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Thermal processing

ISSUE FOCUS ///

HEAT TREAT EXPO 2019

MINIMIZING ENERGY CONSUMPTION

AN INTRODUCTION

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Across International

OCTOBER 2019
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JEFF MARSHALL

VICE PRESIDENT ///
METALLURGICAL HIGH VACUUM CORP

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Industrial Heating Equipment Association (IHEA)

In this section, the national trade association representing the major segments of the industrial heat processing equipment industry shares news of the organization's activities, upcoming educational events, and key developments in the industry. **18**

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Microstructural evolution and its effect on dual phase Ti6Al4V alloy, which is heat treated to enhance the strength of jet engines. **20**

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FROM THE EDITOR ///

Heat Treat 2019 is happening now!

It's finally here.

And by "it," I mean Heat Treat 2019.

If you're reading this, odds are you may be walking the show floor at this very moment. But, if you're not, here's what you're missing out on:

› Three days of face-to-face networking opportunities with about 200 heat-treat exhibitors and companies. All of the top companies and big names in the heat-treating industry are here.

› Latest research and industry insights through more than 125 technical sessions, featuring special symposiums on induction heat treating.

› "This is Heat Treat" free college student program.

› As it has in the past, Heat Treat 2019 continues to partner with the Motion+Power Technology Expo 2019 (formerly Gear Expo), which provides attendees access to an additional network of 4,000 attendees and 250 exhibiting companies.

› Joint initiatives with the Motion+Power Technology Expo 2019 include educational programming, networking events, and much more.

To keep things hot (hey, it's *Thermal Processing*; heat-treating puns are low-hanging fruit), our October issue sets the tone as the perfect primer for Heat Treat 2019. You might even run into some of our contributing authors right here on the show floor.

In our Focus section, you'll find a fascinating article from Damian Bratcher of Super Systems where he discusses how energy consumption related to process control is continuously improving with advancements in technology.

We also have the continuation of an article that began in our September issue. Gary Doyon, Dr. Valery Rudnev, Randall Minnick, and Tim Boussie of Inductoheat Inc. present part two on how to troubleshoot and prevent cracking in induction hardening of steels.

Rounding out this month's trio of main articles, Marc Stringer of TE Wire & Cable, LLC shares his insights on how to optimize temperature measurement in heat-treatment operations.

In addition to those articles, we have a wealth of information in the form of our columnists and a plethora of news updates throughout the industry.

I hope your time spent at Heat Treat 2019 is productive and profitable, and remember that *Thermal Processing* is here to boost that success.

So if you're walking the floor in Detroit, be sure and stop by *Thermal Processing's* booth (#2119) and say hey. I'd love to talk about editorial opportunities, and our advertising representatives would be happy to discuss ways to take your message to the next level.

As always, thanks for reading!

KENNETH CARTER, EDITOR
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Visit us at booth #2013 at Heat Treat 19 at the Cobo Center in Detroit, MI, October 15-17.

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THE BRIGHTEST SOLUTIONS THROUGH INGENUITY

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Allied Mineral Products Inc. held a ribbon-cutting ceremony in August. (Courtesy: U. Glidewell)

Allied Mineral Products completes expansion project

After breaking ground a little over a year ago, Allied Mineral Products' current expansion includes a new manufacturing facility in Pell City, Alabama.

When Allied purchased Riverside Refractories in 2017, they acquired two locations in Alabama — Anniston and Pell City. To better serve its local customer base in the southeast region, Allied combined both locations into one new facility.

The Pell City facility joins Allied's list of U.S. manufacturing operations in Columbus, Ohio; Brownsville, Texas; and Chehalis, Washington.

During the ribbon cutting ceremony, a fountain was dedicated to the Morris family (operators of the former Riverside Refractories) for their service to the refractory industry, local community, and their employees.

Allied Mineral Products is a leading global manufacturer of monolithic refractories and precast refractory shapes with 12 worldwide manufacturing facilities, five precast shapes facilities, and three research and technology centers.

Headquartered in Columbus, Ohio, Allied serves a wide variety of industries with innovative refractory solutions and exceptional service and support, backed by expert engineering and research teams. Allied is proud to be an employee-owned company.

MORE INFO www.alliedmineral.com

Premier/BeaverMatic ships two spray/dunk washers

Premier/BeaverMatic spray/dunk washers were recently manufactured and shipped from Premier's new manufacturing facility in Farmington Hills, Michigan.

The repeat customer is an international aerospace firm, with a facility in the southeastern United States. The spray/dunk washers are designed to clean 1,250 pounds of heat-treated material, using both a full immersion oscillating dunk cycle, propeller agitation, and also using a separate high-pressure, with solution, spray cycle. The washers are fabricated entirely of type 304 stainless steel, and feature safety light curtains, powered access doors, electric heating, automatic water make-up, liquid level switches, and extensive heat shielding as well as guarding to protect plant personnel from incidental contact with hot surfaces. Additionally, the washers are equipped with Allen Bradley PLCs and HMIs, SmartSkim crossflow oil separators, and SBS smart dual bag filtration system. Operators

Operators have the option of running the Premier/BeaverMatic spray/dunks washer systems in either fully automatic mode for production, or in manual mode, for set-up and diagnostic purposes. (Courtesy: BeaverMatic)

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.

have the option of running the systems in either fully automatic mode for production, or in manual mode for set-up and diagnostic purposes.

MORE INFO www.beavermatic.com

TPS ships Blue M batch oven to semiconductor maker

Thermal Product Solutions, a global manufacturer of thermal-processing equipment, is shipping a Blue M batch oven to a semiconductor manufacturing company.

This Blue M batch oven has a designated temperature range of 15°C above ambient to 316°C. The interior of the work chamber has dimensions of 36 W x 36 D x 48 H. This batch oven will assist in both curing of adhesive material on circuit boards and accommodating tight processing specifications. The tip-resistant shelves enable ease of unloading without risk of tipping, while high power is used for fast heat-up to desired temperatures.

The high-volume horizontal air recirculation system and electric heating system allows for maximum temperature uniformity in the Blue M batch oven's overall performance. The horizontal air movement from right to left maximizes heating rates within the oven chamber.

"Industrial batch ovens like the ones at Blue M have been meeting a variety of test and production applications for years. Their reliability and brilliant performance have made them the choice of many industries," said Gary Ingbretson, Blue M Sales representative

Features of this Blue M batch oven include:

› Nichrome wire heater elements for durability.

› Centrifugal type blower wheel for efficient air flow through the system.

› Horizontal, one-pass air flow.

› Profiling or single set point controls.

› Direct drive blower.

› Manually adjustable intake/exhaust system for ease of balancing.

› Enclosed wiring to meet National Electric Code (NEC) for safe operation.

› Stainless steel-reinforced Type 304 interior.

› Fiberglass insulation ¬— four full inches minimize heat loss.

MORE INFO www.thermalproductsolutions.com

Grieve offers No. 841, a 650°F universal oven

No. 841 is a 650°F (343°C) universal oven from Grieve, currently used for a variety of heat-treatments at the customer's facility. Workspace dimensions of this oven measure 36" W x 36" D x 36" H. 9 KW are installed in Incoloy-sheathed tubular heating elements, while a 600 CFM, 1/2 HP recirculating blower provides universal airflow to the workload.

This Grieve universal oven features 6-inch insulated walls, aluminized-steel exterior, and Type 430 stainless steel interior with double doors.

Additional features include a workspace floor reinforced for 500 pounds loading at removable subway grate and an integral leg stand.

Controls on the No. 841 include a digital programming temperature controller, manual reset excess temperature controller with separate contactors and a recirculating blower airflow safety switch.

MORE INFO www.grievecorp.com

L&L ships fifth box furnace for treating biomedical powders

L&L Special Furnace Co., Inc., has shipped the fifth Model GS1714 furnace to a leading manufacturer of calcium phosphate materials used for medical devices. The calcium products are known as orthophosphates and contain a variety of chemical structures deployed in the medical and dental field. In slurry form, the calcium phosphate can be used on various items for medical applications with very low inflammation rates and direct bonding to soft bone and tissue. It is used in a variety of applications including dental implants, bone implants, and other medical procedures.

