dendritically, and alloys that segregate to the liquid will concentrate in the interdendritic regions.

- The degree of segregation is dependent on freezing distance – the distance between neighboring dendrites (and often neighboring nodules).
Fig. 4-23. Influence of silicon content on the impact properties (NCIRA Charpy V-notch test bars) and transition temperature of annealed, fully ferritic ductile irons. (GIRI)
QUESTIONS?
For additional information, please contact:

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- Web Site Address: info@element.com
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- Web Site Address: info@element.com
ALLOY FACTORS FOR HARDENABILITY
MEGHAN OAKS

MEGHAN GRADUATED FROM MICHIGAN TECHNOLOGICAL UNIVERSITY IN 2009 WITH A BACHELOR OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING. THE FOLLOWING SEMESTER, SHE STARTED GRADUATE SCHOOL WORKING UNDER PAUL SANDERS. SHE GRADUATED IN 2011, ALSO FROM MICHIGAN TECH, WITH A MASTERS OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING. HER THESIS TITLE WAS “EFFECTS OF SILICON CONTENT AND COOLING RATE ON THE MECHANICAL PROPERTIES OF HEAVY SECTION DUCTILE CAST IRON”. MEGHAN IS CURRENTLY WORKING AS AN R&D ENGINEER FOR APPLIED PROCESS, IN LIVONIA, MI. SHE WAS OUR GUEST STUDENT DURING THE DIS HEAVY SECTION CONFERENCE HELD IN OCTOBER 2010 IN CLEVELAND, OHIO. SHE IS ALSO A MEMBER OF THE AFS 5R CAST IRON RESEARCH COMMITTEE, DIS RESEARCH COMMITTEE AND THE MICHIGAN TECH FOUNDRY ADVISORY BOARD.

THE DIS WELCOMES MEGHAN WHO IS HERE TO TALK ABOUT “LETTING MR. CHARPY DIE: EVALUATING THE USEFULNESS OF CHARPY IMPACT TESTING ON DUCTILE IRON"
LETTER MR. CHARPY DIE: EVALUATING THE USEFULNESS OF CHARPY IMPACT TESTING ON DUCTILE IRON

Meghan Oaks, Applied Process

Introduction

The Charpy impact test is a simple test designed to evaluate materials under dynamic loading conditions. ASTM E23-07®, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials, outlines the test method as well as specimen size and geometry. Typically, Charpy bars are 10mm (0.39 in.) square by 55 mm (2.2 in.) long. In many cases, the bars have a notch machined into them along their length. This notch can be either v- or u-shaped. The bars are then held horizontally in the test fixture while a pendulum is released from a standard, specified height. The height to which the pendulum rises after impacting the specimen allows the tester to determine how much energy was absorbed by the material during fracture. High absorbed energies typically, but not always, indicate ductile fracture and low values typically indicate brittle fracture.

History of the Charpy Impact Test

In the 19th century, the railroad industry, both domestic and abroad, was growing rapidly. With this rapid expansion came a rise in the number of failures in the rails and axles of the rail cars. All of these failures occurred unexpectedly. Scientists at the time did not have a broad understanding of the intricacies of material properties nor how to properly characterize them. As a result, there was a large driving force to better understand materials, their properties and how to characterize them. One of the tests to be developed during this era was the Charpy impact test.

In 1904, French scientist Consideré noted that as the strain rate increased, so did the temperature at which brittle fracture occurred. The following year, in 1905, Georges Charpy developed his impact test based upon an idea by S.B. Russell. The purpose of impact testing is to evaluate the behavior of materials under dynamic loading conditions. At the time Charpy was developing his test, other tests were also in use. Some of these, such as the Izod impact test, later had standards written for them; however, many others fell out of use. By 1933, the American Society for Testing and Materials (ASTM) had developed a standard, E23¹, to be used for Charpy impact testing.

The full benefit of the Charpy impact test was not realized until World War II. During the war, the United States manufactured upwards of 3000 Liberty ships. Of these 3000 ships, 1200 failed in some way or another. Over two hundred of the failures were considered hazardous while approximately 20 ships broke completely in two. A number of these failures occurred even while a ship was docked. There were three things in common between all these failures: they were sudden, brittle in nature, and occurred at stresses well below the yield stress of the material. In response to the ships’ failures, the US government conducted an investigation to try to determine the root cause. The study, conducted at the US Naval Research Laboratory, discovered that the Charpy impact test could detect a ductile to brittle
transition in the fracture of steel samples that was not predicted by tensile testing, hardness or chemistry. This was a significant finding. In the report issued at the conclusion of the investigation, the scientists recommended that “some criterion of notch sensitivity should be included in the specification requirements for the procurement of steels for use where structural notches, restrain, low temperatures or shock loading might be involved.”

Today, the Charpy impact test is used in a number of ways. Test machines are often instrumented to record the energy absorbed during fracture. By testing at varying temperatures, one is then able to construct impact energy vs. temperature curves. For body-centered cubic materials (such as steel and cast iron), these curves resemble an elongated ‘S’ as shown in Figure 1. Either the inflection point of the curve or the point at which the fracture is 50% brittle, as determined by examining the fracture surface, are used to determine the ductile-to-brittle transition temperature. This transition temperature is not a material property though, and should not be used for design purposes; material properties such as fracture toughness, $K_{IC}$, should be used instead. Despite this, there are still a number of instances when a specification includes a minimum Charpy impact energy requirement. Nuclear pressure vessels and steel bridge designs both have this requirement. A number ductile iron standards, including ISO 1083:2004 (Spheroidal graphite cast irons), DIN 1563 (Founding – Spheroidal graphite cast iron), ASTM A571 (Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service) and ASTM A897 (standard specification for Austempered Ductile Iron Castings) all require minimum Charpy values as well. DIN 1563 has different minimum impact values based upon the section size of the casting; in general, the impact requirement decreases as section size increases.

![Figure 1: Impact energy vs. temperature curves for ductile iron. Image courtesy of the Ductile Iron Society Ductile Iron Data Handbook.](image-url)
The Charpy Test Explained

Inherent in the Charpy impact test are high strain rates. These are so high, in fact, that in practice, they are representative only of ballistics-type applications. While the high strain rates have their place, they are not characteristic of the majority of impact loading instances. Furthermore, due to the small size of the Charpy specimens, a complex stress state develops which is not indicative of real world applications. In real components, the plain strain condition (explained later) is often the dominate state. It is possible to impose this on Charpy specimens, though, using proper sample preparation methods.

