Thermal processing

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COMPANY PROFILE

Metallurgical High Vacuum Corporation

Technologies and Processes for the Advancement of Materials

JULY / AUGUST 2018
thermalprocessing.com

FEATURES

JULY / AUGUST 2018

DEPARTMENTS

JULY / AUGUST 2018
Volume 7 / Number 4

RESOURCES

Cover photo: TimkenSteel

Thermal Processing is published semi-annually by Media Solutions, Inc., 266D Yeager Parkway Pelham, AL 35124. Phone (205) 380-1573 Fax (205) 380-1580 International subscription rates: $105.00 per year. Postage Paid at Pelham AL and at additional mailing offices. Printed in the USA. POSTMASTER: Send address changes to Thermal Processing magazine, P.O. Box 1210 Pelham AL 35124. Return undeliverable Canadian addresses to P.O. Box 503 RPO West Beaver Creek Richmond Hill, ON L4B4R6.

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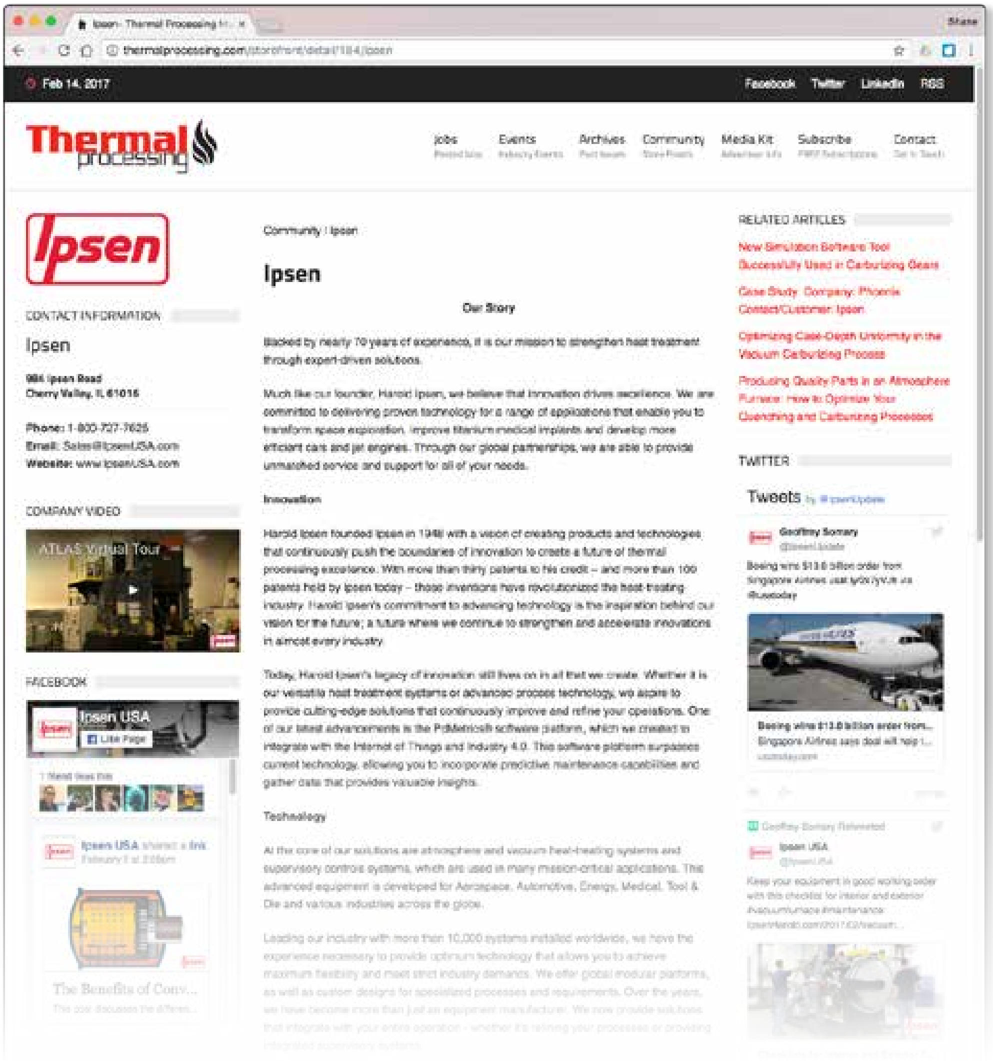

Connect your company to the heat treating industry with a storefront in the Thermal Processing Community. Storefronts paint a portrait of your company with a 500-word description and include your logo, website link, phone number, email addresses, and videos. Your social media pages such as Twitter and Facebook are integrated with live updates, which may also be re-posted through our social media feeds.

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Dave Gomez – national sales manager

800.366.2185 x 207

Thermal processing

Spotlight on quenching, gear applications, and induction heating

This issue of *Thermal Processing* is packed with some amazing information from contributors across the heat-treating spectrum.

With a focus on induction heating, quenching, and gear applications, we have put together a healthy slate of material.

Starting with quenching, experts at TimkenSteel have compiled an article about how aggressive quenching and other drivers can lead to high performance.

With gears and other heavy machine parts experiencing wear, fatigue, corrosion, and other issues, experts from Oerlikon Fairfield compare conventional and accelerated methods of gas carburization.

And last, but not least, our good friend Dr. Valery Rudnev shares his expertise on the induction hardening of cast irons.

In addition to our highly informative focus articles, in this issue's company profile, I had the opportunity to talk with Chris Estkowski, VP of engineering with Metallurgical High Vacuum Corporation. He walks me through MHV's beginnings to how it's become a full-service machine shop with expert skillsets it uses to rebuild quality vacuum pumps and more.

I'd be remiss not to also mention our columnists, who always bring amazing heat-treating information to the table in every issue.

All in all, the July/August issue is full of information I'm sure you'll find as interesting as I did — maybe more so.

So enjoy, and, as always, thanks for reading!

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Thermal processing for Gear Solutions

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PUBLISHED BY MEDIA SOLUTIONS, INC.
P. O. BOX 1987 • PELHAM, AL 35124
(800) 366-2185 • (205) 380-1580 FAX

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Visit thermalprocessing.com often and be one of the first to see the streamlined website, optimized for the best user experience in the thermal industry.
Thermal processing

Upgrades and new partnership for Ipsen Ceramics

Ipsen Ceramics recently completed the task of relining the bricks on one of its roller hearth kilns. This re-bricking project brings the kiln's throughput back to full operating capacity. Additionally, the kiln can now reach greater operating temperatures – up to 2,650 °F (1,454 °C). These improvements mean greater efficiency and more flexibility when processing various materials, such as thermal barrier coatings. Beyond improvements to its equipment, Ipsen Ceramics is also expanding its business connections.

It is collaborating with ceramics distributor Carpenter Brothers, based in Milwaukee, Wisconsin, along with 19 of its sales representatives throughout the United States to gain exposure across multiple industries.

MORE INFORMATION: www.ipsenceramics.com

Ipsen Ceramics recently completed the task of relining the bricks on one of its roller hearth kilns. (Courtesy: Ipsen)

E Instruments offers E8500 Plus portable emissions analyzer

The E8500 Plus Portable Emissions Analyzer. (Courtesy: E Instruments)

E Instruments' new E8500 Plus emissions analyzer is a complete portable tool for EPA compliance level emissions monitoring and testing. The E8500 Plus is ideal for regulatory and maintenance use in boiler, burner, engine, turbine, furnace, and other combustion applications.

New Features:

- Up to 9 Gas Sensors & Chiller
- Optional Sample Conditioning Unit (SCU):
- Minimize NOx Loss from Condensation
- NO & NO2 Sensors for True NOx Measurements
- NEW PID VOC Sensor Option
- New Display Screen & Keypad Design
- Easier Filter Replacement & Inspection
- Expanded Internal Memory (Up to 2,000 Tests)

Additional Features:

- Electrochemical Sensors – O2, CO, NO, NO2, SO2, H2S
- NDIR Sensors – CO2, CxHy, High CO
- Low NOx and True NOx Capable
- Real-Time PC Software Package with Bluetooth
- Wireless Remote Printer
- Internal Thermoelectric Chiller with Automatic Condensate Removal

MORE INFORMATION: www.e-inst.com

SEND US YOUR NEWS Companies wishing to submit materials for inclusion in Thermal Processing's Update section should contact the editor, Kenneth Carter, at editor@thermalprocessing.com. Releases accompanied by color images will be given first consideration.

Dr. Valery Rudnev receives two prestigious heat-treating awards

Dr. Valery Rudnev was recognized during the opening ceremony of the American Society for Materials (ASM International) Thermal Processing in Motion conference. Rudnev, director of science and technology at Inductoheat Inc., an Inductotherm Group Company, received two prestigious awards for his contributions in the field of induction heating and heat-treating.

Rudnev was elected as a Fellow to The International Federation for Heat Treatment and Surface Engineering (IFHTSE), "For his preeminence in induction heat treating and modeling of the induction heat treating process" (IFTSE, 2018). IFHTSE is a nonprofit group of scientific/technological societies and associations, groups and companies and individuals whose primary interest is heat treatment and surface engineering. Rudnev is also Fellow of ASM International and considered by many to be one of the leading global figures in the induction heating and heat-treating industry. He has more than 30 years of experience and is known among induction heating professionals as "Professor Induction." His credits include a great deal of 'know-how,' more than 50 patents and inventions (U.S. and International), and more than 250 engineering/scientific publications.

Rudnev was also presented with the ASM International "Best-Paper in Heat Treating" award for co-authoring an article entitled "Revolution – Not Evolution – Necessary to Advance Induction Heat Treating." The article was published in the September 2017 issue of Advanced Materials & Processes Magazine (HTPro quarterly newsletter), and co-authored by Gary Doyon, Collin Russell, and John Maher. The ASM International

Dr. Valery Rudnev was elected as a Fellow to The International Federation for Heat Treatment and Surface Engineering (IFHTSE) and presented with the ASM International "Best-Paper in Heat Treating" award for co-authoring an article. (Courtesy: Dr. Valery Rudnev)

Heat Treating Society, Research and Development Committee, established this award to recognize the best papers in the heat-treat industry each year. To be considered, papers must appear in either the HTPro quarterly newsletter or be published in ASM's Heat Treat conference proceedings. Papers are judged on several criteria including production readiness and breadth of potential applications.

Rudnev frequently publishes articles on different aspects related to induction heating technologies in *Thermal Processing* and *Gear Solutions* magazines published by Media Solutions, Inc.

MORE INFORMATION: www.ifhtse.org

Dave Wolfe to represent Diablo Furnaces to East Coast

Diablo Furnaces announces that Dave Wolfe has recently joined forces with the company as East Coast sales representative for the following states: Connecticut, Delaware, Maryland, New Jersey, Pennsylvania, New York, Massachusetts, New Hampshire, Vermont, Rhode Island, and Maine.

Wolfe comes to Diablo with a thermal processing background, which spans from technical sales since 1990 to controls engineering.

Diablo expects Wolfe's working within this industry and understanding the manufacturing of ovens and furnaces to be beneficial.

Diablo offers new thermal processing equipment, retrofits, upgrades, recontrols, service, and parts.

Furnace builds include IQ Batch Furnaces 900 pounds to 6,000 pounds, tempers, ovens, washers, charge carts, car bottoms, belt furnaces, custom, and others.

MORE INFORMATION:
www.diablofurnaces.com

Diablo Furnaces' Glogowski completes pyrometry course

Burk Glogowski of Diablo Furnaces completed the pyrometry course by PRI and is certified to conduct SAT and Tus evaluations.

PERFORMANCE Review Institute

This is to certify that

Burk Glogowski

has successfully completed training in

Introduction to Pyrometry
A 14-Hour Course

Joseph G. Pinto
Vice President and Chief Operating Officer
TRAINING DATE: 20-21 March 2018

eQuaLearn

Diablo Furnaces' Burk Glogowski has completed the pyrometry course by PRI and is certified to conduct SAT and TUS evaluations based on NADCAP Interpretation of SAE AMS 2750D. As Diablo Furnaces continues to grow, it has expanded its services and offerings to coincide with customers' needs, which include the SAT and TUS evaluations. Diablo Furnaces is an OEM of atmospheric thermal processing equipment ranging from IQ bath furnaces, tempers, washers, charge carts, car bottoms, mesh belt furnaces, custom, parts and service.

MORE INFORMATION:
www.diablofurnaces.com

Wisconsin Oven ships walk-in industrial oven

Wisconsin Oven Corporation manufactured a natural gas-fired enhanced duty walk-in oven for a transportation technology company. This is a repeat customer for Wisconsin Oven and the industrial oven will be used for heat treating baskets of aluminum parts.

The heat-treating oven has a maximum temperature rating of 315°C (600°F) and work chamber dimensions of 6'0" wide x 15'0" long x 6'0" high. The equipment has sufficient capacity to heat 5,952 kg (1,312 pounds) of aluminum from 21°C (70°F) to 250°C (482°F) within 120 minutes when loaded into an ambient oven.

The industrial oven is designed with a vertical lift, pneumatically operated door and a 12-gauge aluminized floor. A powered load car rated at 13,125 pounds will be used to load and unload the oven. The body is constructed with industrial board type insulation with a 1,200°F service temperature rating. Guaranteed temperature uniformity of ±3°C (5.4°F) at 250°C (482°F) was documented with a standard nine (9) point profile test conducted in an empty oven chamber under static operating conditions.

"At Wisconsin Oven, a large portion of our business is from repeat customers. We focus on providing excellent customer service each step of the way, from the time we take the first call to after the equipment is installed and operational. It is that ongoing dedication to our customers that keeps them coming back," said Nick Toci, sales engineer.

Unique features of this walk-in oven include:

- Programmable controller with batch tracking software and Ethernet capabilities
- Digital chart recorder
- 1,600,000 BTU per hour
- 12-gauge aluminized floor
- Two (2) 22,000 CFM @ 20 HP blowers
- Powered load car rated at 13,125 pounds
- Guaranteed temperature uniformity of ±3°C (5.4°F) at 250°C (482°F)

This heavy duty walk-in oven was fully factory tested and adjusted prior to shipment from our facility. All safety interlocks are checked for proper operation and the equipment is operated at the normal and maximum operating temperatures. An extensive quality assurance check list was completed to ensure the equipment met all Wisconsin Oven quality standards. This equipment is backed by Wisconsin Oven's Exclusive and Unprecedented 5-Year WOW™ warranty (parts only).

MORE INFORMATION: www.wisoven.com

Lucifer Furnaces delivers dual chamber furnace

Lucifer Furnaces delivered a dual chamber fiber-lined furnace to a leading manufacturer of punches and dies in North America.

The upper chamber of this customized Model LI84-M24 heats to 2200°F and the lower draw chamber to 1600°F with 23 KW power. The upper chamber hot face consists of low-heat-storage ceramic fiberboard for fast heat-up and cool-down. Heat radiates from coil-wound heating elements mounted on ceramic rods, which are completely external of the insulation and can be easily accessed for individual replacement. The lower draw chamber is insulated with 2 ½" insulating firebrick.

Both chambers are further insulated with cold face backup insulation. The LI-8000 series lower draw chamber is equipped with a fan assembly and stainless-steel liner for recirculation and uniform temperature. Each chamber measures 12"H x 18"W x 24"L. Chambers are individually operated with separate digital controls and thermocouples. Standard equipment includes pre-mounted horizontal swing doors with microswitch for safety.

The customer invested in this dual chamber furnace to replace an older unit and will be processing small parts in wire baskets as well as parts wrapped in foil during hardening.

MORE INFORMATION: www.luciferfurnaces.com

Debut of CastForge makes Messe Stuttgart glow

CastForge celebrated an impressive debut at the Stuttgart trade fair center. 153 exhibitors from 18 countries (international exhibitors, 61 percent) presented their comprehensive product portfolio at the trade fair for castings and forgings with processing. The exhibitors were impressed with the strong response of around 3,700 visitors and conducted excellent and in-depth discussions.

Successful premiere of the first trade fair for castings and forgings and their processing. (Courtesy: Pilot Protection Fair Stuttgart)

During the three days of the trade fair, the Oskar Lapp Hall (Hall 6) on the Stuttgart trade fair grounds was the new meeting place for the industry of castings and forgings in the D-A-CH region. The exhibiting companies were delighted that with CastForge they now have their own platform for the first time on which they can showcase the entire value-added chain extending from cast or forging blanks and machining through to final components.

"Here at CastForge, visitors have the opportunity to obtain precise information about their product requirements and issues," said Gunnar Mey, department director of Industrial Solutions at Messe Stuttgart, in the opening press conference. "With the clear commitment to the industry we managed to develop a convincing concept and close a gap in the trade fair landscape."

For numerous buyer companies from mechanical engineering and plant construction, drive technology, commercial vehicle, as well as pump and compressor manufacture, CastForge offered a unique platform when it comes to researching high-quality, ready-to-install castings and forgings. Similar to the exhibitors, there was also high international interest among the visitors in the premiere in Stuttgart. The visitors came from 32 countries (21 percent international visitors) besides Germany — mainly from Italy, Switzerland, Austria and France to the trade fair grounds. 32 percent of the visitors were involved in procurement, 13 percent in general/corporate/operational management and another 12 percent in manufacturing/production/quality assurance. More than 80 percent expressed a specific intention to invest or purchase. Overall, 70 percent of the visitors summed up that CastForge offered the right portfolio with its unique focus on castings and forgings and their processing and want to attend the trade fair again.