The calcium phosphate powder is sintered in the furnace at a temperature of about 2,200°F (1,204°C). It is held at temperature for four to eight hours. The top layer is removed after processing, leaving pure calcium phosphate powder. The powder is then mixed with proprietary materials and made into slurry that can be applied to various appliances deployed in the medical field.

Model GS1714 has an effective work zone of 10" high by 15" across by 13" deep. The furnace is designed to be placed on a bench top or an optional stand. It has a program control that has six individual programs with up to six segments each. The furnace can also be equipped with overtemperature protection.

Additionally, model GS1714 can be equipped with datalogging software that allows for multiple furnaces to be recorded at one time. The KISS software enables multiple furnaces to be profiled simultaneously. The furnace is also available with type S thermocouples or Kanthal APM elements, which are both designed for extended high-temperature soaks or dwell times. A ventilation system removes binders that are released by the product during processing.

Calcium phosphate powder is sintered in the GS1714 bench-mounted box furnace at a temperature of about 2,200°F (1,204°C) before being used on various items for medical applications. (Courtesy: L&L Special Furnace Co. Inc.)

The standard model GS1714 is in stock now at L&L and available for immediate delivery. L&L can fit optional features and ship even special GS1714 furnaces in as little as two weeks after receiving an order.

MORE INFO www.llfurnace.com

TPS ships Gruenberg steam-heated granulation dryer

Thermal Product Solutions, a global manufacturer of thermal-processing equipment, has shipped a Gruenberg steam-heated granulation dryer to the pharmaceutical industry.

This dryer had a maximum temperature rating of 66°C with work chamber dimensions of 80" W, with two doorways, each 36" wide openings x 96" D x 80" H. The Gruenberg dryer was constructed from a structural steel frame that supported the 304L stainless steel interior chamber liner and the 304 #4 polished stainless-steel exterior. All interconnecting struts are non-continuous, which keeps the exterior cool.

The front-loaded granulation dryer uses a full focused horizontal airflow, which maximizes heating rates and temperature uniformity of the product load. A circulation fan is in a conditioning plenum chamber on the top of the oven. The fan directs chambers with a solid baffle plate separating both chambers. The air enters the work-

The Gruenberg front-loaded granulation dryer uses a full focused horizontal airflow, which maximizes heating rates and temperature uniformity of the product load. (Courtesy: TPS)

space through a perforated duct wall area running down both outer duct walls. The air flowing down the left side of the unit enters the work chamber and flows left to right, flowing horizontally across the product. The air then exits the left work chamber via a perforated duct wall area near the center of the unit. The air flowing down the right side of the unit enters the work chamber and flows right to left, flowing horizontally across the product.

The air then exits the right work chamber via a perforated duct wall area near the center of the unit.

"Gruenberg products are designed to meet the highest standards of safety specifications. This granulation dryer was designed to accommodate four loading trucks and eighty-eight loading trays for drying of wet granulation," said Denny Mendler, Gruenberg product manager.

Features of this Gruenberg granulation dryer include:

- Steam heat.
- Fully welded 304L stainless steel interior liner.
- Two doors.
- Split construction.
- 3/4" radius corners.
- 3/16" plates floor.
- Door switches.
- Air intake HEPA filter.
- Air exhaust HEPA filter.
- 700 SCFM forced exhaust system.
- ±2°C at 63°C temperature uniformity.
- Copper tube/aluminum finned dehumidification coil.
- NEMA 12 control console.
- Watlow F4 temperature controller.
- High limit thermostat.
- Fused main power disconnect switch.
- Magnehelic gauges.

MORE INFO www.thermalproductsolutions.com

Gasbarre supplies humpback annealing furnace to sink maker

Gasbarre Thermal Processing Systems recently manufactured and commissioned a large, gas-fired, continuous humpback stainless-steel sink annealing furnace for a worldwide manufacturer and distributor of stainless-steel sinks. The system was custom designed to meet the customer's strict process requirements. The furnace measured a total length of 106 feet long with a belt width of 32 inches. The furnace came equipped with six heating zones that can heat up to 2,200 degrees Fahrenheit. The customer was looking to increase production up to 50 percent and worked with Gasbarre to come up with a belt speed of 51 inches per minute to achieve that goal. To aid in keeping the length of the furnace as short as possible, Gasbarre supplied four Hypercooler accelerated cooling units ,which also helped eliminate the effects of stainless-steel sensitization. A closed loop water cooling system was also supplied with the furnace. In addition to the above, Gasbarre installed a Honeywell HC900 HMI to control all functions of the furnace and provide a large selection of data points for analysis and trending.

Located in St. Marys, Pennsylvania, Gasbarre Thermal Processing Systems has been designing, manufacturing, and ser-

vicing a full line of industrial thermal processing equipment for more than 40 years. Gasbarre's product offerings include both batch and continuous heat processing equipment and specializes in temper, tip up, mesh belt, nitriding, box, car bottom, pit, and vacuum furnaces as well as a full line of replacement parts and auxiliary equipment that consists of atmosphere generators, washers, quench tanks, and charge cars. Gasbarre continues to service and support Sinterite brand equipment and custom designs and manufactures thermal processing equipment to meet customer's specific needs.

MORE INFO www.gasbarre.com

The extrusions business of Hydro Extruded Solutions manufactures extruded aluminum profiles and fully fabricated components for applications ranging from residential to industrial and commercial. (Courtesy: Nitrex)

Hydro Poland uses Nitreg® nitriding to improve performance

Nitrex Metal Inc. supplied a nitriding system to Hydro Extrusion Solutions in Trzcianka, Poland, to address the customer's need for improved process performance and more accurate control of nitriding results.

The Nitrex N-EXT 812 nitriding system replaces a decommissioned nitrider that was phased out several years ago due to extrusion die failures and inconsistent metallurgical results. The delivered solution includes Nitreg® technology that helps to optimize parameters for maximum efficiency and quality, increasing die strength and extrusion throughput, while reducing the possibility of potential die failures. Moreover, Nitreg contributes to cost savings from reduced consumption of process gases and energy savings from shorter process times. The N-EXT type furnace has overall chamber dimensions of 31.5" diameter by 47.25" high (800 x 1200 mm) with a capacity to nitride a 2,200-pound (1,000-kilogram) load.

Since the start of operations with the new nitriding installation, treated samples are periodically assessed by an external QA service to validate the nitride quality, specification compliance, and reliability of the Nitreg process. As part of this testing program, Nitreg results are consistently in compliance with Hydro's quality standard.

The extrusions business of Hydro Extruded Solutions manufactures extruded aluminum profiles and fully fabricated components for applications ranging from residential to industrial and commercial. Since 1999, Nitrex Metal has been building a lifelong customer relationship with Hydro Extruded Solutions. Today, the company operates fourteen Nitrex nitriding systems in eleven countries including Argentina, Austria, Brazil, China, France, Germany, Italy, Poland, Romania, U.K., and the U.S.

For more than 35 years, Nitrex Metal has been a world-class partner offering modern nitriding/nitrocarburizing technologies, solutions, equipment and services. Nitreg potential-controlled gas nitriding and Nitreg-C potential-controlled gas nitrocarburizing (ferritic nitrocarburizing-FNC) technologies are applied in the precision parts, automotive, aluminum extrusion, defense, gears, tool & die, plastics, machinery, and many other industries.

MORE INFO www.nitrex.com

Richard Geiss GmbH puts focus on solvent monitoring and care

No fewer than three new products will be presented by Richard Geiss GmbH, Offingen (Bavaria), at the parts2clean 2019 trade fair October 22-24 in Stuttgart: the newly developed Cleanstab S stabiliser, the GEISS Digital Indexer and the RG PROTECT 160 corrosion protection concentrate. In addition to its latest innovations, the solvent specialist will also be showcasing established products for solvent monitoring and care as well as its high-purity solvents and contract degreasing services at the leading international trade fair for parts and surface cleaning (hall 7, stand C52).

"I'm absolutely delighted that we will be presenting as many as three new products at this year's parts2clean", said Bastian Geiss, CEO of Richard Geiss GmbH. "Industrial parts and surface cleaning face many challenges as almost all sectors require ever-higher levels of cleanliness for components. To meet this demand, we offer not only high-end solvents, but also full-package solutions for a safe and stable cleaning process."