Shear Stress vs. Shear Strain

Plane stress is the stress state in which one of the principal stresses is zero. This is shown graphically in Figure 2. The plane stress state typically develops in components when one dimension is much smaller than the other two (i.e. a plate).

In contrast, plane strain occurs when the principal strain in the longest direction is constrained and is assumed to be zero. This state is shown graphically in Figure 3 and generally occurs in components that have one dimension much longer than the other two (i.e. a prism).

![Graphical representation of plane stress](image1)

\[ \sigma_z = \tau_{xz} = \tau_{yz} = 0 \]

Figure 2: Graphical representation of plane stress. The equation to the right indicates which stresses are zero.

![Graphical representation of plane strain](image2)

\[ \varepsilon_z = \varepsilon_{xz} = \varepsilon_{yz} = 0 \]

Figure 3: Graphical representation of plane strain. The equation on the right shows which strains are zero.
Fracture Mechanics of Steel and Ductile Iron

Without going into too much detail, the important points of the fracture mechanics of steel and ductile iron will be described.

Fractured steel Charpy specimens exhibit what are known as shear lips. According to Lai, shear lips form at the boundary between the elastic zone and plastic zone that develop ahead of a crack tip. A number of sources\(^9,10,11\) in the literature state that the presence of these shear lips indicate plane stress behavior within the material. Furthermore, it was shown\(^10\) that steel is much more sensitive to notch geometry than ductile iron, especially with regards to transition temperature and upper shelf energy.

In ductile iron, graphite de-bonding dominates fracture. According to a literature survey conducted by Bradley and Srinivasan\(^12\), Charpy v-notch results are only acceptable “when internodular spacing is less than the standard notch root radius of 0.25 mm. This requires a nodule count of less than 20/mm\(^2\).” This means that a crack must have sufficient matrix material to travel through before it encounters a nodule and this occurs only when nodule counts are 20 or lower. Additionally, In contrast to steel, which experiences plane stress, ductile iron experiences plane strain in a Charpy test\(^13\).

Notch Geometries

There are a number of notch geometries specified in ASTM E23. These include unnotched, v-notched, u-notched, fatigue pre-cracked v-notch and side grooved. Unnotched is typically used for cast irons while v-notched is typically used for steels. U-notched specimens are not common, along with fatigue pre-cracked and side-grooved. However, samples that are v-notched and fatigue pre-cracked tend to have better agreement with results obtained from dynamic tear testing. A sharper notch yields a more conservative estimation of impact toughness and transition temperature. In reality, most cracks that develop in service are sharp and resemble fatigue cracks; therefore, fatigue pre-cracked samples are useful for comparison to results in service components. Side grooving is not, technically, a notch geometry. Rather, it involves machining grooves on the sides of the Charpy bar to, essentially, reduce the cross sectional area at the notch. By doing this, plane strain can be imparted on steel specimens.

Impact Properties of Ductile Iron vs. Steel

Two papers of interest from the literature are reviewed here. Both of them compare the impact properties of ductile iron with those of steel. The first was written by K. E. McKinney at Texas A&M University in 1984 and co-authored by W.L. Bradley and P.C. Gerhardt. The second was authored by R.A. Martinez at the National University of Mar del Plata in 1998. Co-authors included R.E. Boeri and J.A. Sikora.

McKinney, Bradley and Gerhardt\(^10\)

In this study, the authors investigated the impact fracture toughness of ductile iron and compared it to that of cast steel. The two materials were chosen based upon yield strengths. The cast steel was ASTM A216-82 with a yield strength of 36 ksi (248 MPa). The ductile iron chosen was 60-40-18 with a modified
Si content. By lowering the Si content, the authors were able to reduce the yield strength to match the 36 ksi of the cast steel. Four different test bar configurations were evaluated: v-notched, v-notched with fatigue pre-cracks, v-notched with side grooves and v-notched with both fatigue pre-cracks and side grooves. Testing these in an instrumented Charpy tester and at various temperatures, the authors were able to record load-displacement curves for each bar. Using this data, they then calculated the dynamic fracture toughness ($K_{id}$) using the following equations:

$$K_{id} = \sqrt[4]{E} \quad J = \frac{2A}{Bb}$$

In the above equations, $E$ is Young’s modulus, $A$ is the area under the load-displacement curve, up to max load, $B$ is the specimen thickness and $b$ is the un-cracked ligament.

The authors plotted $K_{id}$ vs. temperature. From these plots, they were able to determine that side grooving and pre-cracking affected the upper shelf energy more than transition temperature, especially for the steel samples. In general, the cast steel samples had a higher upper energy as well as a higher lower shelf energy compared to the ductile iron. However, the difference in the transition temperatures of the two materials was significant. In the fatigue pre-cracked and side grooved (to constrain to plane strain) steel samples, the transition temperature was approximately 100°F. In contrast, fatigue pre-cracked ductile iron samples had a transition temperature of approximately -40°F. Figure 4 is a plot from the McKinney paper. It shows that in the temperature range of -50°F to 90°F, the ductile iron actually has higher absorbed impact energies than the cast steel.

![Figure 4: Dynamic fracture toughness vs. temperature plot from McKinney paper.](image)

In this paper, the authors also discussed the comparison of Charpy impact values between cast steel and ductile iron. They state that “it is an apples to oranges type of comparison which may be very misleading if both materials are used in sufficiently thick sections in service to give plane strain conditions.”
Martinez, Boeri and Sikora

The authors of this study investigated the difference in impact and fracture properties of two grades of austempered ductile iron with quench and tempered 4140 steel. Similar to the McKinney study, the materials were matched based upon their ultimate tensile strengths (as opposed to yield strength in the McKinney paper). ADI grades 1050-750-07 and 1600-1300-01 were compared to 4140 quenched and tempered steel at two different temperatures. Notched and unnotched Charpy samples were tested as well as fatigue pre-cracked fracture samples.

Two heats were cast to produce the ADI and were labeled as C1 and C2. Heat C1 was of better metallurgical quality than C2 and had a nodularity of 100% and a nodule count of 250. Heat C2 had a nodularity of 80% and a nodule count of 137.

Comparing the data for the notched specimens, one finds that there is not a large variation for the higher strength samples as compared to the lower strength samples. However, when the data from the fracture toughness testing is evaluated, there is even a smaller difference between the steel and ductile iron. In the experimental set up, the authors did not adjust for the difference in fracture modes between the two samples (plane stress for steel vs. plane strain for ADI), but they did comment on it in the paper. According to the authors,

“The formation of shear lips is the main cause of the significant difference between the Charpy behavior of ductile iron and cast steel...Under plane strain conditions, which could be expected in many component failures, the “shear lip advantage” of steel would be absent, with dramatically lower fracture toughness.”