The exhibitors, who were at the first CastForge, were also impressed with the event. Martina Deul, sales assistant, Dirostahl – Karl Diederichs KG, said, "We are very surprised at the support that CastForge received. We are pleased with the high number of visitors that came to us with direct project requests and inquiries. In the run-up to the event we didn't really expect that these projects would be so detailed, hence why we are pleasantly surprised! Messe Stuttgart also provided us with plenty of useful information during the preparation stage. We are very satisfied with the collaboration and the organization and feel in good hands here in Stuttgart. You can visit us again at the same location at the next CastForge!"

The concept of Messe Stuttgart not only convinced manufacturers from the castings and forgings industry, but also associations who were present with stands in Stuttgart. Josef Hlavinka, managing director of the Association of Foundries of the Czech Republic, said, "We are very happy with how the trade fair went. Our ten exhibiting members confirmed that they received very positive feedback and could talk to the visitors about specific, future projects. The location of Stuttgart as a venue is ideal because a large number of companies from the automotive and engineering field are located here."

Together with the industry, Messe Stuttgart is now further developing the concept. Besides the issue of the correct frequency and date, this also includes the future accompanying program and appropriate parallel events. There is no doubt that CastForge will be a permanent feature in the portfolio of Messe Stuttgart. After all, around 80 percent of visitors consider trade fairs very important when researching suitable suppliers and over two thirds regularly look for new business partners.

As a trade fair, CastForge focuses on castings and forgings with processing. International exhibitors present their products to a wide range of visitors from the fields of mechanical engineering and plant construction, automotive and drive technology, construction machinery, pumps and hydraulic engineering as well as the supply industry.

MORE INFORMATION: www.castforge.de

750°F gas-fired cabinet oven from Grieve

No. 1046 is a 750°F (399°C), gas-fired cabinet oven from Grieve, currently used for baking radiator cores at the customer's facility. Workspace dimensions of this oven measure 80" W x 88" D x 18" H. 800,000 BTU/HR are installed in a modulating natural gas burner, while a 12,500 CFM, 10 HP recirculating blower provides vertical upward airflow to the workload.

This Grieve cabinet oven has a 76" wide x 76" long, 750 lb. capacity pneumatic operated rollout shelf with an insulated plug to seal doorway opening. Features include 8" insulated walls, top-mounted heat chamber and 16-gauge, Type 316, 2B finish stainless steel interior with continuously welded seams.

Additional features include a 16-gauge, 304 stainless steel oven front, with a pneumatically operated vertical lift door, an exhaust hood incorporated into the vertical lift door guard and a 1500 CFM powered forced exhauster with motorized damper to increase exhaust as the door is opened. The oven is equipped with safety equipment required by IRI, FM and National Fire Protection Association Standard 86 for operation with flammable solvents.

Controls on the No. 1046 include a digital programming temperature controller, manual reset excess temperature controller with separate contactors and a recirculating blower airflow safety switch.

MORE INFORMATION:
www.grievecorp.com

Solar Manufacturing breaks ground on new Sellersville Facility

Pictured from left: Jim Nagy, President; Bob Wilson, VP of Engineering; Scott Jacoby, Corporate Controller; Myrtle Jones, Owner; Bill Jones, CEO/Owner; Trevor Jones, CEO; Nick Cordisco, Service Manager; Pete Reh, VP of Sales; Rick Jones, International Sales Manager. (Courtesy: Solar Manufacturing)

Solar Manufacturing, Inc. began a new chapter in its history recently with a groundbreaking ceremony for a new manufacturing facility at the Sellersville Business Campus in Sellersville, Bucks County, Pennsylvania. Due to substantial growth in recent years, Solar Manufacturing expanded into two separate manufacturing facilities located a few miles apart. The new property will allow the 15-year-old company to combine its nearly 50 employees under one roof for more efficient production and triple its current space.

Gorski Engineering of Collegeville, Pennsylvania, will be the general contractor. The nearly 60,000 square-foot building will be built on 8.55 acres and is expected to be completed in early 2019. The new building will contain a two-story office space of nearly 20,000 square feet and 40,000 square feet of crane-served, manufacturing space.

Bill Jones, CEO, said of this $8 million project, "Solar Manufacturing has been very fortunate to experience steady growth over the past 15 years. We needed more manufacturing space to expand and grow our business. Bucks County and Sellersville Borough have been very supportive and welcoming. It is an ideal location for us."

Sellersville Business Campus consists of 44 acres located in the heart of Sellersville Borough. It is the former site of Ametek/US Gauge. Founded in 1904, US Gauge is one of the world's leading suppliers of high quality pressure gauges, temperature gauges and other products. The Gauge, as it was known locally, employed about 1,700 employees in its prime. Bucks County purchased the land from Ametek with financing provided from the Commonwealth of Pennsylvania. The brownfield redevelopment project is the first of its kind in the county offered by the Bucks County Industrial Development Authority. State, County and Borough agencies worked together to offer this prime real estate for industrial development.

Solar Manufacturing is a member of the Solar Atmospheres Family of Companies. Solar Atmospheres is a commercial heat-treater with headquarters in Souderton, Pennsylvania, and has four U.S. facilities with over 60 vacuum furnaces in operation. The close affiliation between the companies affords Solar Manufacturing with an unparalleled testing ground for improving furnace design, operation, maintenance and repair. Together, they offer unmatched expertise to advance the art and science of vacuum furnace technology.

MORE INFORMATION: www.solarmfg.com.

Metalloinvest picks Tenova to upgrade melt shop

Tenova, a Techint Group company specialized in innovative solutions for the metals and mining industries, has been awarded a contract with Metalloinvest, a leading global producer and supplier of HBI and iron ore products and a regional producer of high quality steel, for a major upgrade of the JSC Ural Steel melt shop located in Novotroitsk, Russian Federation.

The contract includes the installation of two Flexible Modular Furnaces® (FMF®), which accommodate a raw material charge mix up to 85 percent hot metal without use of electric energy. FMFs will replace the existing electric arc furnace operating with 100 percent solid charge with Tenova FMF solution, which envisions flexible raw material charging (hot metal, scrap, DRI/HBI) according to its availability and related production cost.

Tenova FMF is a modular concept of smelting furnace that can be developed from core equipment called base module with specific add-ons and has the flexibility of converting various charge mix of raw material (scrap, DRI, liquid hot metal, pig iron, etc.) without the use of electrical energy and electrodes.

A full range of metallic charges can thus be smelted with capital costs reduced at the minimum level.

The adoption of Tenova FMF enables steelmakers to gain a saving in the conversion cost of steel and ultimately to reduce steelmaking costs substantially. Flexibility is another main advantage of this solution. Each module is designed with specific features in order to fit the requirements of the charge mix.

"This contract with Metalloinvest represents the first installation of FMF in Russia, but this technology is already in operation in plants in India and China proving Tenova's leadership in this solution. One of our customers' priorities is to minimize the environmental footprint of the steel production process, and therefore our commitment is to provide them with technologies, like FMF, which can contribute to this goal too," said Andrea Lovato, Tenova chief executive officer.

Tenova, a Techint Group company specializing in innovative solutions for the metals and mining industries, has been awarded a contract with Metalloinvest upgrade the JSC Ural Steel melt shop. (Courtesy: Tenova)

"The modernization of the steelmaking capacities at Ural Steel is an important stage of the integrated investment programe for the reorganization of production at Ural Steel. The use of the newest FMF technology will ensure a reduction in the cost of steel production and increase the efficiency of the activities at Ural Steel. The upgrade of the EAFS will also reduce the man-made impact on the environment of production," said Andrey Varichev, CEO, Management Company Metalloinvest.

MORE INFORMATION: www.tenova.com

Hemsath joins Seco/Vacuum as director of nitriding

Seco/Vacuum Technologies, LLC (Seco/Vacuum) welcomes Mark Hemsath as director of nitriding and special vacuum furnaces. Hemsath had previously held a position with Seco/Vacuum's sister company, Seco/Warwick Corp., as manager of the thermal group from 2014 – 2017 before taking time away to serve as director of sales and marketing with Advanced Heat Treat Corporation in Waterloo, Iowa.

Hemsath will be the primary contact for gas Nitriding furnace applications in North America; he will cover the Southeast USA from North Carolina to Texas for all Seco/Vacuum products; and he will handle special vacuum furnace products throughout North America.

Mark Hemsath

Hemsath boasts a long and rewarding history in thermal processing, having operated his own heat treat furnace manufacturing and alloy fabricating company from 1993-2009. He has also designed, built, and sold vacuum, Nitriding, hydrogen annealing and various other furnaces since the 1980s. And he is a descendant of a well-respected leader in thermal processing; his father acquired nearly 65 patents as vice president of technology for Midland Ross, parent of Surface Combustion.

MORE INFORMATION: www.secovacusa.com

IHEA conducts technical seminars in conjunction with Furnaces North America

IHEA takes educating the industrial heating industry very seriously.

"We know how valuable the information we share with the industry is to ensure that furnaces and ovens are operated in a safe environment," said Anne Goyer, IHEA's executive vice president.

This fall, in conjunction with Furnaces North America, IHEA will offer its three popular training seminars that provide critical and current information to attendees to help them better manage their industrial heating operations.

IHEA will offer three concurrent technical seminars in conjunction with the Metal Treating Institute's (MTI) Furnaces North America (FNA) in Indianapolis, Indiana, October 8-10. This will be the perfect opportunity for manufacturers to expand their technical knowledge as well as spend time on the FNA exhibit floor.

IHEA will conduct its Combustion Seminar, Safety Standards and Codes Seminar, and Induction Seminar throughout the week. The Combustion Seminar and the Safety Standards & Codes Seminar will be all day Monday, October 8, and on the mornings of Tuesday, October 9, and Wednesday, October 10, at the Indiana Convention Center. The Induction Seminar will be Tuesday morning, October 9. This seminar schedule is set up perfectly to allow attendees full access to the FNA expo.

IHEA's 49th Combustion Seminar will provide attendees updated and relevant information from experts in combustion technologies. The seminar is designed for those responsible for the operation, design, selection, and/or maintenance of fuel-fired industrial process furnaces and ovens.

The seminar consists of 18 comprehensive sessions covering a complete range of topics on combustion systems, controls, parts, and maintenance.

A few of the seminar topics include:

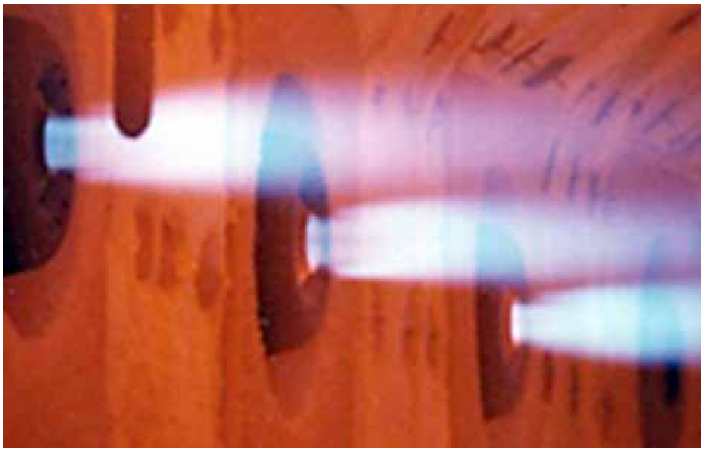
- Fuel/Air Ratio Control
- Combustion System and Flame Safety
- Combustion Troubleshooting
- Optimizing Combustion Systems Performance
- Heat Application - Low and High Temperature

SPEAKER PANEL DISCUSSION ON SYSTEM MAINTENANCE

IHEA's popular Safety Standards and Codes Seminar will provide a comprehensive overview of the NFPA 86, including newly released updates for many areas of safety. Sessions will cover the required uses of the American National Standards governing the compliant design and operation of ovens and furnaces. Speakers will cover the most recent revisions that are incorporated into NFPA 86. This seminar includes detailed presentations on the following:

- Class A, B, & C Furnaces
- PLC Based Burner Management System
- Pulse Fired Systems
- Multiple Burner Systems
- Safety Shutoff Valves
- Purge and Re-start
- Calculation Methods for LFL
- Gas Line Evacuation (Purging) & Charging
- Loss Prevention

Attendees appreciate the opportunity to voice opinions and ask questions. (Courtesy: IHEA)



IHEA will conduct its Combustion Seminar, Safety Standards and Codes Seminar, and Induction Seminar throughout the week. (Courtesy: IHEA)

- Product Liability
- Enforcement

INSURER PERSPECTIVES

The Induction Seminar will offer the basics of induction technology and how the electrically powered induction technology can create heat in parts, up to and including melting metals. IHEA's Induction Division members have developed the material to support the need for additional induction education. Induction Seminar topics include:

- Basics and Applications of Induction
- Innovation in Induction
- Induction Coil Overview
- Utilities & Harmonics

MYTHS & FACTS ABOUT INDUCTION

Register now and plan to attend one of IHEA's Fall Seminars October 8-10 in Indianapolis during Furnaces North America, www.ihea.org/page/Fall18.

Learn from the best by attending one of IHEA's Fall Seminars. IHEA members receive significant discounts on seminars. Consider joining IHEA today to save on registration fees. End users receive four vouchers with their membership that can be used to register for seminars. Visit www.ihea.org for more information about membership and how to join.

THERMPROCESS SUMMIT

Don't miss the International ThermProcess Summit in Atlanta, July 30-August 1.

There's still time to register for IHEA's ThermProcess Summit held in conjunction with the International Finishing & Coatings Summit. Held at the InterContinental Hotel in the Buckhead area of Atlanta, the summit offers a series of important sessions for executives in the industrial heating industry. Presentations include:

Factories of the Future/What Does the Future Workforce Look Like? Speaker: Dr. Irene Petrick, Market Innovation Director, Industrial Solutions Division/Internet of Things Group, Intel Corporation.

Trends in Additive Manufacturing. Speaker: Todd Grimm, Founder and President, T.A. Grimm & Associates, Inc.

Manufacturing USA Initiatives: What They Are and How You Can Benefit? Speaker: Thomas Kurfess, Ph.D., P.E., HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control and Professor in the Woodruff School of Mechanical Engineering at Georgia Tech.

Trump's Washington: The New Normal? Speaker: Omar Nashashibi, Founding Partner, The Franklin Partnership.

TASTE OF THE SOUTH DINNER

Following a day of interesting and informative presentations, you'll have the chance to network with other executives and speakers at the Taste of the South Dinner. Exchange conversation, ideas, and knowledge with all those in attendance in a casual setting.

THERMPROCESS BREAKOUT SESSIONS

Driving Consistent Performance Excellence. Speaker: Dr. Amber Selking, Founder, Selking Performance Group.

Cybersecurity: Keeping Your Business Secure. Speaker: Chad Hunt, Supervisory Special Agent with the FBI Atlanta Office.

Managing in an Unpredictable Economy. Speaker: Chris Kuehl, Co-founder and Managing Director, Armada Corporate Intelligence.

Tomorrow's Talent Today. Noel Ginsburg, CareerWise Colorado.

OEM Manufacturing Perspective. Susanne Lauda, AGCO and Brian Westfall, TRANE.

Transitioning Your Business to the Next Generation. Mike Brown, The BrainzoomingTM Group

To register, go to: www.itps-ifcs.org.

IHEA 2018 CALENDAR OF EVENTS

JULY 30–AUGUST 1
International ThermProcess Summit
In conjunction with the International Finishing & Coatings Summit
InterContinental Hotel | Atlanta (Buckhead), Georgia

OCTOBER 8–10
IHEA Combustion Seminar
Indiana Convention Center | Indianapolis, Indiana

OCTOBER 8–10
IHEA Safety Standards & Codes Seminar
Indiana Convention Center | Indianapolis, Indiana

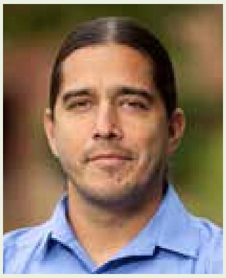
OCTOBER 8
IHEA Induction Seminar
Indiana Convention Center | Indianapolis, Indiana

OCTOBER 15–NOVEMBER 26
Advanced Process Heating | On-Line Distance Learning Course

For details on IHEA events, go to www.ihea.org/events

Cycle verification identifies thermal nonconformance, ensures deviation from requirements is reported

By Jason Schulze



For those of us in the thermal-processing industry, a thermal cycle that does not meet the specified cycle parameters can amount to quite a bit of unplanned time, effort, and money. A less experienced heat-treater may feel confident that the post heat-treat testing will yield positive results. However, a more experienced heat-treater will understand that, no matter the results, it must go through the standard nonconforming material process that applies to the approved quality system.

In this article, we will explore the subject of nonconforming thermal cycles and how they apply to a quality system.

DESIGN AUTHORITY

It's important to understand the term "design authority" when dealing with nonconforming product in any manufacturing setting. My background is in aerospace metallurgy, so this is where I intend to draw my examples. To be the design authority, that particular organization (in most cases, it's not a single person) has a complete understanding of the product and its intended use regarding form, fit, and function. It may also be that an organization purchased the design rights to a product as well. Regardless, that particular organization holds the right to disposition the product as a whole, or in part, when any part of the manufacturing process (including order of operations) of that product is not in accordance with what is specified.