The absolute highlight of the trade fair is the newly developed Cleanstab S stabilizer for modified alcohols. With this product, Richard Geiss GmbH offers a sump stabilizer that stops acid formation in the cleaning system and reduces any acid that has already formed. This prevents acidification or even self-decomposition of the solvent

used and significantly increases the durability of modified alcohols. The Cleanstab S thereby prevents corrosive damage and surface oxidation. The requirements are analysed and determined individually for every system and every customer in the Geiss laboratory at the company's headquarters in Offingen.

Another new product featured at the parts2clean is the RG PROTECT 160 corrosion protection concentrate, which can be used in perchloroethylene, hydrocarbon solvents, and in modified alcohols.

"We have developed the RG PROTECT 160 specifically for companies in industrial parts and surface cleaning that need to conserve very large numbers of parts and require extended corrosion protection," said Dieter Ortner, sales manager surface cleaning at Richard Geiss GmbH. "RG PROTECT 160 has an even higher concentration than our established RG PROTECT 180, enabling companies to save not only corrosion protection concentrate, but ultimately also money."

The solvents are recovered in Richard Geiss GmbH's distillation systems, with distillates achieving 100% of the original product's quality. (Courtesy: Richard Geiss GmbH)

The third new product, the GEISS Digital Indexer for modified alcohols and hydrocarbons, rounds off the corrosion protection package. It determines the concentration of corrosion protection oils in the solvent bath, allowing companies to efficiently monitor whether their parts are sufficiently conserved for later storage.

"The GEISS Digital Indexer is basically the counterpart to our GEISS PER Density Test for perchloroethylene, which was already unveiled in 2017 at the parts2clean and received an excellent response," said CEO Bastian Geiss.

Besides the new and established products for solvent monitoring and care, Richard Geiss GmbH's high-purity distillates will, of course, also be showcased in Stuttgart. The globally operating recycling company specializes in the processing of solvents and their return into a functioning circulation system. The distillates achieve 100 percent of the original product's quality while saving up to 90 percent in carbon emissions.

Contract degreasing, first introduced as a major feature at parts2clean 2017, is another key topic. Given the growing demand for professional contract degreasing, the solvent specialist has since launched an additional parts cleaning system, consistently expand-

ing its range of high-end degreasing services. At the company's headquarters in Offingen, Richard Geiss GmbH offers reliable contract degreasing for small parts and components up to 1,200 mm x 800 mm x 970 mm.

Richard Geiss GmbH, headquartered in Offingen in the Günzburg district, is one of Europe's leading specialists for recovered solvents. The company supplies solvents for industrial surface cleaning and textile cleaning as well as for the chemical and pharmaceutical industry.

MORE INFO www.geiss-gmbh.de

The aerospace equipment manufacturer expects to improve quality and reduce lead times for critical components used in aircraft, defense, and space applications. (Courtesy: Seco/Vacuum Technologies)

Aerospace supplier orders Seco/Vacuum furnace

Seco/Vacuum Technologies (SVT), a Seco/Warwick Group division, with its headquarters in Meadville, Pennsylvania, is working with a prominent aerospace equipment manufacturer to bring its low-pressure carburizing and hardening work in-house. SVT will be supplying its signature CaseMaster Evolution® (CMe) dual-chamber vacuum oil quench furnace to improve lead times and quality objectives.

"We developed the CaseMaster Evolution to help customers in aerospace and other critical industries solve some of the more challenging issues with traditional integral quench furnaces, as well as to produce clean parts typical of vacuum furnaces," said Maciej Korecki, VP, Vacuum Heat Treatment Furnaces, Seco/Warwick. "So, the CMe is a hybrid combining the best of both worlds, resulting in clean parts from a non-toxic work environment, providing greater repeatability of workloads, with no CO/CO_2 emissions, exhaust hoods, or endothermic generators."

The CaseMaster Evolution vacuum oil quench furnace is positioned to improve efficiency in many heat-treatment operations by providing multi-chamber capabilities, including a sealed oil and gas quench chamber, that open new processing opportunities for heat-treaters. The CMe uses one chamber for vacuum heat treatment and a second chamber for oil or gas quenching. In contrast to the company's current procedure — brining in vacuum LPC and hardening — the CMe's vacuum LPC heating and quench

chambers produce uniform, bright, and high-quality parts all while using very low consumption of processing media at high speeds for an economical workflow.

CMe oil quench vacuum heat-treating furnaces have been installed in dozens of locations around the world for many years. Top global manufacturing companies requiring superior mechanical properties choose the CMe over conventional case hardening methods to improve production quality and capabilities, increase carburizing throughput, and reduce environmental impact.

MORE INFO www.secovac.usa

Wisconsin Oven ships Ferris wheel batch oven

Wisconsin Oven Corporation has made an international shipment of an electrically heated heavy-duty Ferris wheel batch oven to the aerospace industry. This Ferris wheel oven will be used to cure epoxy resins and varnishes on assorted aerospace parts.

The maximum operating temperature is 500°F and the work chamber dimensions are 3'4" W x 3'6" L X 3'6" H. Temperature uniformity was documented at ±2°F at 100°F; ±4°F at 200°F; ±6°F at 300°F; ±8°F at 400°F; ±10°F at 500°F in an empty oven chamber under static operating conditions with a 10-point profile test.

The design capacity of the Ferris wheel batch oven, when the configuration of the workload is such that it is capable of absorbing the heat, has sufficient capability to heat 200 pounds of product to the customer's specified temperature range within two hours. The body of the oven is constructed with Wisconsin Oven Corporation's patented, high-efficiency panel seams. This includes a 20-gauge carbon steel exterior and a 20-gauge aluminized steel interior.

"This Ferris wheel batch oven is similar to

The Ferris wheel batch oven will be used to cure epoxy resins and varnishes on assorted aerospace parts. (Courtesy: Wisconsin Oven Corporation)

previous batch oven supplied to this customer with a few modifications. The Ferris wheel inside the oven chamber will run continuously to process the product load. It is 34" in diameter and contains 20 rotating spindles for part rotation," said Tom Trueman, senior applications engineer.

Features of this Ferris wheel batch oven include:

› Low conductivity tongue and groove panel assemblies on the oven shell.

› Door limit switch to prevent the main Ferris wheel from rotating when a door is open.

› Heated by Incoloy-sheathed tubular heating elements for a total of 72 kW.

› 3,400 CFM belt-driven recirculation blower, complete with 3 HP motor.

› Designed for 0.63 gallons per batch of solvent at 500°F.

› 900 CFM exhaust blower at 2.25" SP, including a 1.5 HP motor and V-belt drive.

MORE INFO www.wisoven.com

Gasbarre supplies box furnace system to aerospace company

Gasbarre Thermal Processing Systems recently manufactured and commissioned a high temperature box furnace line for an aerospace company in the midwestern United States. The system is custom designed to meet the customer's strict process requirements, manufacturing methods, and eliminates the need for a quench pit.

The equipment will process 36" wide by 48" long by 24" high workloads, weighing up to 2,000 pounds, and will be used for solution treating of high-alloy forgings. The single zone electrically heated furnace is designed with multiple trim zones to meet AMS 2750 temperature uniformity requirements across a wide temperature range and allows for fast furnace recovery times. The system is equipped with both a water quench tank and air-cooling station which provides process flexibility in a single system. Material handling is done through a pick and place manipulator to improve fixture life. The manipulator's fully automated cycles enable the system to consistently meet strict time to quench requirements.

Located in Plymouth, Michigan, Gasbarre Thermal Processing Systems has been designing, manufacturing, and servicing a full line of industrial thermal processing equipment for more than 40 years. Gasbarre's product offering includes both batch and continuous heat processing equipment and specializes in temper, tip up, mesh belt, nitriding, box, car bottom, pit, and vacuum furnaces.

Gasbarre continues to service and support J. L. Becker brand equipment and custom designs and manufactures thermal processing equipment to meet customer's specific needs.

MORE INFO www.gasbarre.com

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

Infrared technology is hot!

Scott Bishop makes the session interactive with an IR wavelength demonstration.