Limitations of the Charpy Impact Test

There are a number of limitations inherent in the Charpy impact test. Some of these are presented here.

According to the appendix of ASTM E23, the transition temperature varies with the size of the bar that is tested, even for the same material being tested. Furthermore, it stated that correlations cannot be made between these different sized bars. Drop weight and drop weight tear testing partially alleviate this issue. Drop weight tests also show better correlation, especially for the transition temperature, between test specimens and in-service parts.

The data generated from a Charpy test – mainly transition temperature – is not a material property. As a result, these values should not be used in design. A number of references state that actual material properties, such as $K_{IC}$, should be used, for designing of new components.

The test bars in a Charpy test are small. While this is economically favorable, it does not provide conditions that are representative of a majority of service applications. The stress state produced in these small bars is often far more complex than what an in-service component would experience. Fracture mechanics specimens, while larger, help to reduce this disparity between lab and reality generated results.
As noted in a DIS Hot Topic by James Mullins\textsuperscript{14} as well as the ASM handbook\textsuperscript{11}, a high nodule count in ductile iron runs the risk of reducing the impact toughness of a material. As previously stated, the crack needs enough matrix to travel through and high nodule counts decrease the amount of matrix between nodules.

Finally, Charpy tests measure the TOTAL energy of fracture – both the initiation and propagation energies. According to Annex C of ISO 1083:2004, ferritic ductile irons have similar crack initiation energies compared to low alloyed or unalloyed steels, even when the impact energies of the ductile iron are less than half that of the steel.

Conclusions

Charpy impact testing is neither an accurate nor acceptable way to measure impact toughness in cast irons. It is inappropriate to use it as a means of comparison between cast iron and steel. Although the two materials are comprised of the same two base elements, iron and carbon, they differ dramatically in their material properties. Further research into better means to measure impact toughness of ductile iron is needed. Additionally, design engineers need to be better educated as to what the results of the Charpy impact test actually measure and how to best utilize those results.

Acknowledgements

I would first like to thank Richard Larker for his inspiring discussion to “let Mr. Charpy rest in peace.” I would also like to thank Dr. Kathy Hayrynen for her technical direction and review of this topic. Finally, I would like to thank you, the reader, for reading this far.

References

5. The German Institute for Standardization. (1997). EN 1563 Founding - Spheroidal graphite cast iron. DIN.


TOM PRUCHA


THE DIS WELCOMES TOM WHO IS HERE TO TALK ABOUT “THE NEW AFS GUIDE TO DUCTILE MICROSTRUCTURES”
The New AFS Guide to Ductile Microstructures

Thomas Prucha
VP Technical Services
American Foundry Society
AFS Guide to Ductile Microstructures

The New “AFS Guide to Ductile Microstructures” is the latest revision to the AFS publication, formerly called “Foundrymen’s Guide to Ductile Iron Microstructure.”

Why the need for a revision?

- Last revision & update published in 1984
- Edition is no longer in print or available
- Need for better pictures, microstructure examples, latest technology and more descriptive terms and approach that can migrate to e-devices
The New AFS Guide to Ductile Microstructures

Cover concept for new “Guide to Ductile Iron Microstructures,” the new version of the 1984 publication.
# 1984 Foundrymen's Guide Table of Contents

**TABLE OF CONTENTS**

- Preface ........................................................................... v
- Introduction ..................................................................... 1
- Section I: Definition of Terms ........................................... 3
- Section II: Graphite Characterizations ............................... 9
  - A) Graphite Forms .................................................. 11
  - B) Nodularity Ratings ............................................. 17
  - C) Nodule Sizes .................................................. 22
  - D) Nodule Counts .................................................. 27
- Section III: Matrix Structures ........................................... 33
  - A) Pearlite Percentages ........................................... 35
  - B) Carbide Percentages .......................................... 40
  - C) Miscellaneous Structures ..................................... 49
- Section IV: Effects of Alloying and Subversive Elements ........ 59
- Section V: Effects of Common Foundry Practices ............... 73
  - A) Molding and Casting ......................................... 75
  - B) Heat Treatments ............................................. 83
- Section VI: Effects of Other Processes ................................. 93
- Appendix A Preparation of Specimens for Metallographic Examination .................................................. 101
- Appendix B The Image-Analyzing Microscope Used for Quantitative Metallography of Cast Iron ......................... 105
- Appendix C Measurement of the Pearlite Content in Ductile Iron Microstructures ........................................... 113
- Index .......................................................................... 129
# Guide to Ductile Iron Microstructures

New TOC & Progress of drafts

<table>
<thead>
<tr>
<th>First Draft</th>
<th>Second Draft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SECTION 1: DEFINITION OF TERMS</strong></td>
<td><strong>1—TERMINOLOGY</strong></td>
</tr>
<tr>
<td>Types of Cast Iron</td>
<td>Cast Iron Types</td>
</tr>
<tr>
<td>Graphite Forms</td>
<td>Graphite Forms</td>
</tr>
<tr>
<td>Matrix Forms</td>
<td>Matrix Forms</td>
</tr>
<tr>
<td>Compounds and Metallic Phases</td>
<td>Compounds and Metallic Phases</td>
</tr>
<tr>
<td>Chemical Terms</td>
<td>Chemical Terms</td>
</tr>
<tr>
<td>Process Terms</td>
<td>Process Terms</td>
</tr>
<tr>
<td>Metallographic Terms</td>
<td>Metallographic Terms</td>
</tr>
</tbody>
</table>

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Change layout to dictionary format & delete subheads; section could be located at the end of the book.
## New TOC & Progress of drafts (continued)

### First Draft

<table>
<thead>
<tr>
<th>SECTION 2: METALLOGRAPHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREPARATION OF SPECIMENS FOR METALLOGRAPHIC EXAMINATION</td>
</tr>
<tr>
<td>Sampling</td>
</tr>
<tr>
<td>Rough Grinding</td>
</tr>
<tr>
<td>Mounting</td>
</tr>
<tr>
<td>Fine Grinding</td>
</tr>
<tr>
<td>Polishing</td>
</tr>
<tr>
<td>Etching</td>
</tr>
<tr>
<td>ETCHING REAGENTS FOR DUCTILE IRON</td>
</tr>
<tr>
<td>SAFETY PRECAUTIONS</td>
</tr>
<tr>
<td>METALLOGRAPHIC ANOMALIES</td>
</tr>
<tr>
<td>Flatness</td>
</tr>
<tr>
<td>Scratches</td>
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<tr>
<td>Water Stains</td>
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<td>Incomplete Removal of Etch</td>
</tr>
<tr>
<td>Graphite Pull Out</td>
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<td>Effect of diamond Size</td>
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<td>Insufficient v. sufficient Polish</td>
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<td>Comet Tails</td>
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### Second Draft