It's safe to assume that most commercial heat-treaters do not have design authority for any product they heat-treat. There may be certain instances where captive heat-treating is performed on a product produced by the design authority, but, in many instances, this is not the case. If a heat-treater, whether captive or commercial, does not heat-treat in accordance with the specified instructions set forth by the design authority, the product requires disposition from those who do have design authority, regardless if it passes specified hardness, mechanical, or chemical analysis.

Evidence of this can be seen in the Nadcap AC7102 baseline checklist for heat-treat that asks if incoming contracts and purchase orders are reviewed to ensure that the "identification of the prime aerospace customer that has design authority" is stated.

THERMAL CYCLE VERIFICATION

It is important for all heat-treaters to have a cycle verification process in place to ensure nonconforming cycles are identified. In my field, I see many ways this can be accomplished and, more often than not, it is based on the heat-treater's operations (including furnace instrumentation) as well as customer requirements. Typical cycle verification takes the form of a quality representative, or designee, who reviews the thermal cycle record to ensure all variables (i.e. temperature, carbon potential, vacuum, time, etc.) are conforming. Once this review is completed, some form of evidence of review is documented. This may be a stamp or signature and date on a physical chart or paper copy, or an electronic signature and date. Some suppliers also go as far as to include a separate operation on the router or other job planning that has instructions on how to perform the cycle review and a field to sign/stamp and date.

Regardless of the review process, the reviewer(s), whether quality or designee, should have evidence of training that ensures they are competent to perform the verification.

Any review process should be designed in such a way that product that has not successfully passed the process verification and subsequent testing is not shipped.

NONCONFORMING THERMAL CYCLE

A nonconforming thermal cycle may consist of any variable that has not met the heat-treat cycle that is required by the governing specification and/or instructions. This also may include the lack of evidence the thermal cycle was performed, or any variable within the thermal cycle that was not recorded as a permanent record.

Let's look at an example. A supplier receives 150pcs of INCO 718 parts for solution and age heat treatment. The specification requirements for the solution heat treatment are 1,800°F ±25°F for 1 hour +10 minutes / -0 minutes. The age heat-treat requirements are 1,325°F ±25°F for 8 hours, then vacuum cool at 100°F per hour to 1,150°F within one hour and hold at 1,150°F ±25°F for 8 hours +10 minutes / -0 minutes. Both the solution and age treatments are required to be performed in a vacuum of <1 micron.

While reviewing the cycle, it is found that the age cycle was held for eight hours and 16 minutes — six minutes over the time tolerance. At this point, quality will need to segregate the material in question and process this as a nonconformance through its approved quality system. During the nonconformance process, there should be a step that requires the quality team to notify the purchaser of the nonconformance. The purchaser may, or may not, be the design authority. If the customer is in fact the design authority, they would be able to disposition the material themselves. If not, they may need to contact the company that does have design authority to obtain disposition on the material.

Nonconforming thermal cycles should be kept with the corrective action paperwork to ensure evidence of review, and either approval or rejection is able to be produced when required.

WHAT CONSTITUTES AS A NONCONFORMANCE?

To determine what constitutes a nonconformance, we have to look at the requirements that are specified by the customer (in some cases, the design authority) to the heat-treater. Some heat-treaters are given only a material type and, say, a hardness range to achieve. In a scenario such as this, the heat-treater designs the thermal cycle needed to achieve the required hardness, making any variation to the thermal cycle acceptable as long as the required hardness has been met. Considering this same scenario, if a customer also required that the thermal cycle the heat-treater designed be approved and "fixed," then the heat-treater would need to notify the customer of the nonconforming thermal cycle, even if the hardness requirement had been met.

Also, if thermal cycle parameters (including tolerances) as well as post heat-treat testing results and methods are specified, any deviation from those requirements must be dispositioned by the customer.

SUMMARY

This type of topic can be difficult to discuss as there are many different ways in which requirements are flowed down to commercial and captive heat-treaters. In this article, I attempted to cover the most basic of scenarios while maintaining the basis for nonconforming thermal cycle disposition authority. In addition, not all customers flow down requirements to heat-treaters in the same way. Due to this, the heat-treat quality representative must understand and have a system for each customer requirement with regard to nonconforming thermal cycles.

ABOUT THE AUTHOR Jason Schulze is a metallurgical engineer with 20-plus years in aerospace. He assists potential and existing Nadcap Suppliers in conformance as well as metallurgical consulting. He is contracted by eQualearn to teach multiple PRI courses, including pyrometry, RCCA, and Checklists Review for heat treat.

Remembering old-school lab work is a blast from the past

By Jack Titus

As anyone who reads this column knows, I've been doing this — working in the metallurgical and heat-treating business — for a long time, and occasionally I like to give readers a look into what went on in decades past, namely the 1970s.

Following are descriptions of a few projects that occurred in the lab that possessed some very unusual equipment in the decade of the early 1970s.

The first episode involves a "hot stage metallograph." Anyone who has worked in or around a metallurgical lab knows a metallograph, as it was known then, is a glorified microscope designed to view polished and etched metallurgical samples, micros, of metal at high magnification. Today, they resemble a simple microscope seen at any high school or college lab. But back then, a metallograph was an elaborate device that occupied an entire desk top maybe five feet long. It consisted of the microscope with five objectives of different magnifications, generally 5x, 10x, 20x, 50x, and maybe a 100x. These, in combination with a 10x eyepiece, multiplied the objective mag by ten, i.e. 50x, 100x, 200x, 500x, and 1,000x. Plus, there was a system of optical filers to reveal different characteristics of the microstructure. Chemical etches such as 'Nital,' a mixture of 3 percent nitric acid in methanol (methyl alcohol), were used. This is a commonly used etchant applied to reveal pearlite, martensite, and other ferrous alloy microstructures. As is done now, photos were taken for reports. However, today a digital file is created and emailed anywhere in a digital report.

Photos of the microstructure in the '70s were taken with a Graflex Speed Graphic camera that used a spring-back holder for Polaroid P-55 single sheet 4 x 5 slide film packets. When the packet was slipped into the spring-back housing, the metal catch held the negative in place while you pulled the sleeve back out to a stop. This exposed the film sheet or negative to the lens optics. After the shutter was triggered, you pushed the sleeve back into the housing and flipped a lever that squeezed the packet of chemical over the film as you pulled the entire film packet out. The squeeze function spread the chemical developer over the exposed film sheet. After waiting about one minute, the packet covering sheet was pulled away and there was the picture. You then wiped the photo with a preservative. That's how the standard metallograph of the day worked. A few years later, Polaroid created color film using the same method (but we had to wait five minutes for developing).

A metallograph, as it was known then, is a glorified microscope designed to view polished and etched metallurgical samples, micros, of metal at high magnification.

Back to the project: Since this was an R&D department, the interest was in furnace development for the time for iron carbide to go into solid solution in austenite. The only method used at that time was to heat and soak the specific alloy at varying times at temperature, and then make micros of each sample and compare the percentage of carbide remaining — unless you were fortunate enough to have a hot stage metallograph.

This device was a metallograph with a miniature vacuum furnace positioned above the magnifying objective. The bottom of the vacuum system had a quartz window through which you could observe the changes on the polished surface of a ¼" diameter x 3/8" high sample. The sample would be polished and etched so that the face facing the optics of the metallograph could be seen via a special Xenon light system.

The small sample was situated inside two opposing thin strips of molybdenum heating elements designed to form two semi-circles around the sample. Air was evacuated down to about 5 x 10-5 torr (6.5 x 10-5 millibar) with a roughing and oil diffusion pump where heating began. A small platinum/rhodium thermocouple was inserted in a hole drilled into the side of the sample. As the sample was heated and reached the appropriate temperature, the surface of the sample could be seen to change. It was difficult to interpret exactly what was happening because we couldn't tell if the microstructure was changing or whether the etched surface was somehow causing an illusion. Having said that, the iron carbide particles did indeed seem to get smaller over an extended period of time with black outlines forming around the carbide with the carbide becoming smaller.

The next obstacle was how to document this experiment since video recording was only done with special cameras. We rented a Bolex 16 mm camera and set up a timer and solenoid triggering mechanism to create a time-lapse film to record the process over several hours through the optics system of the metallograph. It worked. Without a darkroom we couldn't process the film ourselves, so we sent the film to an outside processing studio for development. Sixteen mm film wasn't something you ran down to the nearest drug store or pharmacy. The time-lapse approach worked as long as the Rube/Goldberg timing arrangement continued through the night hours. Generally, it did and the result — as crude as it was — was beneficial.

Since the carbide project worked so well, martensite and its transformation became our next investigation. That dilemma became a task of cooling a steel sample fast enough to create martensite inside the vacuum system. 52100 steel was chosen as the steel because we thought the sample was small enough that we could cool or quench with nitrogen blasting directly onto the sample above the heating elements. Eventually, to find a faster quench, the nitrogen gas was first passed through a makeshift refrigeration system consisting of ice and water.

The same evacuating and heating procedure in the carbide project was again used here with the exception of the time-lapse process. Since martensite begins to transform instantaneously when the Ms temperature is reached, for 52100 steel it's about 480°F (249°C) when quenched from 1,550°F (843°C). As we watched and filmed in real time, what we thought was the transformation was somewhat confusing. We observed what I described was analogous to popcorn popping. The etched surface of the sample began to change as in a time lapse video of water freezing on a thin surface, like a series of sudden fissures. My project cohort and I were at first perplexed but I personally couldn't explain other than we were witnessing martensite forming. My cohort wasn't so sure, but what else could it be? My memory of those events has dimmed to some degree since the 1970s but we for sure had fun in those days when R&D funding was pretty active.

REFERENCE

My cohort in those days was Jim Conybear, my carpool buddy.

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Lingering stress is not easily identified during production, but has a direct impact on wear performance and fatigue life

By Wei Guo

Residual stress is the stress that remains within a material or body in the absence of external loading or thermal gradients. The engineering properties of bearing components (e.g., dimensional stability, fatigue life, distortion, and wear resistance) can be significantly influenced by residual stress. For example, high-amplitude residual stress stored from heat treatment can increase the costs of subsequent machining, and the re-equilibration of the remaining residual stress can seriously distort the shape of bearing parts. As a result, the bearing industry is making an effort to closely monitor residual stress and minimize the generation of undesirable residual stress during the manufacturing process.

Generally speaking, there are two different types of residual stress that have been classified: macro/long range residual stress and micro residual stress. Macro/long range residual stress can scale over the entire body of a component and is much larger than the grain size of the material. Micro residual stress, on the other hand, exists at micron scale as a result of lattice strains, dislocations, and other crystalline defects.

ORIGIN OF RESIDUAL STRESS

Residual stress can be developed through the simple quenching of a hot solid bearing part and its consequent thermal contraction. During the quenching process, the external surface shrinks first, while the internal core is still hot and counter-strained in the tensile direction. Next, the internal core material starts to shrink and is constrained by the rigid external surface that has already been thermally contracted. This leads to compressive residual stress at the material's surface and tensile residual stress at the material's core [1].

Aside from the residual stress induced by thermal contraction, phase transformation is another important source of residual stress in bearing materials. Austenite has a face-centered cubic (FCC) structure, which is more densely packed than body-centered cubic (BCC) ferrite. Therefore, a local volume expansion can be expected once the austenite is transformed into ferrite (without considering the thermal effects). Both martensite and bainitic ferrite have a body-centered tetragonal (BCT) structure, to which the addition of carbon atoms increases the degree of tetragonality (c/a axial ratio) and expands the BCT lattice volume compared to carbon-depleted ferrite. Such phase transformations can generate micro residual stress and affect the amplitude of macro residual stress.

Figure 1 schematically shows the residual stress distribution of two typical bearing industry products: case carburized bearings and through-hardened bearings. In case carburized bearings, the core first transforms during quenching from austenite to ferrite and martensite, with an attendant relaxation of any transformation stresses. Later, the high-carbon case transforms to martensite at a much lower temperature, inducing volume expansion. But the degree of expansion is constrained by the rigid core material. Therefore, residual compressive stresses are developed in the case, with their maximum at the surface, and residual tensile stresses are generated at the core.

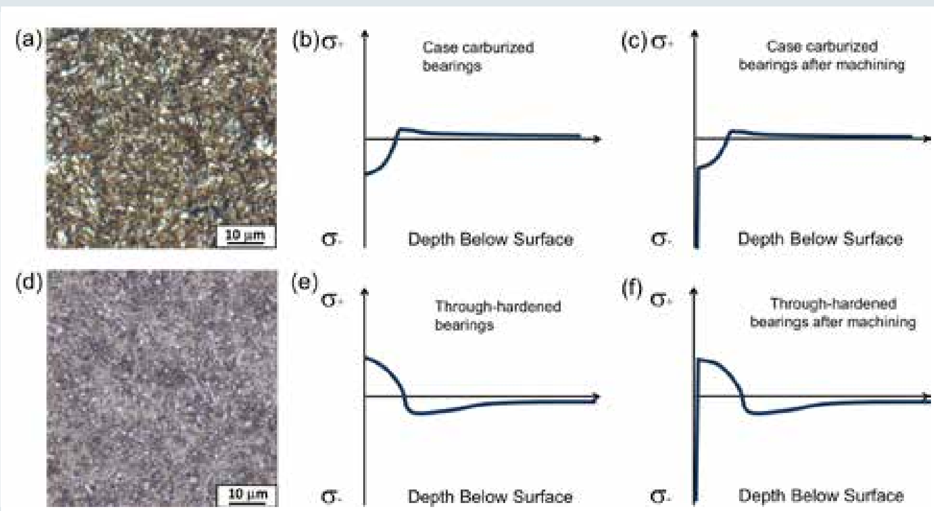

Figure 1: Residual stress distribution for two typical bearing products: (a). Representative optical microstructures of case carburized product. (b, c). Schematic showing depth-dependent residual stress profile of case carburized steel (b) after heat treatment, and (c) after machining. (d). Representative optical microstructures of through-hardened product. (e, f). Schematic showing depth-dependent residual stress profile of through-hardened steel (e) after heat treatment, and (f) after machining.

In actual practice, the exact maximum compressive residual stresses can be tens of microns away from the surface because the decarburizing layer at the surface contains large amounts of retained austenite. In through-hardened cases, hard martensite/bainite first forms at the surface of the bearing rings during the quenching process, along with the associated

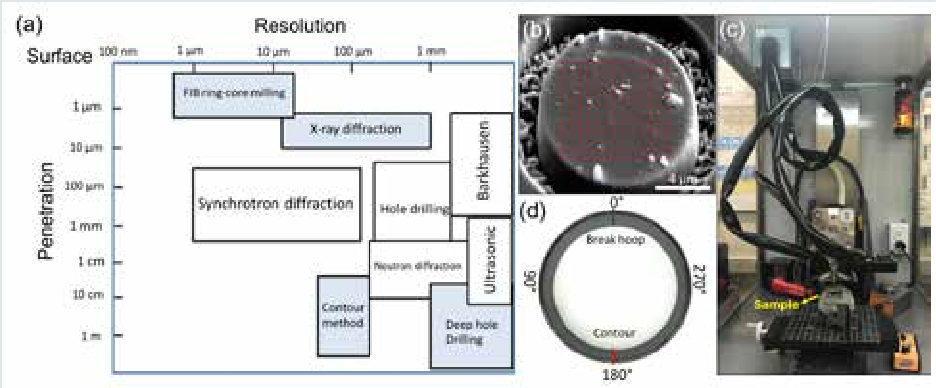

Figure 2: Multi length-scale characterization of residual stress. (a) Various methods can be used to determine residual stress with different materials' penetration and spatial resolution. The rectangle covers the range of penetration and spatial resolution for each technique. (b) Residual stress determined by the focused ion beam (FIB) ring-core milling method. (c) X-ray diffraction method. (d) Contour method.

volume expansion, whereas the remaining parts in the center are still austenite. Later, the remaining austenite transforms to martensite/bainite, but its volumetric expansion is constrained by the hardened surface layers. This dimensional restraint produces compressive stress in the interior and tensile stress at the outer surface.

MULTI LENGTH-SCALE CHARACTERIZATION OF RESIDUAL STRESS

Traditionally, macro residual stress is considered by engineers only when designing parts. However, the constituent microstructures of bearing products consist of micron- or even nanometer-scaled bainite, martensite, and carbide structures. Monitoring micro residual stress can be as important as monitoring macro residual stress because it provides direct guidance for optimizing thermal processing to alleviate the amplitude of the residual stresses formed during phase transformations. There are many different methods of residual stress measurement, as shown in Figure 2, in which the blue boxes represent destructive and semi-destructive methods. In general, the penetration depth of a single measurement can be sacrificed for the sake of higher spatial resolution.

The focused ion beam (FIB) ring-core milling method provides site-specific residual stress measurement at micron scale [2]. This method requires an annular trench to mill the region of interest as a circular island (Figure 2b). Once the milling reaches sufficient depth, the residual stresses are completely relaxed. This induced relaxation strain is then measured by the position changes of pre-marked spots at the surface through the computed digital image correlation. Later, the residual stresses can be calculated by the relaxation strain using Hooke's law.

Among the various methods of residual stress determination, diffraction-based techniques have been widely used to evaluate residual stress in crystalline materials. The elastic strain is determined by the change in the diffraction angle, 2θ, that reflects the change in the interplanar lattice spacing, d, from the stress-free state d_0, according to Bragg's law.