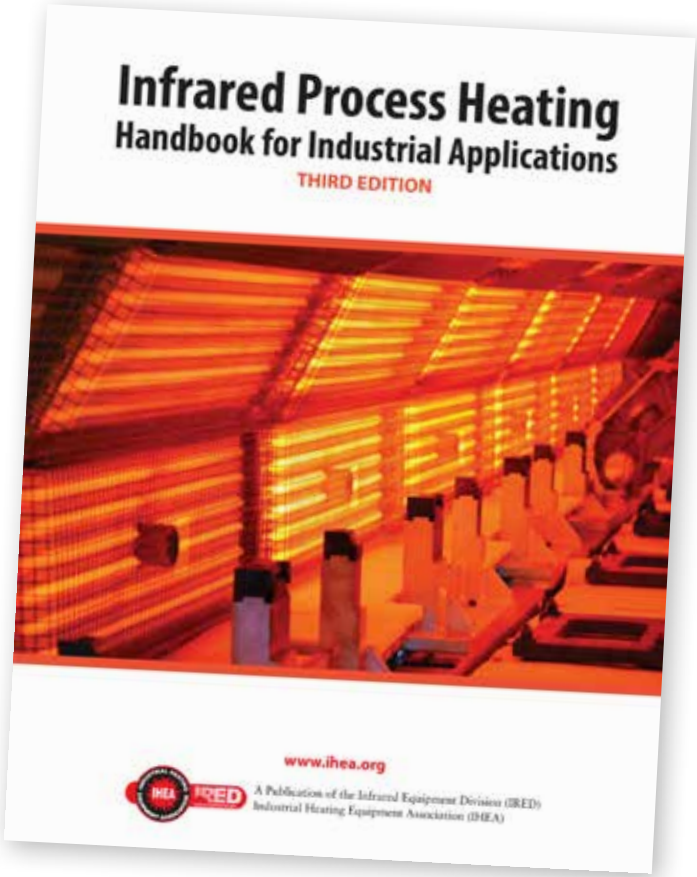
The Industrial Heating Equipment Association's Infrared Equipment Division (IRED) recently completed revisions to its popular *Infrared Process Heating Handbook for Industrial Applications.* This fundamental introduction to the many applications of infrared heating in industrial processes has been updated to include new technical information, additional application examples, and new case studies. Learn how infrared heating has been successfully applied to hundreds of different process-heating applications, such as curing metal finishes and protective coatings; fusing thermoset and thermoplastic powder coatings; forming molded plastics; bonding adhesives and metals; drying papers, inks, and fabrics; and processing foods.

"After eight years from the publication of the second edition of the *Infrared Process Heating Handbook,* the IRED decided it was time to review and update the publication," said IRED Chairman Scott Bishop.

In this edition there are three major updates:

› Fresh, new case studies and infrared process-heating examples

John Podach of Fostoria Process Equipment explaining infrared technology at their FABTECH booth.



IHEA's newly revised third edition of the *Infrared Process Heating Handbook for Industrial Applications* is available now.

categorized by industrial segments.

› A revamped section on controls and how they can be implemented using infrared process heaters.

› Better quality pictures and charts/graphs to enhance the reader's knowledge.

"I would personally like to thank all the contributors for their hard work and diligent efforts that went into creating this new edition of the handbook," Bishop said.

IHEA IRED MANUAL CONTRIBUTING MEMBERS

› Alabama Power
› Electric Power Research Institute (EPRI)
› Fostoria Process Equipment – a division of TPI Corp.
› Gefran Inc.
› Georgia Power
› Heraeus Noblelight America LLC
› Selas Heat Technology Co. LLC

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IHEA'S IRED AT FABTECH 2019

ABCs of Infrared (C20)

Monday, November 11, 2019
10-11:30 a.m.
McCormick Place – Chicago, Illinois
www.fabtechexpo.com

IHEA's Infrared Division (IRED) presents this session at FABTECH each year. It reviews the basics of infrared (IR), including what it is, how it is produced, and its characteristics. It will include all equipment sources of infrared followed by a discussion of the wide variety of IR applications, which showcase the many ways in which IR can be used in today's industrial environment. Attendees will also learn several ways to troubleshoot with infrared technology.

Presenters for this session include: Scott Bishop, Alabama Power Co.; Tim O'Neal, Selas Heat Technology Co. LLC; John Podach, Fostoria Process Equipment; and Lee McWhorter, Heraeus Noblelight America LLC.

For more information on the education program at FABTECH, go to www.fabtechexpo.com/education.

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OCTOBER 7–NOVEMBER 17

Fundamentals of Process Heating On-Line Course

This course provides an overview of the fundamentals of heat transfer, fuels and combustion, energy use, furnace design, refractories, automatic control, and atmospheres as applied to industrial process heating. Students will gain a basic understanding of heat transfer principles, fuels and combustion equipment, electric heating and instrumentation and control for efficient operation of furnaces and ovens in process heating.

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TRIRATNA SHRESTHA
MANAGER OF METALLOGRAPHIC LABORATORY AND CENTRAL COATINGS LABORATORY /// METCUT RESEARCH INC.

Enhancing the strength of jet engines by heat treating dual phase alloys.

Microstructural evolution, its effect on Ti6Al4V alloy

Titanium alloys are extensively used in aerospace, petrochemical, marine, and medical applications, thanks to their superior strength-to-weight ratio at elevated temperature, corrosion resistance, and biocompatibility. Its melting point is close to 1,700°C, density about 4.5 g/cc, and tensile strength above 1,500 MPa for some commercial grades. The alloy undergoes allotropic transformation at about 890°C from hexagonal closed packed (hcp) structure (α phase) to stable body centered cubic (bcc) structure (β phase). The hcp structure has three slip planes: pyramidal, prismatic, and basal with c/a ratio of 1.587. Titanium alloys come in α, near α, α + β, and β microstructures.

Typically, single phase pure titanium alloys are used for corrosion application, while engineered, dual phase α + β alloys such as Ti6Al4V-type are used for aerospace application, e.g. fan blades in jet engine. Titanium forms a passive, protective oxide (TiO2) layer that provides excellent corrosion protection in an oxidizing environment. Dual phase alloys have moderate high temperature strength below 400°C and good fabricability; however, it has lower weldability with high β phase. Constituent elements control the phase content of Ti alloys by stabilizing the α phase or β phase. Some common alpha stabilizers in this type of alloy are aluminum, oxygen, nitrogen, and gallium, while beta stabilizers are molybdenum, vanadium, tantalum, and tungsten. In Ti6Al4V alloy, aluminum acts as an α stabilizer by increasing the α - β transformation temperature and vanadium acts as a β stabilizer.

Dual phase α + β alloys can be heat treated to obtain varying microstructure and properties. Phase diagram of the alloy is shown in Figure 1. The presence of α + β is shown in the gray area. Heat treating above β transus temperatures creates bcc microstructure with large grains, while heat treating at α + β regime creates a variety of microstructure as alpha phase suppresses the formation of β phase. In dual phase regime, volume fraction of alpha phase decreases as

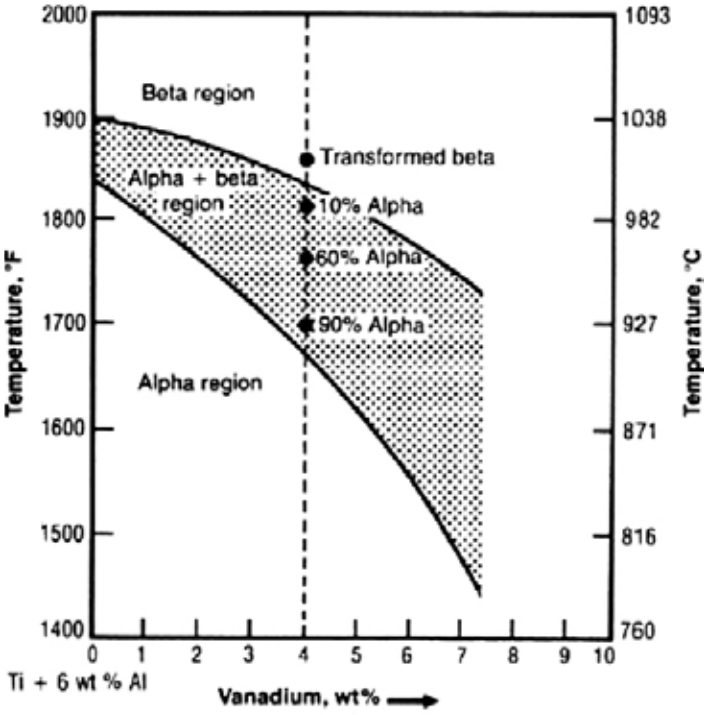

Figure 1: Ti6Al4V phase diagram. [1]