- **2—METALLOGRAPHY**
  - METALLOGRAPHIC SAMPLE PREPARATION
    - Need newer information & automatic sample prep equipment coverage.
      - Sampling
      - Rough Grinding
      - Mounting
      - Fine Grinding
      - Polishing
      - Etching
    - ETCHING REAGENTS FOR DUCTILE IRON This sub-section could be combined with the etching sub-section
    - SAFETY PRECAUTIONS Need new safety info here
    - METALLOGRAPHIC ANOMALIES This Sub-section could be a separate stand-alone Section
      - Flatness
      - Scratches
      - Water Stains
      - Incomplete Etchant Removal
      - Graphite Pullout
      - Effect of Diamond Size
      - Insufficient vs. Sufficient Polish
      - Comet Tails
New TOC & Progress of drafts (continued)

First Draft

SECTION 3: GRAPHITE CHARACTERIZATION
GRAPHITE NODULARITY
GRAPHITE FORM
GRAPHITE SIZE
AFS ASTM CHART
DIS CHART PICTURES
QUANTITATIVE GRAPHITE IMAGE

ANALYSIS
OTHER GRAPHITE FORMS
Graphite Flotation
Crab Graphite
Flake Clusters
Flake Films
Vermicular Graphite
Aligned Graphite
Chunk Graphite
Exploded Graphite
Poor Nodularity

Second Draft
(editor’s recommendations in red)

3—GRAPHITE CHARACTERIZATION Need up-to-date info on all characterization techniques
GRAPHITE NODULARITY
GRAPHITE FORM
GRAPHITE SIZE
AFS ASTM CHART
DIS CHART/PICTURES
QUANTITATIVE GRAPHITE IMAGE ANALYSIS

OTHER GRAPHITE FORMS
Graphite Flotation
Crab Graphite
Flake Clusters
Flake Films
Vermicular Graphite
Aligned Graphite
Chunk Graphite
Exploded Graphite
Poor Nodularity
New TOC & Progress of drafts (continued)

First Draft

SECTION 4: MATRIX STRUCTURES
PEARLITE PERCENTAGES
PEARLITE IN COLOR
PEARLITE WITH SCANNING ELECTRON MICROSCOPE
OTHER MATRIX CONSTITUENTS
- Carbides
  - Inverse Chill
  - Ledeburite
- Acicular
- Austenite
- Steadite
  - Macroporosity
  - Microporosity
  - Incipient Melting

Second Draft

(Second Draft: editor’s recommendations in red)

4—MATRIX STRUCTURES
PEARLITE PERCENTAGES
PEARLITE IN COLOR
PEARLITE WITH SCANNING ELECTRON MICROSCOPE Need info on other imaging techniques
OTHER MATRIX CONSTITUENTS
- Carbides
- Inverse Chill
- Ledeburite
- Acicular
- Austenite
- Steadite
  - Macroporosity
  - Microporosity
  - Incipient Melting
### First Draft

<table>
<thead>
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<td>NORMALIZED AND TEMPERED</td>
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New TOC & Progress of drafts (continued)

First Draft

SECTION 7: DETRIMENTAL CONDITIONS
EFFECTS FROM MOLDING
  Burned-In Sand
  Surface Sand Reaction
  Unmelted Chaplet
  Undissolved Metal Splash
EFFECTS FROM TRAMP ELEMENTS
  Aluminum
  Antimony
  Bismuth
  Boron
  Lead
SLAG AND DROSS
  Slag
  Dross
  Sulfides

Second Draft

7—DETIRIMENTAL CONDITIONS
MOLDING
  Burned-In Sand
  Surface Sand Reaction
  Unmelted Chaplet
  Undissolved Metal Splash
TRAMP ELEMENTS
  Aluminum
  Antimony
  Bismuth
  Boron
  Lead
SLAG & DROSS
  Slag
  Dross
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Status of the Guide to Ductile Iron Microstructures
Section 1—Terminology

• This section requires only minimal additions to update terminology to state-of-the-art definitions.

• Moving section to back of book as glossary/dictionary enhances efficiency of book.
Section 2—Metallography

This chapter is almost identical to the old version. This would be a good place to insert information new equipment, etchants, techniques and safety info. Perhaps info from metallographic suppliers? ASM also has a newer online periodical that offers Metallographic info. There should be some information available to replace the info on grit, mesh and micron size in the figure below.
New information includes 15 anomalies examples in this section. Here is one example:

**Gray Iron Microstructural Preparation Anomalies**

**Description:** Poor Flatness (partially out of focus image)

**Magnification:** 100X

**Condition:** As-polished

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<td>Uneven stage/platen on microscope</td>
<td>Ensure stage, platen and sample are free of debris</td>
</tr>
<tr>
<td></td>
<td>Correctly level microscope stage</td>
</tr>
<tr>
<td>Excessive polishing</td>
<td>Minimize polishing to that required for acceptable finish</td>
</tr>
</tbody>
</table>
Section 3—Graphite Characterization

This chapter uses 24 figures from the old book. New text is needed to accompany the figures. In addition, there are 69 new photos (30 from DIS, 24 from Wells Dura-bar, 5 from Hitachi and 10 from Rio Tinto). The new photos also require text.

Here is an example a new photo: 3-74 Etched chunk graphite from Rio Tinto.

Another example Fig. 3-68 Aligned graphite, courtesy Hitachi.
Section 4—As-Cast Microstructure

Sample Figure 4-10, 20% pearlite
(Artwork courtesy of Stork Climax and the Ductile Iron Society)

Of the 41 figures in this section, 25 are from the old book and the rest from various sources. There is some new text included with the new figures in this section. More text/explanation is needed to support the figures.
Section 5—Heat Treatment

• More explanation on the basic heat treat processes/terms needed, esp. with the following terms: normalized, normalized and tempered, high temp anneal, subcritical anneal, oil quench, oil quench and temper, austempering, decarburization and oxidization.

• Most of the paragraph text is the caption text from the old book. Details needed for the reader. There are 24 (or 25) total figures. (Need an example of pearlite surrounding graphite nodules for Fig. 5-23).
Section 6—Other Processing Effects

- Three figures from Modern Casting article on welding, 2 figures from Wells Dura-Bar, and 9 figures from old book comprise the images used.
- This chapter needs more text in all areas: Welding, Alloyed Iron/Austenite, Annealed Si-Mo Ductile Iron, Pearlite Stabilizing.