X-ray diffraction methods are generally available in regular metallurgy labs and also can be used for measuring both micro and macro residual stress (Figure 2c). However, the penetration depth of normal X-rays is limited to less than 10 µm, so the surface layers must be electro-polished many times to get a reasonable macro-scaled depth-dependent stress profile. The synchrotron X-ray provides much higher-energy X-rays, and the spot of the beam can be as sharp as 1 µm — making measurements with both good penetration depth (100 µm–3 mm) and high spatial resolution (1–100 µm) possible. Neutron diffraction techniques are similar to X-ray diffraction techniques, but the measuring depth can be varied from 0.2 mm for near-surface measurement to 25 mm in steels, thanks to the high-energy neutron beam [3].

The contour method determines residual stress through an experiment that involves carefully cutting a specimen on one side and measuring the resulting deformation due to residual stress redistribution on the other side (Figure 2d), a process based upon solid mechanics [4]. Residual stress is computed by measured displacement data through an analysis using a finite element model that accounts for the stiffness of the materials and part geometry. A spatially resolved map that describes the residual stress field at bulk scale can be generated with micron-scale resolution. This method is especially suited for complex, spatially varying residual stress fields that are difficult to evaluate using conventional point-wise measurement techniques such as X-ray diffraction [4].Residual stress monitoring creates both challenges and opportunities for the bearing industry, particularly because residual stress is not easily quantified or identified during the production process, but still has a direct impact on wear performance and fatigue life. It is expected that understanding and monitoring residual stress, and the generation of statistical data on residual stress, will help the bearing industry advance its development of bearing performance.

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That question is much easier to answer if you learn the indicators, alarms, switches

By Ipsen USA

While vacuum furnace systems are designed to help refine operations, perform specific processes and produce high-quality results, they are also designed with your safety in mind. As such, they are equipped with numerous precautions and system status indicators. However, with the number of components and pieces that make up a heat-treating system, it can sometimes be difficult to recognize an issue or know exactly what the different vacuum furnace alarms and buttons mean.

Following is a list of the various indicators and switches found on your vacuum furnace system, plus a few common alarms and issues that may occur:

EMERGENCY SHUTDOWN/ALARMS

- Emergency stop: Used for emergency shutdown; shuts off power to ancillary equipment (e.g., VRT, hot zone, pumping system).
- Alarm indicator: Lights up in conjunction with an audible alert; indicates a specific alarm condition.
- Alarm acknowledge: Acknowledges the alarm and silences the alert.

BELOW SAFE LEVELS

- Pump water pressure switch: Actuates when the vacuum pump's water pressure falls below a safe level.
- Furnace water pressure switch: Actuates when the furnace's water pressure falls below a safe level.
- Chamber water pressure switch: Actuates when the chamber's water pressure falls below a safe level.
- Inert gas pressure switch: Actuates when the inert gas pressure falls below a safe level.

EXCEEDS SAFE OPERATING PARAMETERS

- Furnace shell over temperature switch: Actuates when the furnace's outer jacket exceeds safe operating temperatures.
- Pump over temperature switch: Actuates when the diffusion pump temperature exceeds safe operating levels.
- Furnace over temperature: Actuates when the furnace's over-temperature thermocouple reaches a temperature that exceeds the over-temperature controller setting.

NO ACTUATION

- Heat exchanger flow switch: Does not actuate unless there is a sufficient flow of cooling water to the heat exchanger.

ON/OFF INDICATORS

- Roughing pump start: Combination switch/light; starts the roughing pump and indicates it is running.
- Roughing pump stop: Stops the roughing pump and turns off the Roughing Pump On indicator.

One of the best ways to keep a vacuum furnace in peak condition is to learn the various indicators and switches, plus a few common alarms and issues that may occur. (Courtesy: Ipsen USA)

- Holding pump start: Combination switch/light; starts the holding pump and indicates it is running.
- Holding pump stop: Stops the holding pump and turns off the Holding Pump On indicator.
- Diffusion pump start: Combination switch/light; starts the diffusion pump and indicates it is running.
- Diffusion pump stop: Stops the diffusion pump and turns off the Diffusion Pump On indicator.
- Valve limit switch: Helps display the current position of valves on the pumping, backfill (i.e., quench), and vent manifolds.
- Diffusion over temperature: Activates when oil inside the diffusion pump exceeds the maximum temperature you previously set.

MODES OF OPERATION

- Heat cycle indicator: Lights up when the vacuum level reaches 80 microns (crossover) and heat is applied to the work zone.
- Partial pressure indicator: Lights up when the system is in partial pressure operation.
- Cooling cycle: Lights up when the system is in cooling mode.
- Vacuum/partial pressure switch: Selector switch for selecting the system mode of operation (partial pressure event must also be programmed in the DCP).
- Gas select switch: Selector switch for selecting the type of backfill/cooling gas.
- Vacuum/static/forced switch: Selector switch for determining the cooling mode.

While it is useful to see an overall list of common indicators and switches on your vacuum furnace, it is also helpful to know what alarms can commonly trigger, and why. One common alarm that will activate is when there is an excessive hold time of parts. This alarm may occur because:

- Temperature uniformity is poor.
- The hot zone has degraded.
- Utilizing load thermocouples (TCs) are past the allowed specifications.
- The load TCs are defective.
- The load TC jack panel is contaminated.

One of the best options to monitor or prevent alarms or issues from happening is to install software systems that are designed for controlling your heat-treatment equipment and processes. (Courtesy: Ipsen USA)

- The dead-band on load soak requirements is too tight.

The chamber water jacket over temperature alarm is another common alarm that can activate during quenching. This alarm may occur because:

- The water supply temperature is not set correctly.
- The water pressure is too low.
- The water balancing valves are not adjusted correctly.
- The hot zone has aged and has excess heat loss.
- The drain manifold is running over five pounds per square inch prior to the quenching cycle starting.

There are a few common problems that can occur that do not have alarms to indicate there is a problem. For example, the furnace door can fail to open. This can occur because:

- The cycle has not completed.
- The furnace is not at atmospheric pressure.
- The temperature inside is not below 200° F.
- The door drifted off of the closed-limit switch.

Another example of a common problem that has no alarm is when a recipe fails to start. This can occur because:

- The furnace door is not properly closed.
- The vacuum pumps are not running, or they are set to automatic mode.
- The load TCs are selected and programmed but not installed.
- The emergency stop button has been hit or the emergency stop reset button hasn't been pressed.
- Other alarms have activated and have not been addressed.
- The auto/manual key switch is not in auto position.
- The VRT circuit breakers have not been reset.
- The over-temperature setting has not been reset.

One of the best options to monitor or prevent alarms or issues from happening is to install software systems that are designed for controlling your heat-treatment equipment and processes. These particular kinds of software reduce the potential for human error and maximize uptime, which in turn allows you to accomplish greater efficiencies.

While vacuum furnaces have several precautionary alarms and indicators, being familiar with commonly activated alarms or issues beforehand can help ensure safe and successful operation of your equipment.

ABOUT THE COMPANY Ipsen USA designs and manufactures integrated heat treatment solutions for a wide variety of industries, including aerospace, automotive, energy, and medical. With an extensive network of global locations in America, Europe, and Asia, Ipsen continues to provide expert-driven solutions that strengthen heat treatment throughout the world. Learn more at www.IpsenUSA.com.

Metallurgical High Vacuum Corporation

MHV test area with a Stokes 16 inch Ringjet Diffusion Booster staged for throughput test. (Photos courtesy: MHV)

Sophisticated engineering, custom applications

With a full-service machine shop and expert skillsets, Metallurgical High Vacuum Corporation has provided customers with quality vacuum pump rebuilds for more than 35 years.

By Kenneth Carter
Editor | Thermal Processing

Finding a company that can reliably repair vacuum pumps for furnaces on a budget can be a daunting task. But for the experts at Metallurgical High Vacuum Corporation, that skill is simply something they do.

"Our ability to do sophisticated engineering, in house machining, and custom applications probably sets us apart from almost every company except the companies that actually make the vacuum heat-treat furnaces," said Chris Estkowski, vice president of engineering at MHV. "But generally, OEMs will be reluctant to come in and do specialized stuff. For them, it gets a little pricey; for us, it's kind of our core competency."

MHV supports a wide range of high-vacuum equipment, including the rebuilding of most OEM brand pumps, Hanbell dry screws, diffusion pumps, boosters, blowers, and auxiliary vacuum equipment.

CUSTOMER SERVICE

But before MVH sees a single pump, the company strives to make customer service its front end, because that's where the relationship begins, according to Estkowski.

"We do custom work for companies," he said. "If they need something that will improve their process and we can do it — we will do the work for them. We've gone into furnaces to troubleshoot leaks and end up getting into various issues related to power feed through redesign and high vacuum valve rod seal problems"

That customer service extends into MHV's capabilities.

"Our machine shop capability is extensive," Estkowski said. "And we have expert welding capability here as well and can produce vac-tite welds confirmed with helium leak testing — not an easy thing to do. Our welding department does it all. TIG (Tungsten Inert Gas), flux core MIG (metal Inert Gas), Silicon bronze onto copper, silver soldering and on a variety of materials; stainless steel, aluminum, copper and mild steels."

That expertise is important when it comes to the services available at MHV.

"Our full-service machine shop does everything from grinding to CNC milling/turning and that really makes a big difference in our ability to produce parts that are no longer available," Estkowski said. "We also create designs and have tooling produced to make castings of components for some of the pumps when parts become scarce or unobtainable. We invest in that as well, specifically for the Beach Russ pumps and the Stokes oil sealed rotary pumps as availability or price becomes problematic for producing value-based OEM spec'd rebuilds. We bring the castings into our shop and machine them to specification, producing direct replacement parts for these cast components."

OPTIMUM EFFICIENCY

And for the companies in the heat-treating industry, MVH works to ensure their pumps run at optimum efficiency in harsh environments, according to Estkowski.

"Many of those production environments can be pretty hot," he said. "Years ago, MHV founder and president Geoff Humberstone designed a pump we manufacture here from our own castings that has a higher pumping speed. It's able to rough down at a much quicker rate. And that benefits heat treaters because it will evacuate the chamber quickly and shorten cycle time. But it also operates very well in high temperature environments because the oil is filtered and removes contaminants providing optimum oil function in high temperature conditions maintaining the proper running clearances and operational efficiency. Essentially, we try to provide a service for the heat-treating community that minimizes their headaches. We troubleshoot for them when they need help and try to provide them with quick service and turnaround, so they don't have extended down time."

TROUBLESHOOTING

Rebuilding and servicing equipment is an important part of

MHV's mission, but MHV wants to be there for heat-treaters regardless of their needs, according to Estkowski.

"We try to offer help to whoever contacts us," he said. "Our goal is to provide customers with what they need and if they don't need to make a purchase or get a pump rebuilt, we help them with what they do need, including providing them the appropriate resource to solve their problem from whatever source necessary. Work automatically comes to you if you provide the customer, whoever they are, with whatever they happen to need at a particular time. If they're just calling us for troubleshooting over the phone, we want to be there if it helps them get running a little quicker or maybe solves some of their problems. We try to give them tips and tricks that will help them with their process that they may not have thought of or that nobody had ever trained them on. Our technical staff is exposed to all kinds of problems with pumps and systems in our shop and on service calls. That experience is used to help our customers.'

Additional training is something MHV works into those troubleshooting incidents.

"We want customers to have a good experience with our company whoever they happen to be interfacing with," Estkowski said. "That just pays big dividends for everyone."

A lot of work at MHV involves vacuum pump rebuilds, according to Estkowski. After an initial contact by a potential customer, experts at MHV let the customer know whether they can actually rebuild the pump in question.

"Normally we can," he said. "There are very few pumps that we are unable to rebuild, really only limited by part availability from OEM's. And so, we will give them an initial cost estimate to help them ballpark a budget. Typically, we are reluctant to lowball even our initial estimates."

BUDGET IMPACTS

MHV provides an initial estimate that's realistic and gives the customer a good estimation of what the cost impact is going to be if the pump is shipped for a tear down, evaluation, and rebuild.

"If the pump is coming to us, we require a Certificate of Contamination so we know what material has been through the pump, allowing us to evaluate if we need to do any type of specialized handling to control hazardous substances and residual waste that may have accumulated in the equipment," Estkowski said. "We want to know what's in there so we can manage it appropriately. We make sure we contain all contaminants and waste and have those removed to the proper facility, usually for reclamation. We are very careful about that."

Once the pump is shipped to MHV, it's brought into the shop and dismantled piece by piece in order to evaluate the condition of the components and pump, according to Estkowski.

"We'll take a look at the residue in the oil," he said. "We'll look at what types of accumulations are in the pumps, so we know what kind of wear and tear has taken place. And we'll measure everything the OEM would measure to get an idea of how extensive the rebuilding effort will be. Then we develop a quotation. It's a very detailed, line-by-line, part-by-part, labor item-by-labor item, quotation for the customer. They see everything line itemed in the cost."

Diffusion pump receiving a new waterline tracing on the body and foreline.

When the customer approves the quotation, MHV orders the materials, works out the machining requirements, and routes the pump to the shop, where it is staged until the materials arrive and the machining is completed, according to Estkowski.

"Once all that is collected, we'll get it back on the shop floor at the bench," he said. "We'll have an individual tech rebuild the pump, assemble it, and then test it — all our pumps are tested, 100 percent — in an area set aside specifically for completed equipment dynamic testing."

DYNAMIC TEST

For each pump, a dynamic test is performed where the equipment evacuates a test chamber to end vacuum level while the technician monitors the elapsed time in order to confirm the pump performs according to the OEM's original specifications, according to Estkowski. For Stokes 412 style pumps MHV balances each one using Fast Fourier Transform Analysis (FFT) to reduce shake and ensure smooth running.

"Then we give it a 24-hour burn-in, and let it run while monitoring the water temperature, oil temperature, and vacuum (pressure level) during the course of that time," he said. "If it meets the requirements, we will shut it down, disconnect it, and move it to the paint area adjacent to the test area. Our painter, an expert former first surface automotive finisher, will prep then coat the pump with a premium finish, using whatever color the customer prefers, including custom colors. Finally, it is secured to a pallet or crated and shipped to the customer with the test documentation."

A pump rebuild usually takes a month or more to turn around, but a faster turnaround is possible when the customer requires, according to Estkowski.

"Most of the time, the delivery urgency is tempered by customer planning, so while urgent crisis rebuilds happen occasionally, most customers have backups that allow them to operate while their spare is being rebuilt," he said. "But we can turn things around in a week and sometimes sooner when it is necessary. For the most part, our lead time issue has nothing to do with routing to the shop. It almost always has to do with our ability to obtain a part. And usually it's one or two parts that hold up the whole show. That comes from the manufacturers having lower inventory levels and in some cases, part scarcity is due to low volume requirements from the industry."

DIFFUSION PUMP REBUILDS

In addition to rebuilding rotary oil sealed, liquid ring, and Hanbell dry-screw pumps, MHV specializes in diffusion pump rebuilds, according to Estkowski.

"We have a Stokes 16 inch Ringjet clone that we can build from scratch," he said. "It's no longer produced, but there are a lot of installations that use them. We rebuild those and all types of diffusion pumps."

One of the components that make the diffusion pump unique is the cooling coil that's on the outside of the shell and foreline of the pump, Estkowski said.

"Generally, that tracing needs to be cleaned free of scale or completely removed from the pump and a new one installed," he said. "That requires sophisticated welding with a special silicon bronze alloy. A lot of folks will silver solder that coil onto the pump body and foreline, but that results in less cooling efficiency, so the pump doesn't operate as well. Instead we weld using silicon bronze to maximize the cooling efficiency. It is a tricky process requiring a high level of expertise and skill, but our welder is quite good at it."

Beach Russ pump rebuilding is another MHV specialty, according to Estkowski.

"They are used often in the food industry for dehydrating and freeze drying," he said. "They handle moisture loads really well. A lot of vacuum pumps don't like water. But these Beach Russ pumps don't mind it at all. We have quite a few customers that use them, and they use them specifically for that. They're a little bit of a different breed of vacuum pump. It's not like the automotive industry where you can pull a part off and put a new part on, and it fits perfectly every time because they're all the same everywhere. These pumps are kind of the same, but there's a little bit of customization for each one when they were built at the factory. The fits are a little bit different on every single pump, and so they require some very careful attention to rebuilding detail when you put them back together to make sure they go together correctly."

BRANCHING OUT

As MHV continues to offer vacuum pump expertise, it is also looking at expanding its knowledge base.

"Power consumption these days is getting to be a real problem, and the less power you can use the better," Estkowski said. "We are at the investigative phase of taking a look at putting VFDs (variable frequency drives) on these rotary pumps to try to manage the pumps' energy consumption."

When a pump is under load roughing down the chamber, a lot of energy is needed for a short period of time to drive the motor, but when the chamber is at process pressure, not as much energy is required, but pump motors only operate at a single speed, according to Estkowski. That means, regardless of the energy requirements, the motors operate using the same amount of power or nearly so.

"What we're looking at is using variable frequency drives, so once you pump down to process pressure, you can throttle the motor down and reduce your energy consumption dramatically while the holding pump maintains the pressure," he said. "But when you do that, though, there are always issues. When you throttle motors down, you're going to have heat buildup. So, we're working on how to dissipate heat and manage the heat on those motors."