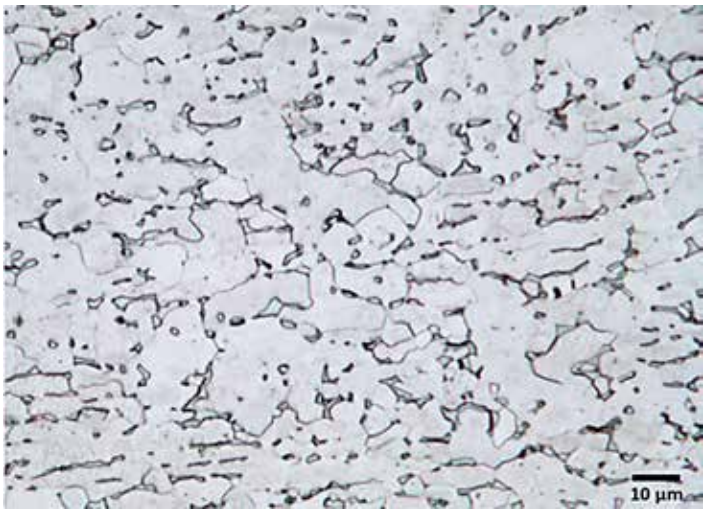

Figure 2: Alpha grain structure.

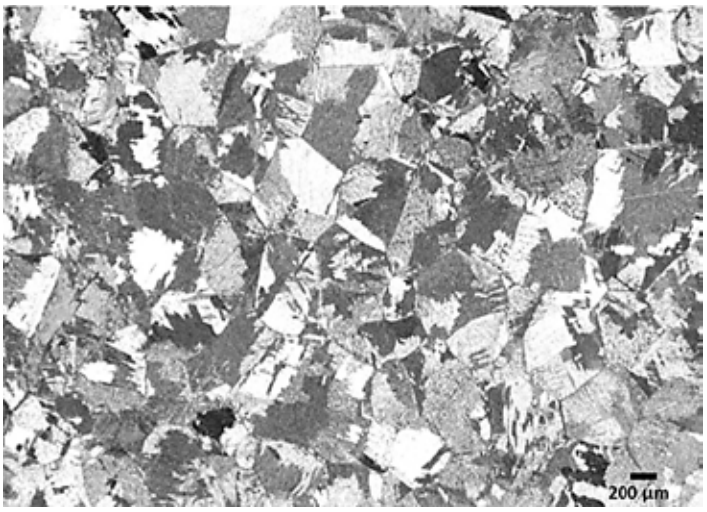

Figure 3: Dual phase alpha/beta structure.

heat treatment temperature approaches α - β transus. The alloy primarily consists of α phase when treated below 920°C. During an in-situ continuous heating up to 950°C, the alloy had a bi-modal microstructure with alpha phase surrounded by acicular, transformed beta structure as indicated in the phase diagram [2]. Extent of phase distribution depends on the current heat-treatment profile, starting with microstructure and cooling rate. Rapid cooling from phase regime creates a metastable, diffusion-free martensitic alpha prime microstructure. Subsequent heat treatment can be performed to obtain desirable microstructure. However, the heat-treater needs to be careful not to form brittle omega phase.

Figure 2 shows α grain structure in annealed cold-worked alloys as a result of slower cooling rate. Figure 3 shows α + β microstructure with fine, acicular alpha in beta grain boundaries. This microstructure is reflective of faster cooling rate with limited diffusion and nucleation of hcp structure along a preferred crystallographic plane in retained bcc structure. With a single forged part, there can be microstructural gradient and differential cooling rate. This poses a significant challenge in strength of a part. An equiaxed α structure has good ductility and is resistant to high cycle fatigue as it can resist crack initiation. While fine, the acicular β phase has better resistance to low cycle fatigue as it can resist crack propagation.

The ability of microstructure, such as the one in Figure 2, in resisting crack propagation is also preferred for enhanced creep properties. However, in a strain controlled low cycle fatigue, time to crack initiation was best for a microstructure containing 90 percent transformed beta and the rest alpha [3]. It must be noted that crack initiation is dependent on many other factors than microstructure, such as texture, presence of interstitial elements, and strength. With the presence of Widmansatten, the alpha colony structure lowers high cycle fatigue strength.

Along with microstructure, texture affects the fatigue properties of Ti6Al4V. With higher Poisson's ratio in longitudinal and short transverse direction being higher compared to long transverse orientation, fatigue properties are lower in long transverse orientation [4]. With multiple slip planes, twinning modes, allotropic transformation and various phase structure, these alloys have mechanical property anisotropy. Certain texture is beneficial in sheet metal forming, while others can be disadvantageous in machining.

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DR. NEIL CANTER
OWNER, CHIEF CONSULTANT /// CHEMICAL SOLUTIONS

This nickel-based superalloy also contains aluminum, cobalt, tantalum, ruthenium, and rhenium.

Developing a superalloy with superior heat resistance

Demand for superior machinery that can operate effectively under extreme conditions is driving the development of newer alloys. One significant example is the preparation of superalloys that exhibit excellent mechanical strength and creep resistance at high temperatures. Superalloys also display other characteristics, including good surface stability, oxidation, and corrosion resistance.

A previous *Tribology & Lubrication Technology (TLT)* article highlighted ongoing research in another new type of metal alloy known as a high-entropy alloy [1]. This alloy contains equal percentages of at least five metals. In the work cited, researchers produced a hexagonal close-packed alloy from a face-centered one using high pressure.

One commonly evaluated type of superalloy is based on nickel. Dr. Subhashish Meher, material scientist at Idaho National Laboratory in Idaho Falls, Idaho, says, "We found that exposure of nickel superalloys to high temperatures over an extended timeframe led to a deterioration in high-temperature performance. These superalloys typically have a microstructure that contains an ordered gamma-prime precipitate in a continuous, gamma matrix. At high temperatures, the alloy will coarsen, which means the small gamma-prime particles will increase in size leading to a deterioration of thermal stability."

Meher indicated that coarsening will lead gamma-prime particles to increase in size from 100 nanometers to one micron. The coarsening process is caused by diffusion of elements from the smaller precipitates into larger particles.

Prior research has shown that one approach for delaying coarsening is to produce a superalloy that exhibits hierarchical microstructure. Meher says, "An alloy containing hierarchical microstructures has the same structure in different sizes. In other words, a structure with repeat characteristics such as a box within a box that is within another box."

A new approach has now been reported for developing a hierarchical microstructure in a superalloy.

HIGH-TEMPERATURE ANNEALING

Meher and his colleagues prepared a nickel-based superalloy that also contained aluminum, cobalt, tantalum, ruthenium, and rhenium and determined through high-temperature annealing the presence of a hierarchical microstructure that improves the thermal stability of the alloy. He says, "We selected this alloy known as F-11 because it has potential to be used in aerospace, solar-, and nuclear-power applications."

F-11 was prepared from scratch with the six elements mixed together in the molten state in a furnace. The researchers then homogenized the alloy at 1,285°C for 12 hours followed by air cooling at an average rate of 57°C per minute to 500°C. Further study of the alloy was then made by annealing at specific temperatures.

The alloy, F-11, has the potential to be used in aerospace, solar-, and nuclear-power applications. (Courtesy: © Can Stock Photo/aapsky)

Meher says, "In the solidification process, the initial crystalline state of the alloy formed is known as the dendritic region. The last part of the alloy to solidify is known as the interdendritic region which is also crystalline."

To better understand how coarsening can be delayed and to determine if a hierarchical microstructure can be formed, the researchers initiated annealing of F-11 at 800°C for 1,500 hours. Meher says, "We began our work at 800°C due to modeling studies that showed the potential for a hierarchical microstructure at that temperature."

After 25 hours, transmission electron microscopy detected the presence of nanoscale gamma precipitates within the gamma prime precipitate. The nanoscale gamma precipitate has a radius between five and 10 nanometers and is similar in structure to the gamma matrix. The researchers found the hierarchical nanostructure in the dendritic region of the alloy.