Image of welding example from Modern Casting that will be used (magnified 1½ X original size).
Section 7—Detrimental Conditions

- Figures included consist of 11 from 1984 book, and 7 newer figures.
- Chapter needs an introduction.
- More explanations needed for the following:
  - Burned-in sand
  - Surface-Sand Reaction (flake skin),
  - Unmelted chaplet
  - Undissolved Metal Splash (Iron Shot)
  - Effects from Tramp Elements (Aluminum, Antimony, Boron, Lead),
  - Slag and Dross (Slag, Dross, Sulfides)
Section 8—Compacted Graphite Iron

- Chapter needs more information on CGI.
- List of properties differences between ductile iron and gray iron.
- Add some info on processing differences.
- Show examples of cast iron matrices.
- Out of 21 figures total, there are 19 figures from SinterCast; more explanation is needed for all figures.
In general, more explanation is needed for all figures. For example, the figure on the right, is captioned with the following:

**Fig. 8-1 0% Nodularity**(courtesy of SinterCast)
Potential example of Instructional Graph that might be incorporated

Inoculation

Modification

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Muskegon, Michigan
Examples of Photomicrographs from Strain-Life Database

Grade 9002 QT 500x

Grade 7003 Normalized
76 mm Test Bar 250x
For additional information, please contact:

- Laura Moreno
- Director of Special Publications
- American Foundry Society
- 800-537-4237, x 241
- lmoreno@afsinc.org
- www.afsinc.org

THE DIS WELCOMES MARK WHO IS HERE TO TALK ABOUT “US FOUNDRY COKE SUPPLY...AND FACTORS THAT DRIVE THE MARKET”

******

SCOTT GLEDHILL/RICK ERICKSON

SCOTT GRADUATED FROM THE UNIVERSITY OF ALABAMA WITH B.S. IN METALLURGICAL ENGINEERING. WHILE AT SCHOOL HE CO-OPED AT STOCKHAM VALVES AND FITTINGS IN BIRMINGHAM SPENDING TIME IN THE BRONZE, GRAY IRON, MALLEABLE IRON AND METALLURGICAL AREAS.

IN 1985, SCOTT STARTED AT GM CENTRAL FOUNDRY IN DEFiance
OHIO.

IN 1992 SCOTT JOINED THYSSENKRUPP WAUPACA AT THEIR MARINETTE PLANT AS PLANT METALLURGIST. DURING SCOTT’S 19 YEARS WITH THYSSENKRUPP HE HAS HELD VARIOUS POSITIONS INCLUDING METALLURGIST, QUALITY MANAGER, PLANT MANAGER, MANAGER OF RESEARCH AND IS CURRENTLY DIRECTOR NEW PRODUCT INTRODUCTION.

SCOTT HAS BEEN INVOLVED IN VARIOUS AFS AND DIS COMMITTEES INCLUDING MOLTEN METAL PROCESSING, MOLTEN-METAL INTERFACE, DIS RESEARCH AND IS CURRENTLY PRESIDENT OF THE DIS. HE IS ALSO CHAIRMAN OF THE INDUSTRIAL ADVISORY BOARD FOR THE METALLURGICAL DEPT. AT THE UNIVERSITY OF ALABAMA.

THE DIS WELCOMES SCOTT WHO IS HERE TO PRESENT FOR RICK ERICKSON AND TALK ABOUT “MATERIAL COST REDUCTION IDEAS FOR TODAY’S FOUNDRY”

*******

ROBERT BIGGE


THE DIS WELCOMES BACK BOB WHO IS HERE TO TALK ABOUT “IMPROVING CUPOLA EFFICIENCY”
US Foundry Coke Supply
...and Factors that Drive the Market

Mark Bidoli
Hickman, Williams & Company
Agenda

• US Foundry Coke Supply
• Foreign Coke Supply & Coke Alternatives
• Understanding the Market
• Blast Furnace vs. Foundry Coke
• What Drives the Market
US Foundry Coke Supply
US Foundry Coke Supply

• ABC Coke, AL (Drummond)
  – Capacity: 500,000 tpy

• Walter Coke, AL (Walter Energy)
  – Capacity: 285,000 tpy

• Erie Coke Corporation, PA
  – Capacity: 160,000 tpy*

• Tonawanda Coke Corporation, NY
  – Capacity: 190,000 tpy
US Foundry Coke Supply

Production is not limited to cupola foundries

- 4”+ material usually ends up in iron or lead making cupolas
  - About 70% of total coke output
- Undersized material is used for other industrial applications
  - mineral wool
  - lime kiln fuel for sugar beet manufacturers
  - carbon raiser
  - binder for foundry coke production
- Foundry Coke producers may also make BFC
Foreign Coke Supply & Coke Alternatives
Foreign Supply

• Columbian Coke
  – Lower Carbon content

• European Coke
  – Poland
  – Italy

• Chinese Coke
  – 40% self imposed export tax keeping exports to a minimum, mainly to India
  – US duties still imposed
Alternatives

• Carbonite Form Coke, VA
  – Made from coal, 50,000 tpy
  – Potential for additional capacity
• Excess BFC from Steel mills or other merchant BFC producers
  – When coke stocks are surplus to mill demand
  – When integrated mills shut down the blast furnace, the coke batteries continue to operate
• Broken, crushed anodes
• Anthracite Coal
Understanding the Market
Understanding the Market

We must not only look to the supply/demand equation, but also the outside factors that may influence the marketplace:

- Metallurgical coal prices
- Global demand for steel
- Blast Furnace coke demand
- Global demand for coal, both met and steam
Recent Headlines for Coal/Coke...