DRY PUMPS

MHV is also looking into moving into rebuilding dry pumps, according to Estkowski.

"As the industry moves more and more toward sophisticated alloys, like titanium and various aluminums, and aerospace and medical requirements, many companies want to move away from oil sealed vacuum pumps, where there is potential to backstream, which could contaminate the process," he said. "They're moving to dry pumps. We've taken steps to align ourselves and cooperate with companies that make the dry screws and rebuild them."

One of the companies MHV recently has associated with is Hanbell in Taiwan.

"They're probably the world's premiere screw pump manufacturer for compressors," Estkowski said. "We went there for training, and we have the knowledge and capability to repair their dry screw pumps and blowers. We're preparing ourselves for the inevitability of dry screws taking a bigger and bigger share of the market. And we suspect that someday, the other dry screw manufacturers of the world are going to open up and share some of those rebuilds with the aftermarket community. So, we will be prepared to do that. Meanwhile, we'll be rebuilding Hanbell pumps and trying to sell Hanbell pumps, which are every bit as good and, in some cases, better than the competition."

1981 BEGINNINGS

Since its inception in 1981, MHV has been rebuilding vacuum pumps, including being a certified rebuilder of Stokes vacuum pumps, and later, becoming a certified rebuilder of Leybold vacuum pumps.

Over time, MHV founder Humberstone realized that, in order to deliver and rebuild pumps, he needed a machine shop with sufficient capacity and skill to do a lot of the necessary machining on various parts to bring the pumps back to OEM manufactured performance levels.

"Without having the machining capabilities, everything had to be brought in, purchased new and refitted, which inflates the rebuild cost," Estkowski said. "Sometimes it's necessary, so Geoff invested in machinery over the course of time."

As MHV continued to grow and move to different places, Humberstone acquired more machinery and more capability.

Some of that capability has proven to be advantageous to MHV's heat-treating clientele, according to Estkowski. And that advantage is evident in the HS430 oil sealed rotary vacuum pump designed by Humberstone.

"It rotates at a higher RPM, so roughs down the chamber much quicker," he said. "It has pressure lube filtration to lubricate the faster moving parts and extend pump life dramatically when the ½ micron filters are changed according to how contaminated the process. Generally, the HS430 pumps will run in excess of 60,000 hours with semi-annual oil changes because of the filtration capabilities. And that was a real indication of the capabilities of MHV. Essentially, MHV did everything from scratch: the design, having the castings made, sourced in the United States, machining, and assembly. And that's not easy to do anymore. Most folks are going overseas to do that."

To demonstrate how versatile MHV is to custom work, recently MHV created a number of huge vacuum chambers for a customer that were 16 feet by 15 feet by 10 feet to dehydrate ceramic investment molds, according to Estkowski.

"They were made from scratch," he said. "Geoff designed the chambers — I think there were four or five of them. The customer provided dual pumping systems, including blowers on those pumping systems. That required a great breadth of engineering and manufacturing capability. I don't think there's any aftermarket rebuilder of vacuum pumps in the country that can do that other than us."

MORE INFORMATION www.methivac.com

A seamless mechanical tube enters the quench phase of its thermal treatment path. Quench-and-temper operations such a this provide uniform product heating, quenching, and cooling that ensure steel meets demanding material property specifications, as well as tight temperature tolerances for the most demanding applications. (Courtesy: TimkenSteel

Getting the thermal treat results you want

How aggressive quenching and other drivers lead to high performance

By Scott Wade, Buddy Damm, Matt Widders, Paul Petrovic, and Krich Sawamiphakdi

Increasing demands and the need for higher performance mean the steel used in today's applications has to be more reliable than ever before. New technologies like the ability to produce both high strength and high toughness in steel grades can make a meaningful difference in performance. To achieve these characteristics, consistent and effective thermal treatment is critical. That performance-based microstructure is achieved with a solid quenching practice.

The big picture: Factors that promote heat treating results

When designing a heat treatment, consider three factors:

- Material composition: Analyze the material's ability to form martensite, a favorable microstructure in steel that's used to optimize mechanical properties.
- Quenching medium: This should be coupled with the material composition to effectively and rapidly remove temperature from the material.
- Product cross section and shape: As the size of the product changes — increases or decreases — so does the temperature gradient over the cross section of that product.

WHY QUENCH?

Simply, quenching steel makes it stronger. Quenching — the process of spraying water or other quenching fluid on heated steel or immersing the steel in a fluid — forms martensite, a hard, steel crystalline structure that results from the rapid cooling of the austenite form of iron. The martensitic reaction begins when austenite reaches the martensite start temperature and the austenite becomes mechanically unstable. As the steel is quenched, more of the austenite transforms to carbon-saturated martensite until the lower transformation temperature is reached. The shear deformations that result from the process produce a large number of dislocations, which ultimately strengthen the steel.

As quenched martensite is hard and strong, but not necessarily tough or ductile, tempering following the quenching process for any given chemistry provides the best

As the steel moves through the thermal treatment process, operators audit the piece surface temperature to ensure desired quench stop temperature. (Courtesy: TimkenSteel

opportunity for both higher strength and higher toughness in steels.

COMPONENTS OF QUALITY QUENCHING

Essentially, quenching provides the very foundation for high-performance steel; without it, characteristics like higher strength and toughness cannot be achieved. Several factors in the quenching process contribute to the steel's reliability in demanding applications:

- Uniform heating: Maintaining a tightly controlled furnace temperature produces uniform mechanical properties and greater consistency from piece-to-piece, or even within a given piece.
- Fast transfer: To ensure martensite forms, it's important to move the piece quickly from the furnace to the quench process to avoid premature, accidental formation of non-martensitic structures such as ferrite or bainite. The term slack quench is used when the product is delayed in transferring from the furnace to the quench, resulting in cooler product temperature prior to quench. Slack quenching is prohibitive to achieving high-performance mechanical properties.
- Adequate soaking: Having the ability to soak the entire length and cross section of the piece at the aim austenitizing temperature provides increased quality.
- Maintaining quench efficiency: Having a consistently heated product going into the quench is critical for effectiveness. This includes piece-to-piece and along-the-piece temperature control. Uniform temperature from front to back ensures better efficiency. Additionally, using the correct media (water, oil, polymer, etc.) is critical to ensure the quench practice extracts heat at the desired rates, as well as minimizes thermal stresses created during microstructure transformations. With a quench rate that's too slow, the material may not achieve the desired microstructure to meet properties. In contrast, a rate that's too aggressive can lead to undesirable thermal stresses, or worse, cracking of the components at stress risers.
- Uniform quench coverage: Uniform spray, like the unique, shell-shaped quench system offered with TimkenSteel's advanced quench-and-temper facility, means the quenching fluid penetrates at the same depth for all product sizes. This removes heat and avoids the formation of a steam vapor barrier, which would prevent heat transfer from the piece. Uniform coverage also offers constant agitation, pressure, and flow throughout the process and can help maintain straightness of many products throughout the process.
- Uniform quench exit temperature/temper entrance temperature: Modeling is especially effective in identifying the right controls to achieve these temperatures. Large section sizes may quench to desired surface temperatures; however, the core temperature of the product may be significantly higher. This is typically seen in "rebound" where the product surface temperature will reheat after quench as the core temperature conducts back to the surface. Achieving uniform temperature post-quench ensures the desired microstructure through the full cross section of the component. Proper modeling can ensure the component is heat treating as desired.

PROCESS CONTROLS MONITOR EFFECTIVENESS

To ensure heat treatment consistency, it's important to have process controls in place that monitor what's happening throughout each step. Some of these may include:

- Furnace modeling to guarantee piece-to-piece consistency.
- Thermocouples to monitor temperature uniformity within the zones.
- Infrared pyrometers to monitor the surface temperature of the product as it begins or completes critical stages of heating and cooling.
- Heat exchangers and/or cooling towers to maintain quench medium temperature control.
- Flow meters and pressure gauges to monitor quench uniformity and severity.

Proper controls promote the highest product quality by creating a reliable and repeatable process. These controls save time and money by allowing early notification of needed adjustments, as well as real-time adjustments at each step that eliminate the need for re-work.

A special bar quality steel bar processes through the austenitize coils of TimkenSteel's Quench Temper Facility. This line combines induction and combustion (natural gas) to ensure the best temperature uniformity — end-to-end and piece-to-piece — throughout the cross section. (Courtesy: TimkenSteel)

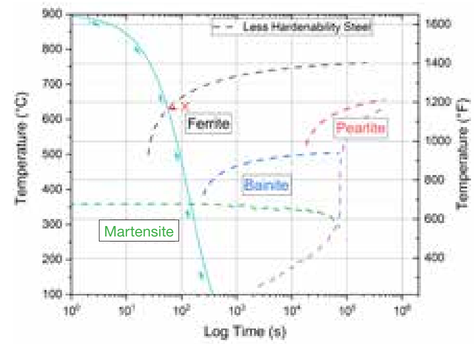

Figure 1: CCT diagram for less hardenable steel.

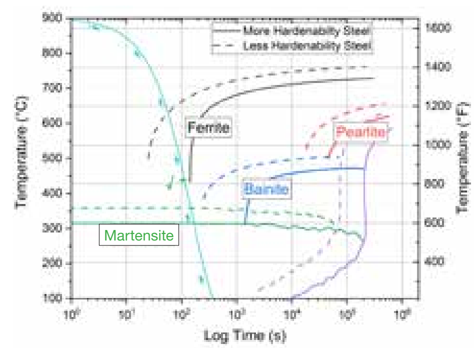

Figure 2: CCT diagram for more hardenable steel.

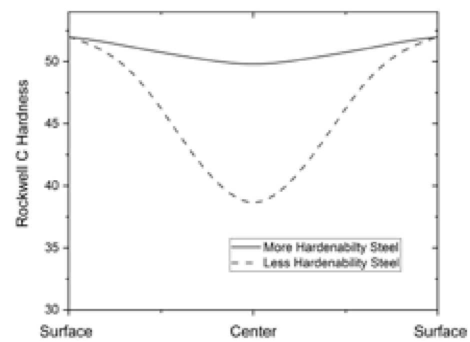

Figure 3: Hardens through the cross section.

ADVANCED MODELING OFFERS FORESIGHT

Consider the analogy of buying a car. When purchasing a vehicle, chances are you do a lot of research beforehand to ensure you're getting one that best suits your needs. Advanced modeling in heating and quenching offers similar advantages in that it allows you to understand the overall process more thoroughly and to identify the best approach to apply heat treatment and how to correctly implement various process parameters to achieve the desired result.

Further, advanced modeling tools also may decrease the resources spent in quenching. Material models are extremely powerful in optimizing process design factors.

HARDENABILITY REDUCES TRANSFORMATION

Steel hardenability refers to its ability to produce hard martensite at depths below the quenched surface. During quenching, the surface cools rapidly as the quenching aggressively removes heat. Further into the steel, cooling is limited by the steel's ability to conduct the heat. In larger cross sections of steel, this slower cooling rate could allow the austenite to transform into a structure other than martensite.

Hardenability is related to the content of carbon and other alloy elements in steel, as well as the grain size of the austenite. The quenching fluid influences the cooling rate due to varying thermal conductivities. Hardenability is measured with a Jominy test: a round metal bar of standard size is fully transformed to austenite through heat treatment and is then quenched on one end with room-temperature water. The cooling rate is highest at the end being quenched and decreases as distance from the end increases. After the cooling is completed, a flat surface is ground on the test piece, and the hardenability is determined by measuring the hardness along the bar. The farther away from the quenched end the hardness extends, the higher the hardenability.

The Jominy specimen is typically tested using Rockwell C hardness at specified distances from the quenched end. Each of these test distances correlates with a cooling rate, which can be superimposed onto the cross section of a component. Jominy tests for a given lot of steel can therefore be used to predict microstructure and as-quenched properties through the cross section.

The goal of any quenching process is to form martensite throughout the entire cross section, or at least to form martensite in all parts of the cross section where high strength and high toughness are required.

Figures 1 and 2 are called continuous cooling transformation (CCT) curves. These time (logarithmic scale) vs. temperature curves help describe how hardenable a given steel is, and what structures can form in steel as a function of cooling rate. The light blue curve annotated with arrows in Figure 1 is the approximate time vs. temperature during cooling at the center of a 6-inch diameter, water-quenched bar. It takes a little more than 300 seconds — or 5 minutes — to get the center to cool by about 100 degrees Celsius. At about 6x10 seconds (60 s), the center reaches 640 degrees Celsius and ferrite begins to form. As cooling continues, more ferrite forms until the center of the bar reaches about 360 degrees Celsius, at which point the remaining austenite transforms to martensite.

Now, consider Figure 2. Here, a second set of CCT curves is included for a steel that has higher hardenability. This higher hardenability is achieved with the addition of alloying elements that delay the ferrite, pearlite, and bainite transformations, causing the CCT curve to be pushed to the right to longer times. Here, the same cooling path now misses the "nose" of the ferrite transformation curve and only martensite is formed at the bar center.

The difference in hardness associated with these illustrations is shown in Figure 3. A higher-hardenability steel allows you to achieve high hardness throughout the cross section.

The unique, proprietary shell-shaped quenching system in TimkenSteel's Advanced Quench-and-Temper Facility produces a stronger water flow at a faster rate than other quench-and-temper operations. This results in high-martensitic structures that are critical to achieving the higher strength and toughness properties customers need. (Courtesy: TimkenSteel)

APPLICATION TO BATCH PROCESSING

The above discussion focuses primarily on continuous or in-line quenching. However, many of the same principles apply to batch and component processing. Variables such as fast transfer, monitoring quench medium temperature, constant agitation, and limited load for uniformity are all important in guaranteeing a high-quality end product. Both batch and component processing present additional, unique challenges.

With good quenching and tempering practices, the real benefit to any steel customer is an end product that's more reliable, with the ability to achieve higher levels of performance. Following a solid heat treatment path means steel is stronger, tougher, and ultimately more capable, which may translate to higher loads or better endurance at existing loads, increased fatigue strength, wear resistance, and resistance to bending overload damage.

The classical trade-off in all materials is that increasing strength nearly always results in reduced toughness. But, with careful design and calculated processing — including thorough quenching and tempering — today's steels can achieve significant strength improvement with excellent toughness properties. For customers, that means enhanced solutions for demanding applications.

ABOUT THE AUTHORS

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Learn more at www.timkensteel.com/what-we-make/specialized-services/thermal-treatment.

Gas carburization techniques

A comparison of conventional and accelerated methods for surface hardening

By Aaron Flesher, Tyler Logan, and Daniel H. Herring

Gears, shafts, and other parts for heavy machinery experience wear, fatigue, corrosion, and other service-related issues during their lifetimes. To meet both customer product performance requirements and service life expectations, the surface of these parts needs to be manufactured with a high surface hardness and a soft, ductile core to avoid brittle fracture. These products must also be able to withstand the high Hertzian stresses present along the active flank and the significant bending moments within the root. These challenges can be met with a cost-effective surface-hardening solution such as gas carburizing.

Gas carburizing involves heating a carbon steel to austenitizing temperature in the presence of a carbon-rich atmosphere. It is common to use a carrier gas, such as endothermic ("Endo") gas along with hydrocarbon enrichment (natural gas or propane). Carbon atoms from the atmosphere diffuse into the surface of the part and create a hard case at a desired case depth along with a soft core. A proper case depth and case microstructure produce the necessary wear resistance and surface hardness needed without adversely affecting the core properties. Too much carbon within the case, however, can lead to microstructures with large or continuous carbide networks (aka carbide necklaces) leading to premature fracture in the field.

Manufacturing companies, such as Oerlikon Fairfield, use this technology. Oerlikon Fairfield does it within a large heat treat shop incorporating numerous batch and continuous furnaces running endothermic gas and operating 24/7.