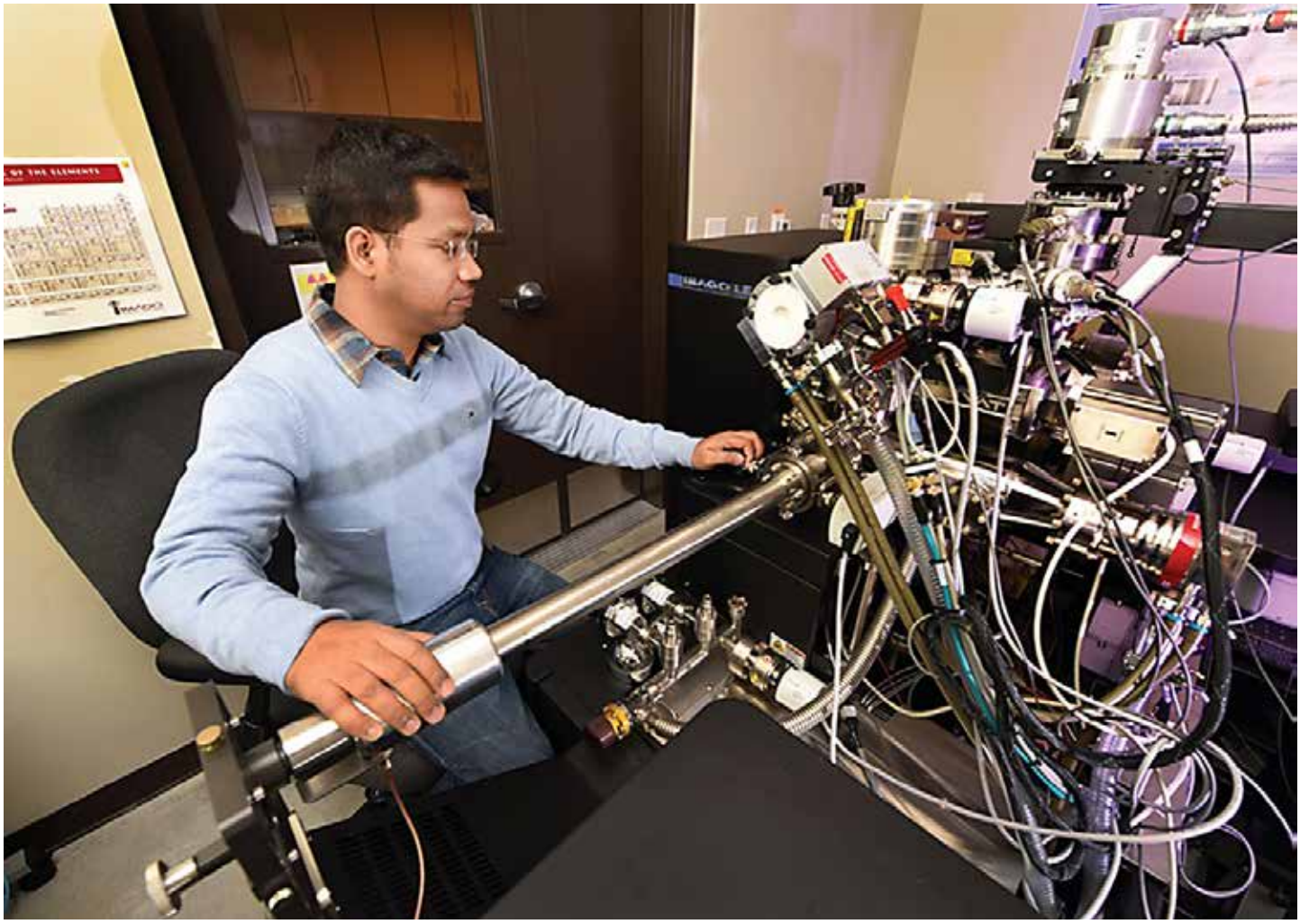

Figure 1: A local electrode atom probe was used to study the hierarchical microstructure formed when the superalloy F-11 was heated at elevated temperatures. (Courtesy: Idaho National Laboratory.)

Structural analysis was conducted by a local electrode atom probe (Figure 1) using a technique known as atom probe tomography (APT). Meher says, "The value of this technique is that we are able to develop three-dimensional images of sections of the alloy enabling us to determine if the microstructure formed during annealing is hierarchical."

When F-11 was subjected to annealing at a higher temperature of 1,000°C, the researchers did not detect the formation of a hierarchical microstructure. Meher says, "We believe that the rhenium present in F-11 caused the diffusion within the alloy to slow down, reducing the rate of coarsening and enabling the structure to exhibit enhanced thermal stability."

An estimate of the thermal stability was carried out by the researchers using phase-field modeling. Simulation studies indicate that F-11 can exhibit significantly more heat resistance up to 20,000 hours compared to the 3,000 hours now obtained empirically prior to heat-induced failure.

Meher said that further modeling studies will be done with F-11 to better understand how the hierarchical microstructure is formed and remains stable. He says, "We also will introduce other elements such as platinum to see how this impacts the thermal stability of the alloy. Simplified binary alloys such as nickel, aluminum, and tertiary alloys such as nickel, aluminum, and titanium also will be studied to gain a better understanding of the hierarchical microstructure.

Additional information can be obtained from a recent article [2] or by contacting Meher at subhashish.meher@inl.gov.

KEY CONCEPTS

› The performance of nickel superalloys at high temperatures deteriorates due to coarsening caused by the increase in size of gamma-prime particles.

› A newly developed superalloy known as F-11 shows superior heat resistance after extended heating at 800°C due to the formation of a hierarchical microstructure.

› Phase-field modeling studies indicate that F-11 can exhibit significantly more heat resistance up to 20,000 hours compared to the 3,000 hours now obtained empirically.

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JASON SCHULZE
METALLURGICAL ENGINEER /// CONRAD KACSIK

Know your quality requirements, make sure the seller knows them, and remember it's your responsibility to verify the furnace meets all applicable requirements.

Purchasing a furnace: Quality concerns to consider

For any heat-treater, whether captive or commercial, purchasing a furnace is the largest investment that can be made. It is important to establish a process that accounts for the quality requirements throughout the purchasing process. Too often the purchaser may not understand or account for specific requirements causing the process to be either delayed or more expensive or both. In this article, I will point out specific quality requirements that should be accounted for when purchasing a furnace.

PURPOSE

Each organization has a different purpose for purchasing a new or used furnace. It may be due to process expansion, where a processor has decided to bring heat-treating in-house rather than outsource it. It also may be due to an old furnace needing to be replaced. No matter the purpose of acquiring a new or used furnace, the quality tasks associated with the purchase will be the same.

PROCESS

The next step is to determine the use of the furnace. Will it be used for nitriding, through-hardening, carburizing, etc.? The answer to this question will direct the purchase to a specific design of a furnace, and at times, a specific manufacturer. As an example, if a processor is carburizing, using an integral quench furnace with an endothermic generator or similar will be in order. On the other hand, if a processor intends to solution and age semi-finished/finished INCO 718 parts, a vacuum furnace with a control system that allows controlled cooling will be needed. This may be challenging for captive heat-treaters as, at times, captive heat-treaters may not have the expertise on staff to determine the furnace needed based on process. In this case, it is recommended a metallurgical consultant and/or a furnace manufacturer be contacted to help with the selection of the appropriate furnace for the process.

NEW OR USED?

The decision to purchase a new or used furnace is typically based on two factors: capital and frequency of use. The amount of capital available at the time of purchase has a significant influence on this decision. Large companies with a significant cash flow or small businesses that choose to funnel the profit back into the company will have more options regarding a new or used furnace. If a used furnace is being considered, it is important to understand what repairs and/or upgrades will be needed to ensure process conformance. Examples of repairs include insulation or mechanical repairs as well as control system repairs if the as-purchased control system is outdated and will not meet the quality requirements of the process. These repairs and/or upgrades, at times, may be so high they equate to the cost of a new furnace or comes close enough to invest more for a new furnace.