- *China’s demand for coke in 2015 to reach 380 Mt*, by Shi Lili, Steel Times International, March 2012
- *Chinese coke output set to rise to 450 Mt*, *China Metals*, Steel Times International, March 2012
- *Coal exports surge to highest level since 1991*, by Matthew Brown, Associated Press, April 10, 2012 7:36pm
- *China to see slow growth in Q2 coal demand*, by Yamei Wang, Xinhua News, April 8, 2012, 9:19 pm
- *Utilities Give Coal the Heave Ho*, by Rebecca Smith, WSJ, May 1, 2012
- *Thermal Coal Prices drop to lowest levels in 18 months*, by Emiko Terazono, Financial Times, May 2, 2012
- *China buyers defer raw material cargoes*, by Javier Blas and Jack Farchy, Financial Times, May 19, 2012
Recent Headlines for Steel

- **Glut of Steel in China likely to last throughout 2012**, China Metals, Steel Times International, March 2012
- **China’s steel market is warming up**, by Shi Lili, Steel Times International, April, 2012
- **Steelmakers Confront Oversupply Worries**, by John W. Miller, WSJ, April 30, 2012
- **Industry Picks up the Pace**, by Conor Dougherty, WSJ, May 2, 2012
- **Arcelor Mittal returns to profit, sees global demand up 4-4.5%**, Platts, May 10, 2012
- **World apparent steel use revised downward in April 2012 Short Range Outlook**, by Jessica Wagner, NerdsofSteel.com
- **Analysis: China’s Towering metal stockpiles cast economic shadow**, by Fayen Wong and Jane Lee, Reuters, May 18, 2012
Coking Coal Market

- Hard Coking coal prices are down from record highs last year
- Quarterly contract prices for hard coking coals lowered significantly but have recently turned up again for 3\textsuperscript{rd} Quarter contracts
- Prices could weaken again due to the situation in Europe
- High demand for thermal and met coals in Asia could rebound the market later this year
Metallurgical Coal Qualities

- **Thermal Coals**
  - Mainly used in power generation
  - Least expensive, widely available
  - Lowest ranking bituminous coal

- **Low Vol, Mid Vol, High Vol coking coals**
  - “Hard coking coals”
  - Used primarily for coke making
  - Tend to be higher quality for stronger coke properties
  - Low availability, have become difficult to extract.
Appalachian Met Coal Production
Blast Furnace vs. Foundry Coke
BFC vs. FC

Blast Furnace Cokes (BFC) and Foundry Cokes (FC) are made by blending metallurgical coals to provide the desired properties

• Blast Furnaces produce hot metal via a reducing atmosphere where Oxygen is removed from the Iron Ore
• Cupolas produce iron via a melting process of cast iron scrap, pig iron and/or steel
Blast Furnace Coke

Blast Furnace Coke is designed to support a significantly higher burden in the furnace than in a traditional iron cupola:

- CRI – Coke Reactivity Index
- CSR – Coke Strength after Reaction
- Steel makers are also interested in coke porosity and fissure formation
- Usually sized 1” x 3”
- Typical oven time is 18 hours
Foundry Coke

Cupola operators are interested in larger sized material, but do not usually specify strength or reactivity requirements.

- Coals are blended to achieve larger piece formation.
- Blend requires a higher concentration of Low Vol coals ($$$$
- Sized at 4” x 6” for smaller diameter cupolas.
- Sized 4” x 9” for larger diameter cupolas.
- Typical oven time is 28 hours.
BFC v. FC

Blast Furnace Coke

Foundry Coke
What Drives the Market
Global Demand for Coal

- In late 2008 before the financial crisis, the US became a swing supplier to the global coal trade due to continuing issues with coal production in Australia.
- US coal exports continue today as China continues to import coal even as the demand for steel and coal has slowly dwindled since the beginning of 2012.
- Hard coking coal prices remain strong due to low supply and high extraction costs.
Global Demand for Coal

- Low NG prices in the US have tempered domestic demand, causing some production to be shuttered, maintaining some price support
- Coal will continue to be a significant energy source for the rest of the developing world
- Continued mining issues in Australia will help support US coal export trade
Other Issues with Coking Coal

• Coals are more expensive to mine
  – Digging deeper, smaller seams
  – Increased regulatory burden from entities such as MSHA, EPA, etc
  – Mine startups require large capital expenditure
• Decreased availability of higher quality coals causing steel makers to turn to thermal grades
• Political pressures
Conclusions

Domestic and global factors will affect coal and coke markets going forward:
• Limited number of Foundry Coke Producers and alternative materials
• Coal export market
  – Energy demand
  – Steel demand
• Environmental pressure on coal mining and coal use for electricity
• Increased costs of mined coals
For additional information, please contact:

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Improving Cupola Efficiency

Robert Bigge
Iron Casting Research Institute
History of ICRI

• In the 1930’s a group of iron foundries funded research at Battelle Memorial Institute to look at improving cupola operations.

• Some of the researchers from Battelle were spun off to form the Gray Iron Research Institute.
• In the 1970’s the name was changed to Iron Casting Research Institute to reflect that we were involved with all type of iron castings.
General Comments

• Operate the cupola continuously
• Operate the cupola at constant blast
• Blast rate should be in the range of 2.4 – 2.6 times the cupola cross-section in inches
• Size tuyeres to achieve a tuyere velocity of 12-15,000 ft/min cold blast
General Comments

• Any changes made to improve the efficiency of the cupola will increase the melt rate.
• If you can’t get rid of the additional melted iron you are not going to maximize the cupola operation.
General Comments

• You need to work with scheduling to evenly load the molding lines to have a constant metal demand.
• The cupola should be sized so that the cupola is pushed to achieve the required metal demand.
Effect of Lining on Heat Loss

Heat Loss to Shell Water Cooling

- Unlined Cupola
- Unlined Cupola in Meltzone
- Lined Cupola

Diameter of Cupola Shell, inches

% of Total Heat Lost

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Muskegon, Michigan
Sizing of coke

Reference: Some Variables in Acid Cupola Melting; 1954 AFS Transactions
Effluent Gas Composition

CO/CO₂ Balance in Effluent Gas

% CO in Gas

% CO₂ in Gas

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Energy Loss to CO Formation

Heat Loss to CO, BTU/1000scf

% CO in Gas

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Coke used to Generate CO

Total Carbon Used, #C/1000scf

% CO in Effluent Gas

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Effect of Hot Blast

Available Energy From Heated Blast Air, BTU/1000scf

Temperature of Blast Air, °F

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Divided Blast

Reference: Further results of investigation of improved cupola performance by proportioning the blast between two rows of tuyeres; 1972 BCIRA Report 1057

Fig. 3 Reduction of charge coke quantity and increase in melting rate by operating cupola with 2 rows of tuyeres with proportioned blast supply. (Blast rate 1 600ft³/min).
Use of Oxygen

Reference: Developments in Cupola Melting; 1979 BCIRA Conference paper

Fig. 8 Effect of 4% oxygen enrichment of blast in conventional and divided-blast operation
Effect of Humidity in Blast Air


Fig. 14-23. Coke to be added to the base charge to compensate for moisture in the blast.
Savings from Dehumidification

17,500 scfm blast rate; melting 50 TPH; operating 50% of available hours/month; $500 per ton for coke