INCREASED PRODUCTIVITY INVESTIGATION

The metallurgy team at Oerlikon Fairfield decided to investigate a new process technology being offered by Heavy Carbon Co., LLC (Pittsford, Michigan) known as the Endocarb system, which claims to dramatically reduce cycle time without sacrificing product quality. This is accomplished by alternately increasing and decreasing the carbon potential within the furnace, producing parts more quickly [1] and resulting in less soot than a typical conventional gas carburizing setup. The Endocarb system differs from a conventional gas carburizing system in two important ways:

1. The Endocarb system is the source of process gas and its control. The hardware is mounted directly on top of the furnace, simplifying gas piping and avoiding transmission issues. The close proximity also mini-

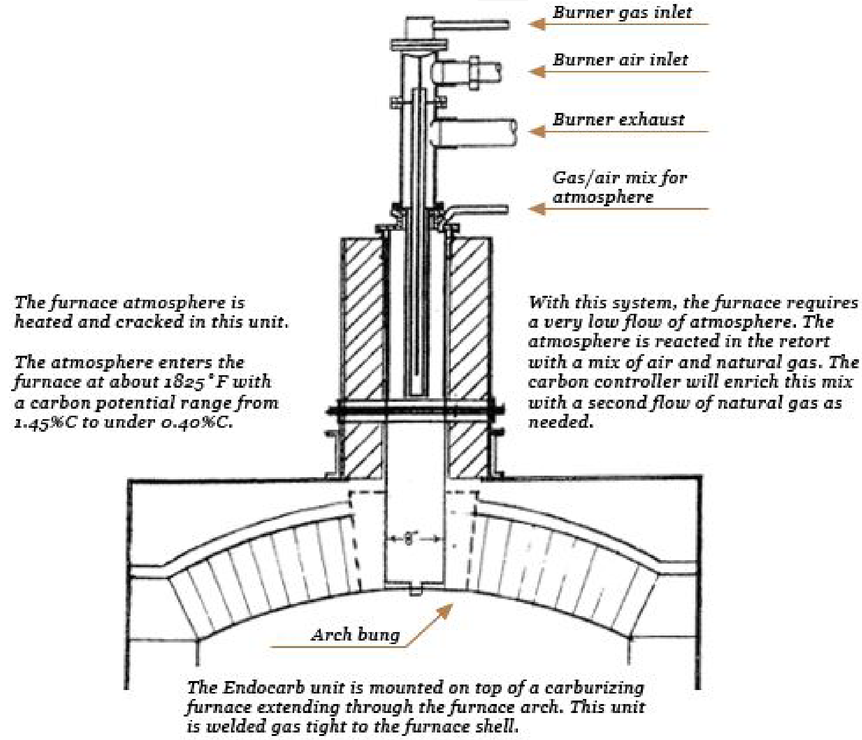

Figure 1: Diagram of Endocarb setup on top of furnace [1].

mizes the risk of gas leaks and decreases the amount of necessary system maintenance. The system can easily be set up so that the furnace runs at reduced gas flowrates. A diagram of the Endocarb system is shown in Figure 1.

2. The process at 925°C can be set to run at a carbon potential of nearly 1.5 percent, which is significantly higher than conventional values (often in the range of 1.00 to 1.05 percent but certainly no higher than the limit of carbon saturation in austenite for the given process temperature. A maximum carbon potential limit is established to eliminate the likelihood for both "sooting" the furnace and forming excessive carbides, resulting in either a halt in production to clean the furnace or scrap parts. The increased carbon potential in this advanced technology also decreases the run time for the load. The carburizing time to achieve a 2.3-mm effective case in a large bull gear was decreased by nearly 18 percent. A sharper drop-off in carbon after the case can also be expected, producing a soft, ductile core.

So, the question remains: How can such a high carbon potential be used with no negative effects? The Endocarb system acts to create and control the furnace atmosphere. Being attached to the top of the furnace allows for direct control of the gas flow in and out of the system, allowing the ability to change carbon potential quickly. Like a traditional "endo" gas generator, a nickel catalyst is used to "crack" natural gas (or another suitable hydrocarbon such as propane) in the presence of air. The Endocarb system creates atmosphere through the use of a constant flow of air and adjusting the flow of hydrocarbon gas. With this, high carbon potential levels can be achieved. The atmosphere created is injected directly into the furnace without any cooling or additional piping. This "rich" gas is ideal for efficient carburizing. A traditional endo generator must cool down the gas to eliminate the potential for soot formation (i.e., the carbon reversal reaction). This is eliminated with the Endocarb system.

The Endocarb system is designed to both produce a protective atmosphere and an atmosphere having a high carbon potential for carburizing [1]. When lower carbon levels are needed, the amount of gas to the Endocarb system is reduced. Since the air flow remains constant, this creates a "lean" gas. As this leaner gas enters, it "cleans" the furnace by reacting with any soot present. This mixture also serves to rejuvenate the atmosphere accelerating carbon absorption at the high carbon potential.

While a conventional carburization furnace maintains a constant carbon potential during the "boost" and "diffuse" phases, the Endocarb system allows for the use of "carbon cycling" (i.e., the process starts at a much higher potential, then is rapidly lowered well below the initial setpoint). The carbon potential at 925°C can reach almost 1.5 percent before the Endocarb system determines that the gas is "over saturated." Once this determination is made, the amount of endo gas being supplied by the generator is greatly reduced, and the carbon potential lowers to about 0.8 percent. The carbon potential is then boosted back up to 1.5 percent. This cycling continues throughout the run, allowing for the desired case depth to be achieved more quickly. The constant carbon cycling also produces a uniform case depth.

With a lower cycle time, similar processing temperature, and improved level of furnace cleanliness, the Endocarb system would have a relatively quick payback [2] compared to conventional carburization. This is due to "carbon-cycling" that allows for the case depth to be achieved more quickly. A typical Heavy Carbon cycle can be seen versus a conventional gas carburizing cycle in Figure 2. To test the claim that the Endocarb system produces the same quality of parts with better efficiencies at a lower cycle time, a trial plan was devised by Oerlikon Fairfield to test whether there was a significant difference in

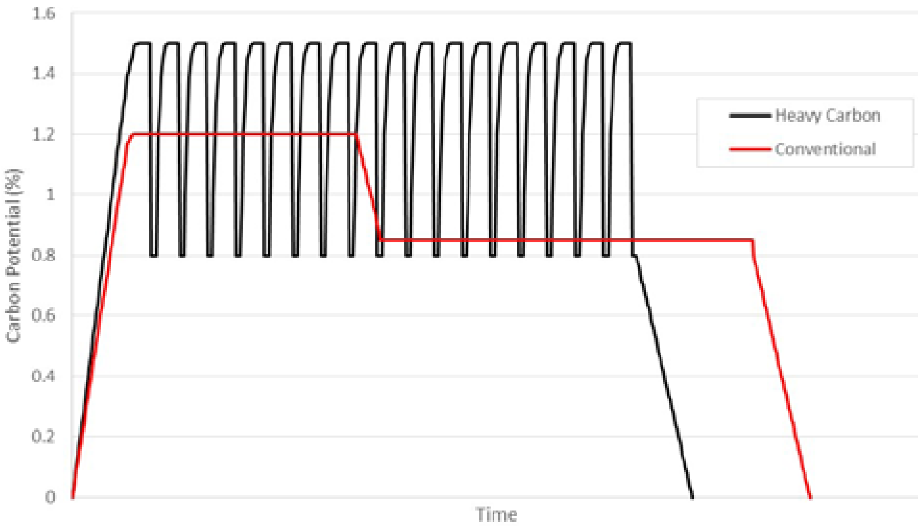

Figure 2: Example of a comparison between conventional and Heavy Carbon methods.

Figure 3: Bull gear just before carburizing.

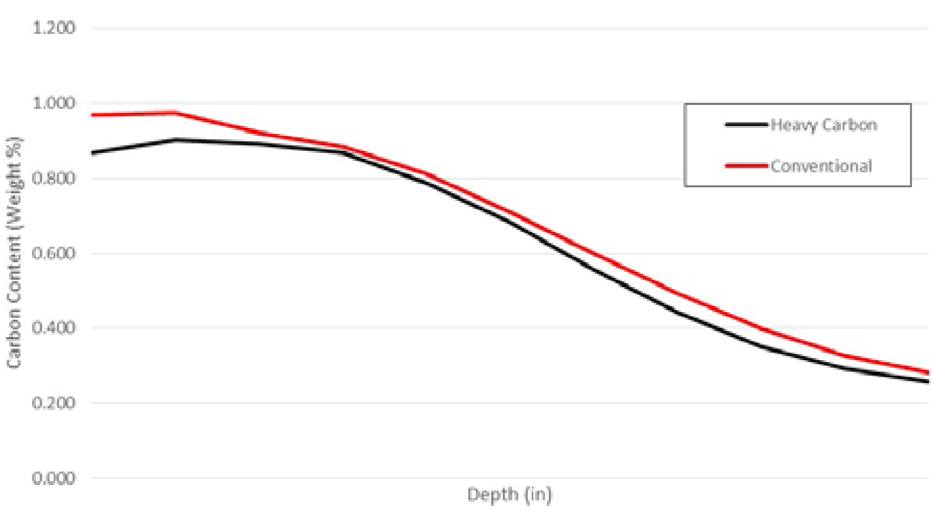

Figure 4: A comparative example of carbon analyses from both Euclid Heat Treat (Heavy Carbon Endocarb) and Oerlikon Fairfield (conventional carburizing).

part quality between the two gas carburization methods.

TRIAL AND RESULTS

In order to determine potential cost savings with equal or better quality, Oerlikon Fairfield decided to conduct an investigation to determine whether the time savings claimed could be achieved without sacrificing metallurgical quality or performance characteristics of parts. For testing purposes, the austenitizing and carburizing temperatures were held constant for both trials. The parts were furnace-cooled after carburizing from both processes, then reheated and quenched in the same furnace to eliminate any difference related to the quenching process.

Carbon content was analyzed for each of the samples sent to a commercial heat treater whose furnace was equipped with an EndoCarb unit installed on it, namely Euclid Heat Treating (Euclid, Ohio) [3] as well as those run at Oerlikon Fairfield. For clarification, the cycle ran at Oerlikon Fairfield will be referred to as "Conventional" and the cycle ran at Euclid Heat Treating will be referred to as "Heavy Carbon." The carbon content at various depths was taken as a percentage and charts of identical samples sent to each testing facility were compared. One such comparison of results is reported in Figure 4.

Effective case depth measured to 50 HRC (ECD @ 50 HRC) results as well as surface hardness measurements of the parts created by both carburization techniques were compared (Tables 1 and 2, respectively). These show the measured ECD difference and percent difference between the two comparable samples. Parts from both techniques were tested by Oerlikon Fairfield and Euclid Heat Treating respectively, and independently by The HERRING GROUP, Inc. (Elmhurst, Illinois).

Figure 4 illustrates there is no significant difference in carbon weight percentage at varying depths on comparable samples. This suggests there is no compositional carbon difference in the products produced by both the conventional and Endocarb carburization methods.

The indication is there are few differences between all four measurements conducted for each tooth of the bull gear. The main experimental difference, defined here as more than 10 percent or 3 HRC difference, comes from the ECD measurement of bull gear B. However, the third-party ECD measurements were very similar for this tooth in both instances. Overall, there is only a slight difference between measurements, indicating that, again, there is only a slight variance of the essential characteristics within the parts produced by the two carburization techniques.

Although the balance of all measurements (not reported here) supported this conclusion, microstructural analysis was conducted to characterize the microstructure (Figures 5-7) before and after etching [4]. The microstructure is consistent between samples (the color difference in Figure 7 is due to an etching effect and differences in lighting). These microstructures confirm there is virtually no difference between the parts produced via both systems.

Table 1: Effective Case Depth Comparison

ECD (in.)	Bull Gear A	Bull Gear B	Bull Gear C	Comparison
Conventional [a]	0.0865	0.0916	0.0789	✓
Conventional [b]	0.0844	0.0844	0.0769	
Heavy Carbon[a]	0.0858	0.0739	0.0783	✓
Heavy Carbon[b]	0.0843	0.0886	0.0859	

Notes: a. Oerlikon Fairfield Testing, b. Third-party testing. Diametrical Pitch = 2.7922 in.

Table 2: Surface Hardness Comparison

Surface Hardness (Midpoint, HRC)	Bull Gear A	Bull Gear B	Bull Gear C	Comparison
Conventional [a]	61.5	63.8	63.8	✓
Conventional [b]	62.7	63.1	63.1	
Heavy Carbon [a]	63.7	62.6	61.6	✓
Heavy Carbon [b]	63.5	62.7	63.3	

Notes: a. Oerlikon Fairfield Testing, b. Third-party testing. Diametrical Pitch = 2.7922 in.

TRIAL SUMMARY

The Endocarb system was determined to have achieved the same results as found with conventional endothermic gas carburizing for the parts in this study. The principal conclusions reached were:

- Carbon Potential: The higher and lower carbon potential set point throughout the process produced less soot accumulation within the furnace resulting in less "housekeeping" for the pyro technicians. Sooting from conventional processing is known to cause significant equipment problems and process variation.
- Temperature: The temperature fluctuations necessary to control the varying carbon set points was not shown to adversely affect the quality of the gas carburized products.
- Time: The cycle time for gas carburizing was found to decrease by approximately 18 percent, allowing higher productivity and associated cost savings.
- Microstructure, Case Depth, Surface Hardness, Retained Austenite: The analyses of both the Fairfield and Heavy Carbon treated parts produced similar

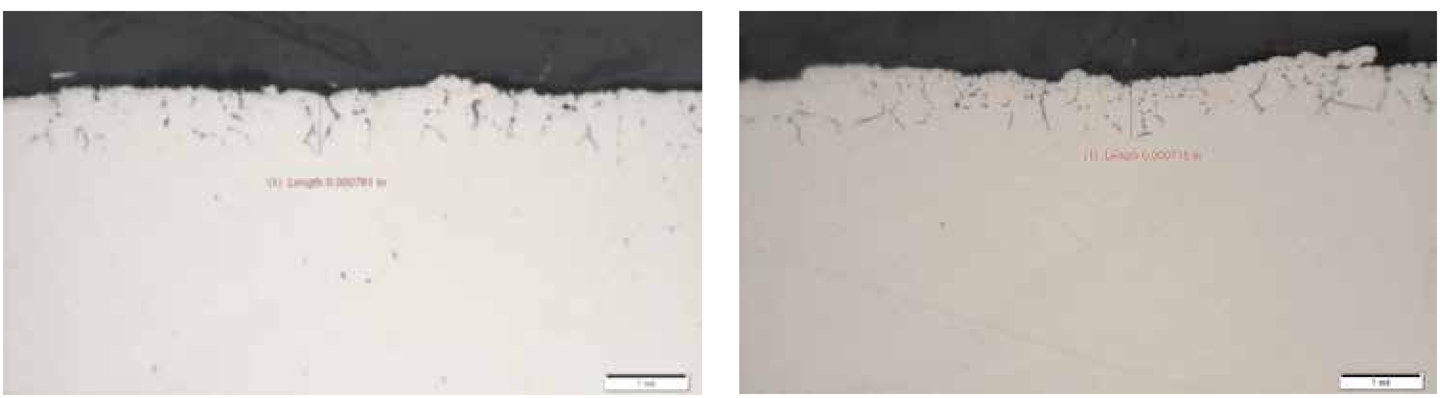

Figure 5: Intergranular oxidation (IGO) comparisons on bull gear B from both facilities [4].

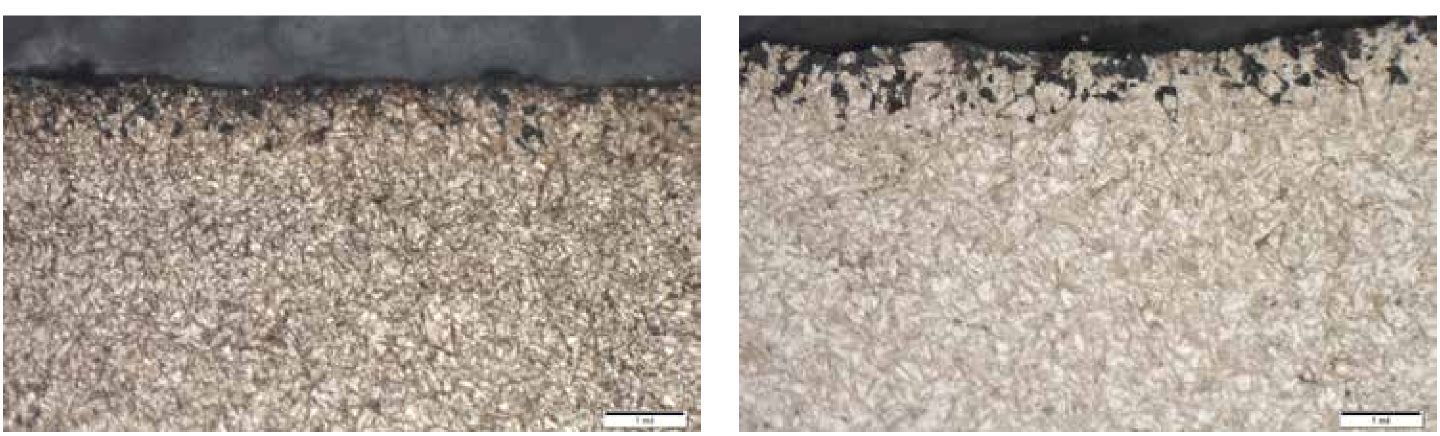

Figure 6: Flank (midpoint) comparisons performed on bull gear B from both facilities [4].

Given that the Endocarb system appears to produce parts of identical quality in less time at lower cost, the heat-treatment department will operate more efficiently, shorten product lead times, and still meet or exceed customer expectation.