QUALITY REQUIREMENTS

Regardless of a new or used furnace, the quality requirements as they apply to the heat-treat process will remain the same. Establishing the quality requirements is one of the most important steps in the process. Assuming the mechanical aspects of the furnace are in working order, typically the first requirement to establish is the temperature uniformity characteristics. These characteristics are flowed down from the customer to the heat-treater via PO/print/specification. This can be identified by statements such as "heat treat at 1,600°F ±15°F." According to AMS2750, ±15°F would then identify a Class 3 furnace, as shown in Figure 1.

This may seem simple, although there are some instances where a customer may not flow down the temperature tolerance, making it difficult to designate a furnace class. In this case, if the heat-treater is Nadcap accredited, the customer/subscriber would need to be contacted to establish the temperature tolerance (see Nadcap Pyrometry Reference Guide 1.5.2017 question #21). Each part that will be heat-treated, or is heat-treated, should be examined to establish the necessary furnace class. Let's look at an example.

Furnace Class	Temperature Uniformity Range (Degrees F) (1)	Temperature Uniformity Range (Degrees C) (1)
1	±5	±3
2	±10	±6
3	±15	±8
4	±20	±10
5	±25	±14
6	±50	±28

(1) Uniformity range requirement is established by the specification for the material being processed.

Figure 1

Based on the example in Figure 2, if all of the part numbers will be or are currently processed in a single furnace at a captive heat-treater, the simplest action would be to require a Class 2 (±10°F) for the entire qualified operating range of the furnace. Of course, in some instances, the furnace may not be capable of this tight of a tolerance at all temperatures, so multiple qualified operating ranges may be needed. For the sake of this example, let us consider a single qualified operating range designated a Class 2 (±10°F).

The next quality requirement to consider is the intended qualified operating range. Based on our example in Figure 2, this would be 1,400°F to 2,050°F.

Other quality requirements may be vacuum level (whether partial pressure or hard-vac), atmosphere gas such as argon or nitrogen,

Part Number	Customer	Heat Treatment	Temperature	Required Class
1548G402P62	GEAE	Solution	2050°F	CL-5 (±25°F)
30794785	Honeywell	Age	1400°F	CL-2 (±10°F)
78963F209L	Boeing	Age	1600°F	CL-3 (±15°F)

Figure 2

other atmosphere considerations (dissociated ammonia, endothermic, etc.) as well as cooling conditions such as oil quench, water quench, or gas fan cool-type quenching.

QUALITY REQUIREMENT FLOW DOWN

The next step is to flow down these requirements to the furnace/oven manufacturer or seller. This can be challenging depending on the type of seller. Sellers who manufacture and/or refurbish furnaces typically have a very good idea what their furnaces are capable of and can commit to the quality requirements flowed down to them. If the seller is a distributer who purchases and then sells furnaces directly, they may have limited knowledge of the furnace capability and may not be able to guarantee the quality requirements can be met.

Using the example in Figure 2, we could state that the intention is to purchase a vacuum furnace that can achieve <1-micron vacuum level (no partial pressure) during production. It must be capable of operating from 1,400°F to 2,050°F at ±10°F (CL-2). If a heat-treater was to purchase a vacuum furnace, it would be prudent for the purchaser to request the seller perform a temperature uniformity survey in the soon-to-be qualified work zone to ensure the furnace can meet the CL-2 requirements. This is important when purchasing any furnace — request the manufacturer/seller perform a temperature uniformity survey prior to shipment. Keep in mind that the TUS performed at the manufacturer/seller is not enough to qualify as an initial TUS per AMS2750. The heat-treater is responsible for performing the initial TUS, SAT, and instrument calibrations prior to running production hardware in the furnace.

SUMMARY

Purchasing a furnace/oven can be a long process. This process can be made easier when the quality requirements are established ahead of time and clearly flowed down to the furnace/oven manufacturer/seller. In the end, it will be the responsibility of the heat-treater to ensure the furnace meets all quality requirements that apply.

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OPERATIONAL EFFICIENCIES AND MINIMIZING ENERGY CONSUMPTION

AN INTRODUCTION

An open die forge heat furnace. (Courtesy: Super Systems Inc.)

Energy consumption as it relates to process control is continuously improving with advancements in technology.

By DAMIAN BRATCHER

Energy conservation is the prevention of the wasteful use of energy. In today's economic and climate-change environment, regulations and competition for resources require industrial users to minimize their energy footprint.

Energy conservation can take on many different forms, the largest of which is combustion optimization. A 2-percent reduction in excess oxygen in a combustion process can reduce fuel consumption 4 percent and NOx emissions by 40 percent. Current combustion optimization technologies allow power-generation facilities to balance their boilers, center the fireball, minimize NOx, and maximize MW per ton of coal. These same technologies allow the steel industry to control scale formation during the billet/slab reheat process while minimizing energy and maintenance costs.

For example: Glass production worldwide is estimated to consume 10^{15} BTU or 1.055 x 10^{18} joules per year. From the energy used in the production of container and flat glass, emissions are estimated to be 50-60 metric tons of CO_2 per year. With the adoption of best available technologies, energy efficiency in the glass production sector could be improved by as much as 35 to 40 percent.

In large-scale manufacturing, proper plans incorporate the latest techniques in fabricating components and building finished goods to optimize resources. Heat treating in general delivers stronger, lighter, more durable products. It takes less energy to heat-treat a part than it does to produce the part again.

Currently, the metal-treating industry is challenged with delivering the highest quality parts in a competitive environment while costs are rising. Energy conservation is the most economical solution to this increase in energy costs. Many companies are experimenting with alternative processes to traditional heat treating, but a majority of heat treaters are looking at current operations and trying to find ways to optimize existing practice. Today's technology provides heat treaters with opportunities to be more efficient — with the use of sensors, process controls, and access to information.

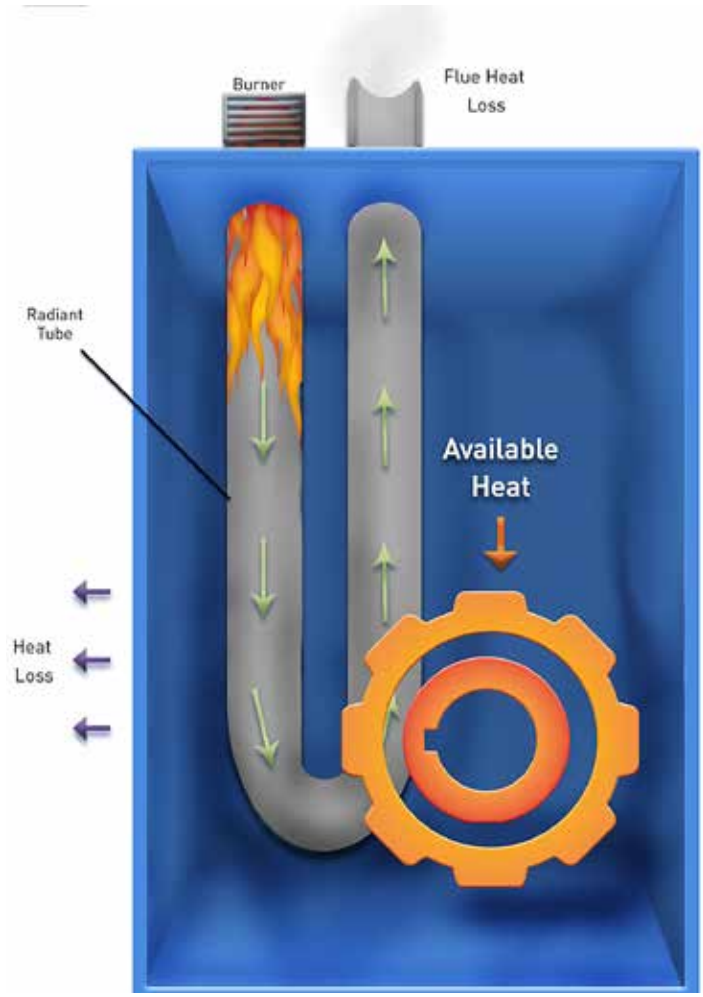

Figure 1.