Total Savings

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Natural Gas & Liquid Fuels

• In the late 60’s and early 70’s tests were run using natural gas and fuel oil burners in the tuyeres of cupolas.
• Some of this work was actually done here in Muskegon at CWC. This work was done by Battelle Memorial Institute and Columbia Gas.
• The burners were fired with air.
Effect of Burners on Melt Rate

Reference: Oxy-Fuel Tuyere Burners; 1966 AFS Transactions

Oxy-NG Burners

MELTING RATE – VERSUS – WIND RATE
OXY-GAS BURNERS – HIGH FLOWS

MELTING RATE NO. OF 5000 LB. CHARGES MELTED PER HOUR

0 1 2 3 4 5 6 7 8 9 10
WIND RATE – SCFM x 1000

0 1 2 3 4 5 6 7 8 9 10
MELTING RATE NO. OF 5000 LB. CHARGES MELTED PER HOUR

Oxy-Oil Burners

MELTING RATE – VERSUS – WIND RATE
OXY-OIL BURNERS – HIGH FLOWS

DIS Annual Meeting, June 7, 2012
Muskegon, Michigan
Natural Gas Burners

- In the mid 90’s and later the use of natural gas burners fired with oxygen was developed in Europe and many papers were published. These papers all indicated reduced coke usage.

- I was involved with the installation of oxy-NG burners at Wheland Foundry in the late 90’s.
Natural Gas Burners

- These burners were quite small in energy input. Approximately 5 million BTU/Hr total through 3 burners.

- We experienced an increase in melt rate of 5-10%, a reduced coke consumption of approximately 5%, and an increase in silicon recovery.
Natural Gas Burners

• The European reports of oxy-NG burner use in the last decade have reported much more substantial improvements in cupola efficiency.

• The burner outputs are substantially greater than those at Wheland Foundry.
Material Cost Reduction
Ideas for Today’s Foundry

Tell City Melt Department
Waupaca Foundry
Materials Costs

• Over the past 4 years or more we have watched melt material prices, particularly for ductile operations skyrocket.
• The costs are difficult to recoup from some customers in a timely fashion.
• To off-set these increases we began to look internally for cost savings programs.
Flashings

• We found something that most foundries, particularly cupolas, are not able to use and may sell for low costs.

• This waste stream was the fine re-melt particulate from our “grizzlies” that we call flashings.
Cost Savings Calculations

• P5 Sand system presently separates 9 ton of flashings per day.
• These flashings are presently landfilled as we have no market for them.
• We began investigating the option of “canning” these fines.
Cost Savings Calculations

Time study to analyze labor costs

- Time needed to fill and close 1 can: 0.1 Hour
- Process cans per hour: 12 each
- Weight of turnings per can average: 140 lbs.
- Cans required per ton of turnings: 16.0 each
- Tons processed per hour: 0.75 tons
- Tons processed per shift: 6.00 tons

- Note all wt is Net Tons
Cost Savings Calculations

• Then the potential cost savings was analyzed as a comparison value to purchased cast.
• Limited to present collection of 9 Tons per day (estimate)
• Labor rate of $17.31 per hour (example)
• Purchased cast @$415.00 GT (example)
Cost Savings Calculations

• Potential tons processed daily 9 tons
• Tons processed hourly 0.75 tons
• Total cost canned grizzlies $74 per ton (material, labor, cans etc)
• Final cost savings vs. cast $340 per ton

• Potential daily savings $3,068.64
• Monthly potential for canning savings $61,373
Equipment required

• Purchased small hopper and feeder system with holes drilled for sand separation, overhead hoist and jib crane.
• Procured source for new cans @$3.81 per can (factored in cost per ton)
• Total cost for all equipment to date $24,000
• Dust collection still to be tied in.
Equipment required
Equipment required

• A turntable was added to expedite lid closing and handling process.
• Pneumatic “hog ring” stapler to insure lids stay closed
• Now investigating pneumatic lid closer (additional $2400)
Equipment required
Equipment required
Final Product

• Finished product is apx. 140 lbs per can charged on our pig iron shaker (rarely used now) in grey charge mixes.
• 95% metallics content (still considering adding magnetic separation)
Final Product
Results to date

• This project kicked off in mid-August 2010.
• During the initial month we found many more “waste streams” where formerly useless material was being land-filled. Multiple presses, grinders and separators were identified.
• For August 2010 we “canned” and charged 167.57 tons of material for a cost savings of $50,946.46.
Results to date, con’t

• We have run above 1% of our charge as “canned” with no detrimental effect in the cupola operations.

• We are still capturing more of the waste streams and learning how to handle them. We expect to see around 20 ton per day from these alone.

• Future plans include canned borings, short shovelings, and possibly DRI fines (trial upcoming) for additional savings.
Results to date, con’t

• 2011 savings were $1.14M
• Additional alternatives and waste streams were added to the program in 2012 and have netted $1.3 M so far this fiscal year.

• In summary, the use of alternatives and waste stream materials can do for any foundry what it has done for us…you just have to find them.
PETE SATRE

PETE GRADUATED FROM OHIO STATE UNIVERSITY IN 1994 WITH HIS BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING. PETE STARTED HIS CAREER WITH FORD MOTOR COMPANY IN CLEVELAND, OHIO AS PROCESS ENGINEER, REFRACTORIES SUPERVISOR, AND MAINTENANCE PLANNING SPECIALIST. PETE WAS THERE FOR A TOTAL OF 10 YEARS IN THE MELTING DEPARTMENT OF THIS CAPTIVE GRAY AND DUCTILE IRON FOUNDRY. HE THEN MOVED TO COLUMBUS, OHIO AND BEGAN HIS NEW CAREER WITH ALLIED MINERAL PRODUCTS AS A PRODUCT SERVICES ENGINEER. HE IS CURRENTLY THE MANAGER OF ENGINEERING, WHICH INCLUDES PRODUCT APPLICATION AND ENGINEERING RESPONSIBILITIES WORLDWIDE. PETE IS A MEMBER OF THE AFS AND PAST CHAIRMAN OF THE MELTING METHODS AND MATERIALS AND PAST CHAIRMAN OF THE CUPOLA COMMITTEE.