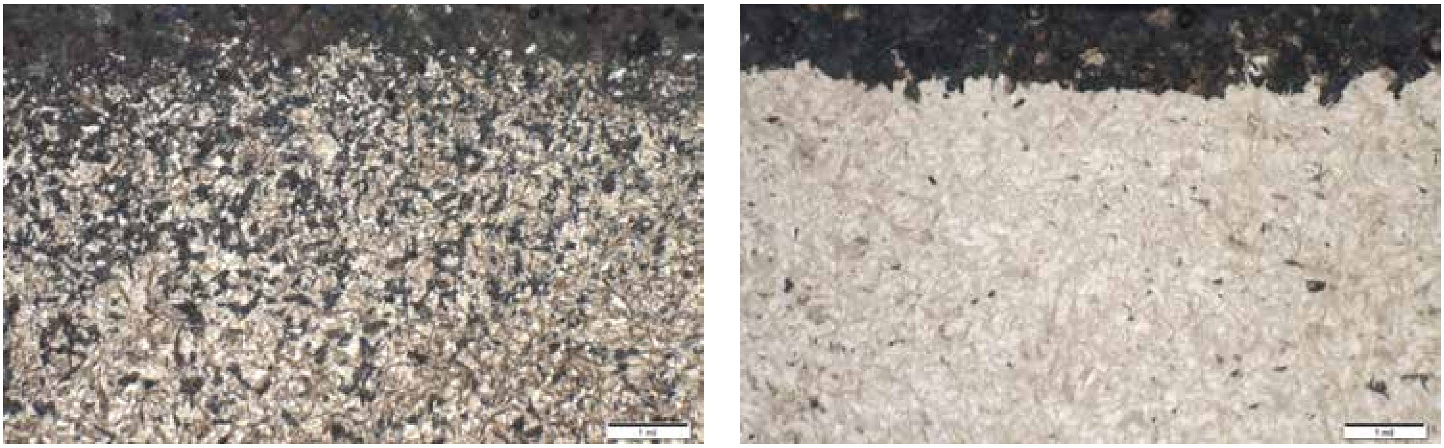

Figure 7: Root center comparisons performed on bull gear B from both facilities [4].

measurements. No significant differences in mechanical properties are expected from identical parts produced by both processes.

Given that the Endocarb system appears to produce parts of identical quality in less time at lower cost, the heat-treatment department will operate more efficiently, shorten product lead times, and still meet or exceed customer expectation.

ABOUT OERLIKON FAIRFIELD

Oerlikon Fairfield has been a technology leader and product innovator in gear and drive design for nearly 100 years. Its people, knowledge, and resources help to provide unique solutions for a wide range of customer application needs.

With manufacturing operations in the United States, India, and China, Oerlikon Fairfield has the capability to produce up to AGMA Class 14 spur, helical, or bevel custom gears from 20 mm to 2 m in diameter. Oerlikon Fairfield also designs and builds custom drives for mobile equipment and stationary industrial machinery with torque outputs from 800 Nm to more than 4 million Nm. Products designed to provide integrated solutions for mechanically, hydraulically, or electrically driven systems require Torque Hub® planetary drives, drop boxes, right angle drives, transfer cases, specialty transmissions, differentials, differential carrier assemblies, and housing and custom drive assemblies.

Oerlikon Fairfield has extensive in-house heat-treat capability and the conventional gas carburizing method has been used for years to successfully enhance quality drive solutions; but the company is always looking for a more efficient methods for surface hardening of steel.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals and companies for their contributions to this study: George Barbour (Heavy Carbon Co., LLC), Jon Vanas (Euclid Heat Treating), Marc Abney, (retired, Oerlikon Fairfield), Ryan Wilmes (American Axle and Manufacturing), and the Oerlikon Fairfield MetLab Technicians (Oerlikon Fairfield).

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4. Independent third-party analysis, The HERRING GROUP, Inc. (www.heat-treat-doctor.com)

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Figure 1: Induction heating is successfully applied for heat treating of a variety of iron castings offering numerous attractive properties, microstructures, and cost advantages for different commercial applications. (Courtesy: Inductoheat Inc., an Inductotherm Group company)

Induction hardening of cast irons

The success in induction hardening of cast irons and repeatability of obtained results are greatly affected by a potential variation of matrix carbon content.

By Dr. Valery Rudnev

Steel components by far represent the majority of thermally processed workpieces for which electromagnetic induction is used as a source of heat generation. At the same time, induction heating has also been successfully applied for heat treating of a variety of iron castings offering numerous attractive properties, microstructures, and cost advantages for different commercial applications (Figure 1). This includes hardening of camshafts, crankshafts, sprockets, crane wheels, gear housing, cylinder liners, rollers, rocker arms, flywheels, connecting rods, and many others.

Induction hardening (IH) of cast irons has many similarities with hardening of steels; at the same time, there are specific features that should be taken into consideration [1]. Some of those features will be reviewed in this article.

FAMILY OF CAST IRONS

The term *cast iron* does not represent one particular material but a large family of metallic alloys featuring the high carbon content region of the phase transformation diagram (2 percent and higher). Generally speaking, the family of cast irons can be categorized into six groups: white, gray, malleable, ductile (also called nodular, spheroidal, or SG), compacted graphite (CGI), and

special high-alloy cast irons [2-5].

Upon the completion of solidification of cast irons, either graphite particles of different morphologies (for a majority of commercial cast irons) or cementite Fe_3C (e.g., white cast iron) are formed.

Besides carbon, commercial cast irons consist of 0.6 percent to 4 percent Si (with 2 percent to 3.5 percent Si being more typical), making these the two principal alloying elements. Silicon promotes a graphite formation. Therefore, because of the considerable amount of, it is more appropriate to consider commercial cast irons not as binary alloys but at least ternary Fe–C–Si alloys. In contrast to the Fe–C diagram, the eutectic reactions on the Fe–C–Si diagram occur at higher temperatures and over a range of temperatures that increases with an increase of both the carbon and silicon content.

In order to provide certain properties for a particular type of cast iron, various alloying elements (including Mn, P, Ni, Mg, Ce, etc.) may be added [2-5]. Unlike steels, different types of cast irons may have similar chemical composition but substantially different response to IH.

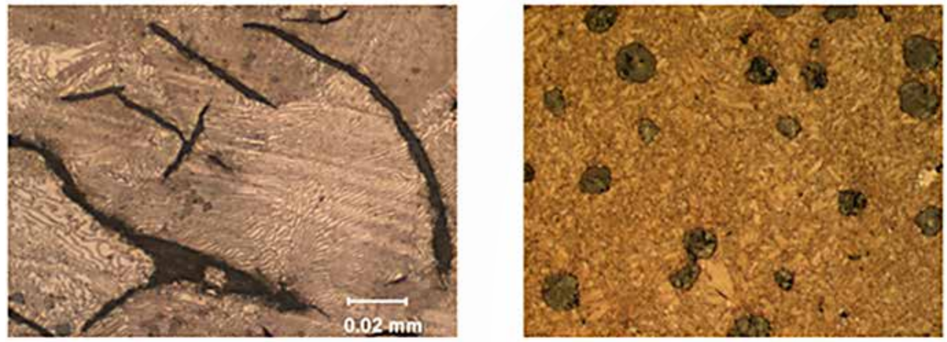

Figure 2: Ductile cast irons consist of graphite in shapes of spheroids or nodules (right). Graphite particles of gray irons appear in 2D metallographic examination in flake-like form (left) [1].

The graphite particles appear in cast irons in different forms ranging from flakes and clumps to spheroids. Gray, ductile (nodular), and, to a lesser extent, the malleable and compacted graphite irons are four groups of cast irons that more frequently undergo induction hardening.

Gray cast irons, being relatively inexpensive metallic materials with remarkable castability and machinability, excellent wear resistance, and resistance to galling and seizure/spalling (graphite flakes provide solid lubrication) are very attractive for a variety of applications.

It is quite easy to distinguish gray irons from ductile irons. Ductile irons consist of graphite in shapes of spheroids or nodules (Figure 2, right). In contrast, graphite particles of gray irons appear in 2D metallographic examination in flake-like form (Figure 2, left).

INDUCTION HARDENING OF GRAY CAST IRONS

The properties of gray irons and their ability to be induction hardened greatly depend on the type of the matrix structure (e.g., ferritic, ferritic–pearlitic, or pearlitic). Cast irons with a ferritic matrix or predominantly ferritic matrix are commonly considered unsuitable for rapid IH due to the lack of ability to obtain the typically needed hardness levels. Fully pearlitic or predominately pearlitic (e.g., a mixture containing 90 percent pearlite and 10 percent ferrite) gray irons have better response to IH compared to a matrix with an increased amount of ferrite.

Fine graphite flakes that are uniformly distributed and randomly oriented (type "A") are the most preferable type of flakes for IH [1]. Being stress-risers, graphite flakes may act as crack initiation sites presenting some brittleness and introducing certain challenges because of the tendency toward cracking upon rapid heating as well as during intense quenching in particular when dealing with complex geometries. Preheating and the use of moderate intensity quenchants may be applied to reduce thermal stresses.

At the same time, there are cases when gray irons have been successfully surface-hardened using a short heat time (less than 3 seconds) and water spray quenched. As an example, Figure 3 shows a unitized machine for IH of gray iron cylinder liners for commercial vehicle engines. It combines two independently operated heat stations for hardening and tempering. High-speed, servo-driven scanning assemblies and an optimized process recipe allow very short heating times and production rates as high as 50 liners per hour. Hardness case depth is 0.75 mm (0.03 inches). The entire inner surface of the liner is hardened except for a 6-mm (1/4-inches) band at each end with minimum distortion.

INDUCTION HARDENING OF DUCTILE (NODULAR) CAST IRONS

In contrast to gray irons, ductile irons have graphite particles in the form of isolated nodules (Figure 2, right). Graphite nodules serve as "crack-arresters," providing ductile irons with important advantages over other cast irons, including but not limited to ductility, relatively high tensile and bending strength, moderate elongation, and better toughness with comparable machinability. Though there is an optimal combination of the size, number, and distribution of the nodules for certain applications, usually graphite nodules of smaller diameters that are uniformly dispersed within the matrix are preferred.

Ductile irons represent a group of materials offering versatile properties. The group can be divided into five subgroups based on the structure of the matrix: ferritic, pearlitic-ferritic, pearlitic, martensitic, and austempered ductile irons. Similar to gray irons, the matrix structure of ductile irons is also controlled by the cooling intensity during casting, as well as by alloying (e.g. Ce, Mg, etc.) and heat treatment.

IH is usually applied to martensitic and pearlitic (or predominately pearlitic) ductile irons and, to lesser extent, pearlitic-ferritic ductile irons having a considerable amount of ferrite. Ductile irons consisting of a ferritic matrix structure are commonly considered non-hardenable by induction because of the inability to obtain the hardness levels typically needed for most applications.

However, as always in life, there are some exceptions. It has been reported [6] that upon rapid heating, short austenitization, and intense quenching, the fatigue strength of ferritic ductile irons has been noticeably improved compared to untreated castings. It was suggested that several factors contributed to observed improvements. One such factor is related to the formation of so-called ringed martensite formed around the graphite nodules, thanks to the short-distance diffusion of the carbon from the graphite nodules. The presence of ringed martensite leads to a localized hardness increase and is associated with an increase of strength. Another possible factor may be associated with favorable distribution and magnitude of compressive residual stresses. As a result of the bending fatigue test of an untreated specimen, it was noted that the crack initiation site was located around the graphite spheres, and it propagated through the ferritic matrix and graphite nodules [6]. In the case of the induction heat-treated specimen, the graphite area was somewhat smaller, and the crack was initiated within the ferrite phase and propagated, avoiding graphite nodules surrounded by a halo of the ringed martensite.

Nevertheless, IH of ferritic ductile irons used in this case study is more the exception than the rule and for the majority of IH applications, a ferritic or predominantly ferritic matrix of cast irons is highly undesirable because of the inability to achieve the consistency and hardness levels typically needed in industry.

Being inherently strong, ductile irons can handle much greater stresses than gray irons. Though, graphite nodules of ductile irons serve as "crack-arresters," their existence does not guarantee that ductile iron castings will not crack during rapid heating or severe quenching. Caution should be applied when choosing process parameters for surface hardening of iron castings of complex geometries.

Figure 3: Unitized machine for IH of gray iron cylinder liners for commercial vehicle engines (Courtesy: Inductoheat Inc., an Inductotherm Group company).

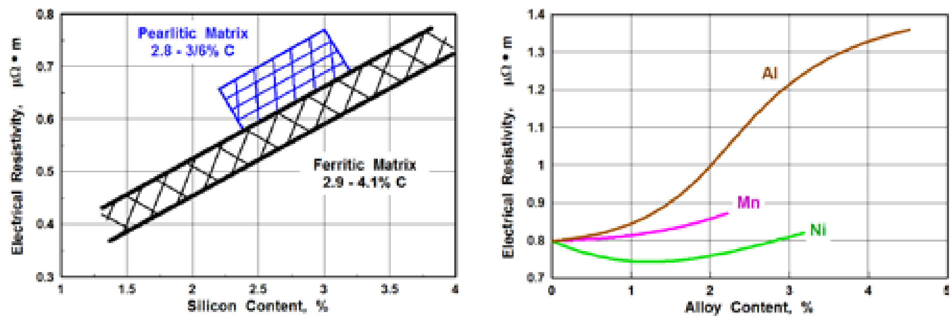

Figure 4: Effect of Si on r of pearlitic and ferritic ductile cast irons at room temperature (left). (Based on materials published in www.ductile.org.) The influence of Al, Mn, and Ni on r of gray cast irons at room temperatures (right). (From C. Walton, T. Opar, Iron Castings Handbook, Iron Castings Society, Inc., 1981; I. Iitaka, K. Sekiguchi, Influence of added elements and condition of graphite upon r of cast iron, Reports of the Casting Research Laboratory, No. 3, Waseda University, Tokyo, Japan, 1952, pp. 23–25.)

ELECTRO-THERMAL PROPERTIES OF CAST IRONS

Unlike alternative processes, the performance of induction systems first and foremost is affected by the electromagnetic properties of the heated materials, including electrical resistivity ρ and relative magnetic permeability μ_r.

The chemical composition and volume fraction of graphite, its morphology, and the matrix structure of cast irons affect not only mechanical properties but also electromagnetic and thermal properties. For example, gray irons with large graphite flakes are known to have a higher thermal conductivity *k* and a lower electrical resistivity ρ. Ductile irons with a ferritic matrix have a higher *k* compared to pearlitic or Q&T grades.

The thermal conductivity of cast irons decreases with an increase in Mn and P content. It has been reported [2] that if Cu content is less than 2 percent, it lowers *k*. Cu additions greater than 2 percent have no appreciable effect on *k*. An increase in Si reduces *k* of most cast irons. For a given grade of cast iron, *k* usually decreases with temperature.

Reference [2] provides comprehensive data regarding the electromagnetic properties of cast irons and can be summarized using the following selected points:

- ρ gradually increases with the temperature rise and behaves in a complex manner, being a function of chemical composition, morphology of the graphite, and microstructure of matrix.
- Cast irons with nodular or close-to-nodular morphology of graphite (e.g., ductile or malleable cast irons) exhibit lower ρ compared to gray irons.
- Gray irons with courser graphite flakes exhibit higher ρ compared to finer flakes.
- Figure 4, left, illustrates the effect of Si on ρ of pearlitic and ferritic ductile cast irons at room temperature. Figure 4, right, shows the influence of Al, Mn, and Ni on ρ of gray irons at room temperature [2,7].
- A pearlitic matrix results in increased ρ compared to cast irons with a ferritic matrix. Pearlitic cast irons having fine spacing between the lamellae have greater ρ compared to coarser pearlites. Ductile iron with a ferritic matrix has the lowest ρ.

Cast irons with a ferritic matrix have higher magnetic properties compared to pearlitic irons. It appears that ductile and malleable irons exhibit greater magnetic induction *B* and higher μ_r compared to the respective properties of gray irons. Cast irons exhibit noticeably lower residual magnetism, magnetic saturation, and μ_r compared to carbon steels.

GOOD PRACTICES IN INDUCTION HARDENING OF CAST IRONS

PROCESS RELATED SUBTLETIES

Among other factors, the ability of cast irons to exhibit certain as-quench hardness and strength depends upon the amount of carbon contained in the austenite, which is greatly affected by the matrix. The proper hardening parameters include, but are not limited to, an appropriate temperature and time at the austenite phase, which, besides other factors, are functions of the cast iron grade, its matrix, heat intensity, and quenching specifics.

In steels, the carbon content is fixed by chemistry and, upon austenitization, cannot exceed this fixed value (rare attempts to use a carbon-enriched environment are excluded from consideration). In contrast, in cast irons, there is a "reserve" of carbon in the primary (eutectic) graphite particles. The presence of those graphite particles and the ability of carbon to diffuse into the matrix at temperatures of austenite phase can potentially cause the process variability, because it may produce a localized deviation/increase in an amount of carbon dissolved in the austenitic matrix respectively affecting the obtained hardness and its uniformity upon quenching [1].

Higher temperatures of the austenite phase and longer times at those temperatures are associated with a greater amount of carbon being dissolved within the matrix. Since some of the graphite can go into solution in proximity to nodules or flakes, it

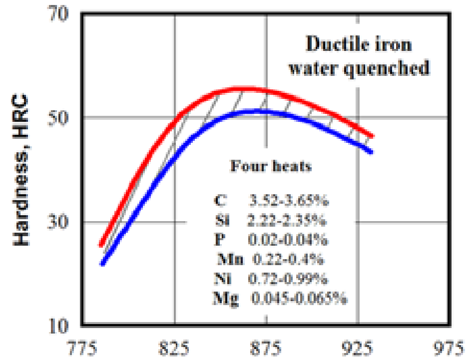

Figure 5: Influence of austenizing temperature on hardness of ductile iron. Specimens were slow heated, held in air for one hour, and water quenched. (From ASM Handbook, Vol. 4, Heat Treating, ASM Int'l, 1991.)

can locally increase the carbon level in the austenite, shifting CCT curves, affecting martensitic formation and M_s temperatures, as well as amount of retained austenite (RA). This tendency is an important metallurgical factor representing one of the major differences between hardening cast irons versus steels and potentially resulting in a variable amount of carbon in as-quenched structure. This is one of the reasons why the requirements for process control and monitoring when hardening cast irons are usually more stringent compared to hardening steels.