THE DIS WELCOMES BACK PETE WHO IS HERE TO TALK ABOUT “REFRACTORARY ALTERNATIVES FOR COMBATING ELEPHANT’S FOOT EROSION AND TOP CAP WEAR IN CORELESS FURNACES”
Refractory Alternatives to Combat Elephant's Foot Erosion and Top Cap Wear in Coreless Furnaces

Peter L. Satre
Manager, Engineering
Allied Mineral Products, Inc.
Traditional Furnace Lining

- Coreless melting of ductile based iron has been used for 50+ years, now has become a preferred melt system.
- Advantages
  - Melting of low S scrap
  - Flexible operations
  - Low emissions
  - New power technology
Traditional Lining Methods

- SiO₂ with Boric Acid or Boron Oxide binder

- Advantages
  - Inexpensive
  - Excellent thermal shock resistance
  - Good resistance to iron and slag penetration
Expansion Properties
Traditional Furnace Lining

Disadvantages

- Relatively weak strength
- Lowest refractoriness of the major refractory components
- Phase transformation requires extended sinter time
Elephant’s Foot Erosion

- Severe erosion in the bottom 5 – 15% of the furnace sidewall

- Causes
  - Heel Melting
  - High Temperature
  - Ductile Base
Elephant’s Foot Erosion

- Medium frequency, batch melting furnaces not as affected

- Process improvements
  - Installation
  - Temperature control
  - Charge selection
  - Sintering
Silica enhancements

- Zircon
- Chrome
- Fused Silica
- Carbon, SiC

Product remains silica based
Alumina Lining Alternatives

- Andalusite based
- Optimized for thermal shock resistance
Previous alumina lining trials
Candidates for andalusite

- Severe taper or elephant’s foot erosion
- Limited thermal cycling
  - Heel melting
  - Good torch control when out of operation
- Short or erratic lining life
Alumina Advantages

- Quicker sinter – 400 °F/hr or 220°C/hr
- Eliminates elephant’s foot erosion
- Upper sidewalls will erode evenly
- Can be easier removal/push out
Comparison of grain structure
Can alumina and silica be zoned?

- Eutectic point is formed below iron melting temperature
- Zoning has been normally limited to the top cap area
Top Cap Issues

- Area above the active power coil
- Heat exposure is radiant except during pouring
- This area is the primary maintenance point for many coreless applications
Exposure Conditions

- Impact from charge
- Thermal shock cracking (temperature difference)
- Separation of top cap lining from primary lining
Temperature Difference

- Large pollution systems cause a difference in temperature at the top of the furnace.

- Large temperature differences result in cracking and seam separation.
Impact from Charging

- If charge material is loaded by magnet or shaker it can impact the top cap and wear the refractory
Separation

- Different material classifications and minerals do not always bond completely.
Major Problem of Metal Leakage to Coil

- If the top cap is not maintained, metal can leak from seam to contact coil, creating electrical ground.
Procedure to Install Top Cap

- Two different materials require a “transition” layer
- This layer will minimize seam separation
- Use normal procedure for working lining, add 50% working lining material and 50% top cap material, mix vigorously
- Continue normal procedure.
Coreless furnace are designed to operate with metal level at the high of the active coil.

Only at the sintering, to get better results at the top area, metal must go up to the spout area.
Top Cap Sinter

Operate this level only on sinter heat
Refractory Families for Top Cap

- Silica-based dry vibratables
- Fused silica-based dry vibratables
- Alumina-based dry vibratables
- Castable
- Plastic and plaster
- Wash coating
Silica Based Dry Vibratables

Procedure
- Increase bond content to 1.5 – 1.8 % B.O.(2.5% B.A.)

Advantages
- No seam separation (mineral base is the same)
- Low cost mineral

Disadvantage
- Not very good at resisting mechanical impact
Fused Silica Based Dry Vibratable

Material
- Quartz based with fused silica addition of 15 – 50%.
- Bonded by boron oxide or boric acid

Advantages
- No seam separation (mineral base is the same)
- Excellent thermal shock properties

Disadvantage
- Not very good at resisting mechanical impact
Material Selection
- Material can be based on chamotte, bauxite, mullite, or andalusite

Advantages
- High strength for impact resistance
- Good sintering properties

Disadvantage
- Seam will separate between materials
- Area between top cap (alumina) and working lining (quartz) is low temperature eutectic
Castable

Materials
- Low cement or no cement castables based on chamotte, mullite, andalusite, or bauxite

Advantages
- Very high strength

Disadvantage
- Must be dried out
- Requires mixer to install
- Consideration for keeping moisture from working lining
Castable Installation

Moisture separation barrier  Castable installation
Top Cap Comparison

Dry Vibratable

Castable

After 200 tons throughput
Plastic and Plaster

Material Selection
- Material can be based on chamotte, bauxite, mullite, or andalusite
- Phosphate or air set binder

Advantages
- High strength for impact resistance
- Can be installed with or without form

Disadvantage
- Seam will separate between materials very easily
- Dryout is necessary
New Technology – Fiber Reinforced Dry Vibratable

- Chamotte based dry vibratable with stainless steel fiber addition
- Excellent toughness
- Virtually eliminates cracks
- Expansion to match silica lining
Modulus of Rupture Comparison
Summary

- Audit operation and wear mode to see if alternative lining materials are applicable.

- Identify wear mode in top cap
  - Mechanical impact
  - Thermal shock
  - Seam separation

- New technology of fiber containing dry vibratable addresses issues
Thank You!
MEETINGS

The Ductile Iron Society Fall Meeting will be held October 24-26, 2012. This event will be held in East Peoria, Illinois at the Embassy Suites, 100 Conference Center Drive, East Peoria, IL 61611. The foundry tour will be to Caterpillar, Inc. in Mapleton, at the Wyndham Hotel in Gettysburg, Pennsylvania. There will be a visit to TB Wood's in Chambersburg, Pennsylvania.

BUSINESS

CASE STUDY

Project: Restoring Original Furnace Capacity in Holding Channel Furnaces (ductile iron)

Problem: Qty: 2 - 65 Ton Vertical Channel Holding Furnace capacities were less than 35 tons after 11 months of operation.

Solution: 0.05% Redux Flux was added continuously to transfer ladles feeding the channel holders - for 3 weeks.

Results: Build-up was removed AND capacity was fully restored to 65 tons. These furnaces now last 24 months instead of 12 months!

Savings: $100,000 for each furnace!

How much is slag build-up costing your foundry?

Slag build-up costs foundries in many ways:

- Loss of effective melt power, slower melting rates
- Loss of furnace capacity, reduced production rates
- Increased refractory life, fewer refractory re-lines
- Ladles stay cleaner, reduced maintenance
- Ductile tundish ladle service life extended 5 fold
- Improved magnesium recoveries
So, unless you sand blast your charge materials, you will generate slag when melting! It’s inevitable!

**About the Solution: Redux EF40L (or LP) Flux**

A mild fluoride-free, chloride-free flux. Redux EF40 is used successfully to combat most build-up conditions in ferrous melt and pouring conditions.

**To find out how much Redux can save you...**
call ASI Alloys (800) 860-4766