An attempt to compensate for the lack of carbon content in the ferritic matrix trying to purposely diffuse a greater amount of carbon into austenite by applying excessively high temperatures and dissolving the primary graphite particles cannot be considered a good universal practice because it is associated with not only the necessity of reaching unduly high austenizing temperatures but also the need to hold the cast irons at those temperatures for an extended period. This discourages one of the main advantages of induction, the short process time and results in grain coarsening, excessive amount of RA, irregular hardness patterns, and crack susceptibility.

On the other hand, insufficient austenitization produces heterogeneous structures

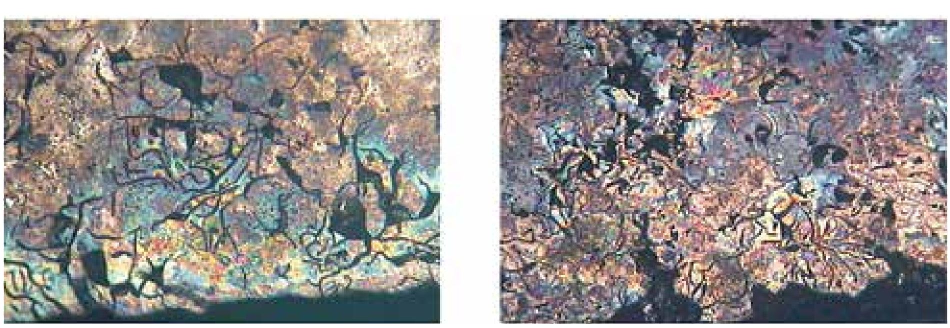

Figure 6: Large graphite flakes or clusters having a preferred orientation of flakes located near the surface serve as stress raisers and should be considered to be undesirable prior microstructures [1].

forming a mixture of martensitic and non-martensitic products ("ghost" products) and undesirable engineering properties. The industry has accumulated several recommendations to estimate the appropriate hardening temperatures. For a rough estimation of the minimum required austenitizing temperature of unalloyed cast irons heated at moderate heat intensity, the following expressions are often applied:

Austenizing temperature, °C = 800 + 28(%Si) - 25(%Mn)

Austenizing temperature, °F = 1,472 + 50(%Si) - 45(%Mn).

Besides the minimum austenitic temperature, there is a maximum recommended temperature that should not be exceeded. The temperature range of 860°C (1,580°F) to 930°C (1,706°F) is typical for IH of gray and ductile iron castings. As an example, Figure 5 shows the influence of austenitizing temperature on the hardness of water-quenched ductile iron [8].

Keep in mind that, as a result of the non-equilibrium nature of rapid induction heating, all critical temperatures are shifted toward the higher temperatures. Cast iron eutectic melts at temperatures of approximately 150°C to 250°C lower than the majority of plain carbon steels. For example, in the case of moderate heat intensity, the unalloyed cast iron eutectic starts to melt at temperatures of about 1,130°C (2,066°F). Therefore, if something goes wrong, there is a distinct possibility for overheating owing to the relatively low liquidus and solidus temperatures of cast irons. The situation becomes more complicated, as certain alloying elements (such as copper or tin, which may be added to some cast irons) have low melting temperatures.

In contrast to steels, there is very limited information in the literature with respect to the continues heating transformation (CHT) diagrams suitable for IH of cast irons, forcing heat treaters to rely solely on experiments and laboratory developments to determine the most appropriate temperatures for rapid IH.

When heating cast irons susceptible to cracking, it is sometimes useful to preheat the castings allowing the reduction of thermal shocks or to apply modest heat intensity in particular during the initial stage (from room temperature to approximately 550°C/1,000°F).

Quenching oils at elevated temperatures and suitable aqueous polymer solutions may be used for surface hardening of gray irons, allowing minimization of the probability of cracking and excessive distortion. In contrast to hardening steels, "mass quenching" does not typically apply even in cases of shallow case depths. However, short quench delay (0.5 to 1.5 seconds) is applied quite regularly.

Since the Mf temperatures of cast irons are always below room temperature, there will be a certain amount of RA formed in as-quenched structures. The amount depends on chemical composition, hardening specifics, and the process recipe. As expected, the greater amount of RA directly affects the as-quenched hardness and the magnitude of residual compressive surface stresses. This could alter critical mechanical properties, including wear resistance and fatigue strength. Besides that, the load stresses that appear during the operation of the component could transform the RA into untempered martensite, introducing brittleness and potentially causing dimensional instability. There are a number of corporate standards to specify the maximum permissible levels of RA for a particular cast iron application, some of them specify maximum of 8 percent to 12 percent of RA).

It is a common good practice to temper as-quenched cast irons as soon as possible to relieve excessive residual stresses and to form as-tempered martensitic structure, improving toughness, and avoiding delayed cracking.

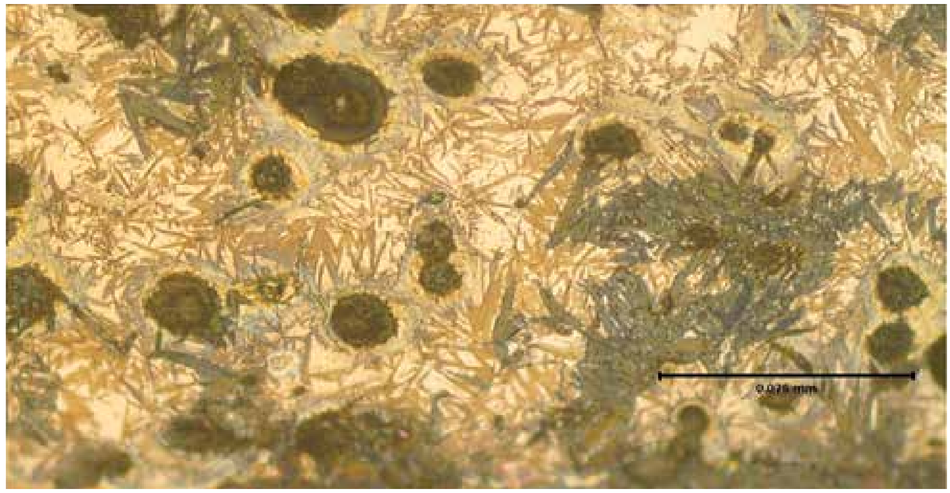

Figure 7: An attempt should be made to avoid the formation of an undesirable mixture of martensite and upper transformation products in as-quenched microstructure [1].

Figure 8: Close-up of Inductoheat's SHarP-C inductor (a) and as-hardened microstructure (b) that reveals the two-phase (fine-grain martensite and nodular graphite) structure with an insignificant amount of retained austenite. (Courtesy of Inductoheat Inc., an Inductotherm Group company.)

FRIENDLY/UNFRIENDLY PRIOR MICROSTRUCTURES

The task of successful IH of cast irons will be simplified by having a friendly initial prior microstructure that is responsive to rapid heating. As stated earlier, ferritic cast irons or cast irons with a substantial amount of ferrite in the matrix are not well suited for rapid hardening, because carbon has poor solubility in ferrite.

A small amount of ferrite adjacent to the graphite nodules ("bull's eye") usually does not affect the achievable hardness, because the carbon might be able to sufficiently quickly diffuse into those thin regions from carbide nodules, enriching them with an adequate amount of carbon (assuming that the temperature and time at the austenite phase are appropriate).

Structure consisting of large graphite clusters (Figure 6) cannot be considered a friendly prior microstructure. Large graphite flakes or clusters having a preferred orientation of flakes being located within the hardness depth serve as considerable stress risers. In this case, gray iron's sensitivity for crack initiation during rapid heating is increased, and a redistribution of localized eddy current flow may occur (particularly for frequencies of 50 kHz and higher). The soft spots may occur within the as-quenched structure in areas where large clusters are present.

A friendly microstructure of the matrix of cast irons (e.g. pearlitic) allows fast transformation at minimum hardening temperatures, making it imperative to minimize distortion.

PROPER CHEMICAL COMPOSITION

If, for some reason, cast iron does not respond to IH in an expected way, then one of the first steps in determining the root cause for such unexpected behavior is to make sure the chemical composition and matrix are appropriate. In some cases, what is supposed to be the same iron castings purchased from two different suppliers may have appreciable variations of composition, matrix, and properties.

Silicon should be closely controlled because of its powerful impact on the ferrite and graphite formation, eutectic reaction, and solubility of carbon in austenite. Extreme levels of Si are undesirable: a very low Si content promotes carbide formation, while excessive Si levels may promote more ferrite in the matrix [9].

Although carbon and silicon are two of the principal alloying elements in gray, malleable, and ductile irons with a significant influence on the as-hardened microstructure, the examination should not be limited to an evaluation of only these two elements. Commercial cast irons may have a considerable amount of other alloying elements, and their inappropriate levels may have an impact on results of IH. For example, the phosphorus concentration should be below its prescribed maximum level. It has been reported that an excessive amount of P (the normally specified amount for ductile irons is ≤0.05%, whereas that for gray irons is ≤0.2%) can form a low melting point phase (steadite) producing increased brittleness and reduced impact strength, which worsen with increasing hardening temperatures and phosphorus concentration.

An excessive amount of P is also associated with a greater risk of melting a phosphorus eutectic. Therefore, elevated levels of phosphorus should be taken into consideration if problems arise. At the same time, it should not be assumed that elevated amounts of P automatically cause cracking problem. On several occasions, investigations reveal that cast irons containing an elevated amount of phosphorus (0.39%–0.57% P) have been induction hardened without cracking [9].

All commercial cast irons, to a different extent, consist of traces of residual impurities resulting from raw materials and the ironmaking practice. These residuals and alloying elements under certain conditions may have mutual interactions affecting the results of hardening. Even seemingly small amounts of such elements (e.g., Bi, Pb, Ti, Ni) may have a marked effect on the results of hardening.

It is also imperative to remember that some elements have a combined effect (i.e., carbon and silicon, sulfur and manganese); therefore, it is important to control their combined effect. An increased Mn content exhibits a tendency to increase the amount of RA, causing Mn segregation and reduced hardness readings [10]. On the other hand, it is necessary to have a sufficient amount of Mn to neutralize S. Some investigators suggest following the Mn–S correlation for a minimum amount of Mn in gray cast irons [9]:

$$Mn(\%) = 1.7 \cdot S(\%) + 0.3\%.$$

DESIGN FACTORS AND QUALITY OF CASTINGS

Poor-quality castings and casting defects can cause problems by themselves. For example, the presence of such casting defects as porosity, abnormal inclusions, sand and gas defects, blowholes, pinholes, and excessive segregation may cause a deviation in eddy current flow, local overheating, stress concentration, cracking, hardness scatter, etc.

When iron castings have a complex shape featuring geometrical discontinuities and irregularities, the regions with substantially different masses have a tendency to heat and quench differently. This promotes the appearance of thermal gradients and undesirable transient stresses that could create conditions for excessive distortion and cracking.

CONCLUSION

Among other factors, the success in induction hardening of cast irons and repeatability of obtained results are greatly affected by a potential variation of matrix carbon content. This requires tighter control of the process recipe/protocol. An attempt should be made to select a process recipe that would allow avoiding the formation of undesirable transformation products in the as-quenched microstructure. Figure 7 illustrates an example of such undesirable mixed structures.

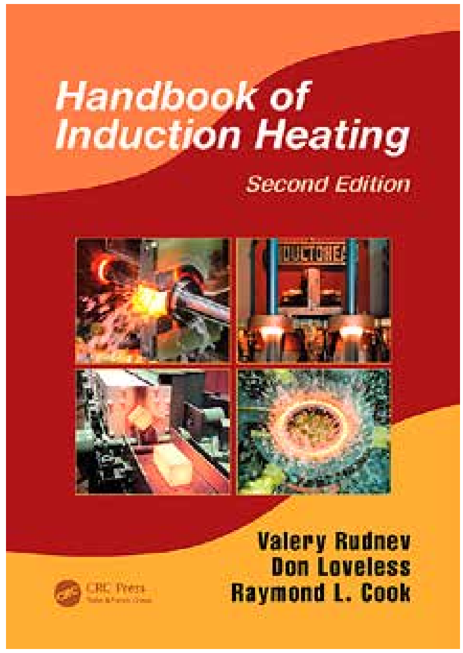

Figure 9: More information related to induction heating and heat treating can be found in the 2nd Edition of the Handbook of Induction Heating, shown here (CRC Press, 2017). The publisher has granted permission publishing the materials contained in this article.

"Friendly" prior microstructure in combination with advanced technology produce fast phase transformations at minimum hardening temperatures with minimized distortion [1,11,12]. For example, the case study provided in [11] reveals achieving almost undetectable camshaft distortion of approximately 3 to 5 microns (based on 1.5- and 2.0-L diesel or regular fuel engines) while applying Inductoheat's non-rotational technology (SHarP-C Technology). In many cases, this technology eliminates sequential camshaft straightening operation. Figure 8 shows a close-up of the unique design of the SHarP-C inductor (left) and the as-hardened microstructure (right) that reveals a two-phase structure (fine-grain martensite and nodular graphite) with an insignificant amount of retained austenite.

NEW TECHNICAL RESOURCE FOR INDUCTION HEATING PROFESSIONALS

Space does not permit a discussion of all the intricacies of induction heat treating of cast irons. More information can be found in the 2nd Edition of the Handbook of Induction Heating (Figure 9), which embarks on the next step in designing cost-effective and energy-efficient induction processes. It is intended to reach a variety of readers including practitioners, engineers, metallurgists, managers, students, and scientists.

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MARKETPLACE

Manufacturing excellence through quality, integration, materials, maintenance, education, and speed.

AD INDEX

COMPANY NAME PAGE NO.

"Custom electric has a 50-year history of delivering quality heating elements."

Tell us about your company and its core philosophy.

Custom Electric Manufacturing Co. designs and manufactures original equipment and replacement heating elements for electric thermal processing equipment. The company was founded in 1970.

The focus of Custom Electric is metallic heating elements. Product offerings have expanded to include elements for all types of industrial heating equipment and most electric thermal processing applications.

Today, Custom Electric has a global customer base. Manufacturing floor space has doubled. Ongoing investments in CAD/CAM technology, CNC forming equipment, and a computerized plant management system ensure manufacturing efficiency. Investing in skilled people ensures product quality. For more than 50 years, our core philosophy has been to supply a quality product in a timely manner to the heat-treating community

What are your duties?

We design custom electric heating elements and assist in the design of furnaces and other high-temperature heating systems.

What products and services does your company offer?

We design, build, and repair all types of electric resistance heating elements. The Custom Electric engineering team has more than 75 years of heating element design experience. Working with original equipment manufacturers and end users, they design elements for new and unusual applications in addition to replacement elements that ensure production efficiency. Examples of elements designed to solve specific customer heating problems are:

- Bayonet Elements.
- C-Mersion Elements and Tubes.
- Edge-Wound Ribbon Bayonet Elements.
- Plug/Rack (Open Coil) Elements.
- Ribbon/Strip Elements.
- Rod Overbend Elements.

Custom Electric's product offerings have expanded to include elements for all types of industrial heating equipment and most electric thermal processing applications. (Courtesy: Custom Electric)

- Rod Overbend Fiber Module Systems.
- Helical Coil Elements.
- Tubular Elements.
- Silicon Carbide Elements.
- High Temperature Radiant Tubes.
- Thermalloys Protection Tubes.

What are your company's goals as they pertain to the heat-treating industry?

We continue to strive to expand into those areas of heat-treating that require electric heating because no component of an electric thermal processing system has a greater impact on furnace performance, productivity, and operating costs than heating elements. Custom electric has a 50-year history of delivering quality heating elements that last longer, have lower maintenance costs, and reduce replacement downtime while increasing productivity.

To support day-to-day maintenance requirements, Custom Electric also provides element and element layout upgrading support, element repair support, spare parts, and furnace accessories, as well as stocking programs tailored to customer requirements.

What are some of your company's proudest achievements?

We are proud to be recognized as the leading heating-element manufacturer in the heat-treating industry. Our products keep America running, and we are very proud of that.

What sets your company apart when it comes to what you can offer a customer?

The short answer is product line focus and application experience. Heating elements have been the focus of Custom Electric for 50 years. It is all the company does and what it strives to do better than any other company in the electric heating industry. Because of the breadth of its product line and diversity of markets served, few companies can match the application experience of Custom Electric. The engineering team has more than 75 years of element design experience. It can design quality replacement elements for any thermal processing system or develop custom heaters for new equipment and applications.

Where do you see the future of your company and its place in the heat-treating industry?

We see ourselves continuing to lead the pack with innovative custom designs and excellence in customer service.

MORE INFORMATION www.custom-electric.com

Custom Electric Manufacturing

Your one-stop-shop for American-Made Heating Elements

Knowledge

For answers regarding element life, reliability, or performance, simply speak to the engineer that designed your elements. Problems solved

Convenience

We handle any size order for any style heating elements, old or new, to meet your specific requirements

Made In America

Avoid import delays, currency exchange rates, and high transportation costs. Our products arrive within days after leaving our facility, not weeks

Local Support

We know your equipment! Our local sales reps and heating system design engineers are there to assist you.

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