COMBUSTION EFFICIENCY

Most high temperature direct-fired furnaces, radiant tubes, and boilers are designed to operate with 10 to 20 percent excess combustion air at high fire. This excess air helps prevent the formation of carbon monoxide and soot deposits, which can affect heat-transfer surfaces and radiant tubes. (See Figure 1)

For the fuels most commonly used in the U.S. (including natural gas, propane, and fuel oils), approximately one cubic foot of air is required to release 100 BTUs in complete combustion. Process-heating efficiency is reduced considerably if the air supply is significantly higher or lower than the theoretically required air.

In the September 1997 issue of *Process Heating* magazine, Richard Bennett provided calculations for an available heat chart (which was republished in May 2002 by the Department of Energy). This chart is an excellent basis to determine potential savings in a combustion process. To determine the potential savings, consider the following information:

› Exhaust gas temperature as it exits the furnace, tube, etc.

› % excess air or oxygen in the flue gas (actual).

› % excess air or oxygen in the flue gas (target).

The available heat chart is shown in Figure 2.

Using the chart, determine the percent available heat under actual and target conditions. The intersection of the measured exhaust gas temperature and % excess air (%O_2) curves provides these values. The potential fuel savings are calculated as follows:

% Fuel Saving = 100 x ((%AH Target - %AH Actual) / %AH Target)

AVAILABLE HEAT LOAD TRIALS

Forge heat furnace: A 6 mmbtu/hr open die forge reheat car-bottom furnace was equipped with an in-situ oxygen sensor. Baseline readings of excess O_2 and fuel consumption were collected over a three-month period. Based on this data, monthly fuel consumption was determined, as was the average high-temperature O_2 readings. The operation's personnel were concerned about over-trimming the excess O_2 level. Lowering O_2 levels can lead to reduced uniformity on the heated ingot. Thus, the O_2 levels were lowered incrementally to ensure

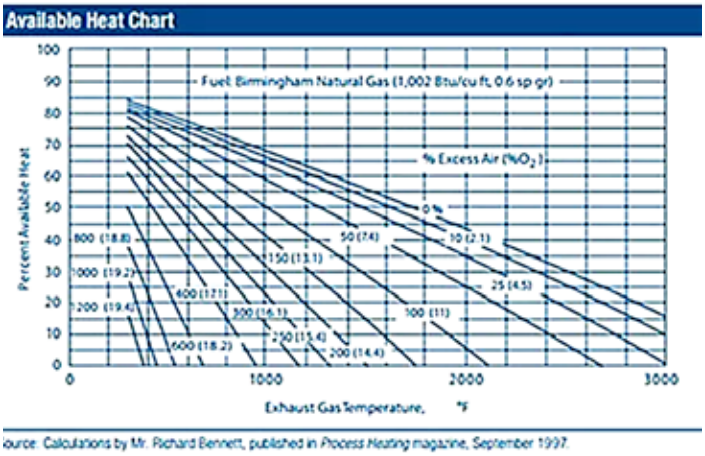

Figure 2: Available Heat Chart.

that no impact occurred to product quality.

At the end of the first incremental change and after process verification, the customer had lowered his excess O_2 and documented a 20.5-percent reduction in metered gas consumption.

The customer had a goal of reducing the excess % O_2 several percent. At his target level, he would reduce his fuel costs on his average furnace by an estimated 30 percent. (See Figure 3)

The customer's metered reduction in fuel corresponded directly to the Efficiency Improvement Calculator available from the U.S. Department of Energy. At full utilization, the savings would reach $98,550 for this furnace. For all 14 furnaces in the facility, the fuel savings have the potential to exceed $1 million.

A side benefit to the fuel savings is a documented CO_2 reduction. For each MCF CH4 burned completely, 117 pounds of CO_2 is produced. In this particular case, the customer was able to document a reduction of 175,500 pounds or 87.75 tons of CO_2. At full utilization on this one furnace with a 1-percent reduction in excess O_2, the reduction would be 630,006 pounds or 315 tons. If the customer has similar success on other furnaces and is able to achieve the O_2 target, his potential CO_2 reduction is 8,000-plus tons.

Batch furnace utilization and fuel savings: The benefits to monitoring the excess oxygen in these combustion systems is illustrated in trials run on a batch furnace. To ensure consistent results, the trials used an identical load/thermal mass with the mass and furnace at the same temperature when the test was initiated. (See Table 1)

The two significant highlights from the trials were the significant improvement in ramp rate (8.82 vs. 6.75 °/min) and a 30-percent reduction in the amount of high-fire time. The improved heating rate shortens the time required for the load to reach heat and shortens cycle time by 15 minutes per load. The 30-percent reduction in high fire time is a direct reduction in fuel costs required to maintain temperature set point. The other significant result is the utilization improvement. (See Table 2)

By optimizing come to heat time, one can maximize the utilization of the equipment. While 15 minutes may be seen as a small incremental improvement, it represents a significant increase in production for short cycle processes.

ENDOTHERMIC GENERATORS

Generated endothermic atmosphere is used in many heat-treating applications. The traditional endothermic generator produces a fixed amount of endothermic gas regardless of demand. If the demand does not match the generator's output, the excess gas is simply diverted and burned. The small and large "burn off" flames seen on many generators carry a significant financial and environmental cost. Modern generator control systems allow for the reduction or complete elimination

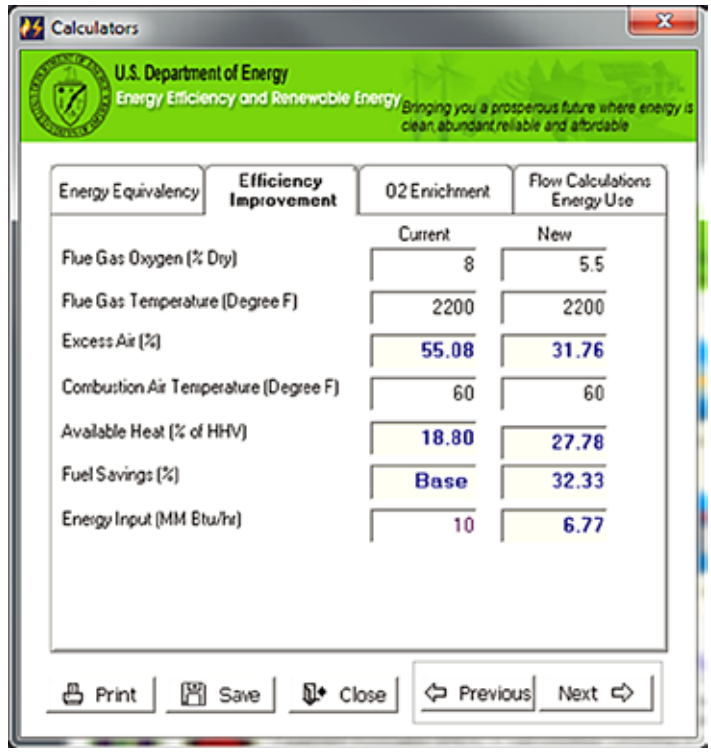

Figure 3: PHAST Efficiency Improvement Calculator.

	TEST 1	TEST 2	TEST 3
Excess % O2	5	4	2
Min Temp after loading	1137	1131	1143
Target Temp – Set Point	1580	1580	1580
Heat up rate of change, °/min	6.75	7.31	8.82
Time to Heat, 5% or 6.75 °/min	65.67	–	–
Time to heat, 4% or 7.31 °/min		61.46	
Time to heat, 2% or 8.82 °/min	–	–	49.53

Table 1: Furnace trial test results.

CYCLE TIME (IN HOURS)	3	4	5	8
UTILIZATION IMPROVEMENT	9.1%	6.7%	5.3%	3.2%

Table 2: Utilization improvement.

NATURAL GAS AT $5 A MMBTU/DECATHERM

ENDOTHERMIC GAS BURN OFF	ANNUAL COST	CARBON EMISSIONS
500 CFH	$7,220	79 Metric Tons
1000 CFH	$14,440	158 Metric Tons
1500 CFH	$21,660	237 Metric Tons

Table 3: Endothermic Generator "burn off."

of this "burn off." (See Table 3)

An incremental change to the existing control solution will have a significant impact on the bottom line. Instead of a supply focused generation system, a demand-based solution will reduce the operating cost and environmental impact of the endothermic generator by eliminating the "burn off."

PROGRAMMABLE CONTROLS

Process control in the heat-treating industry uses standard techniques

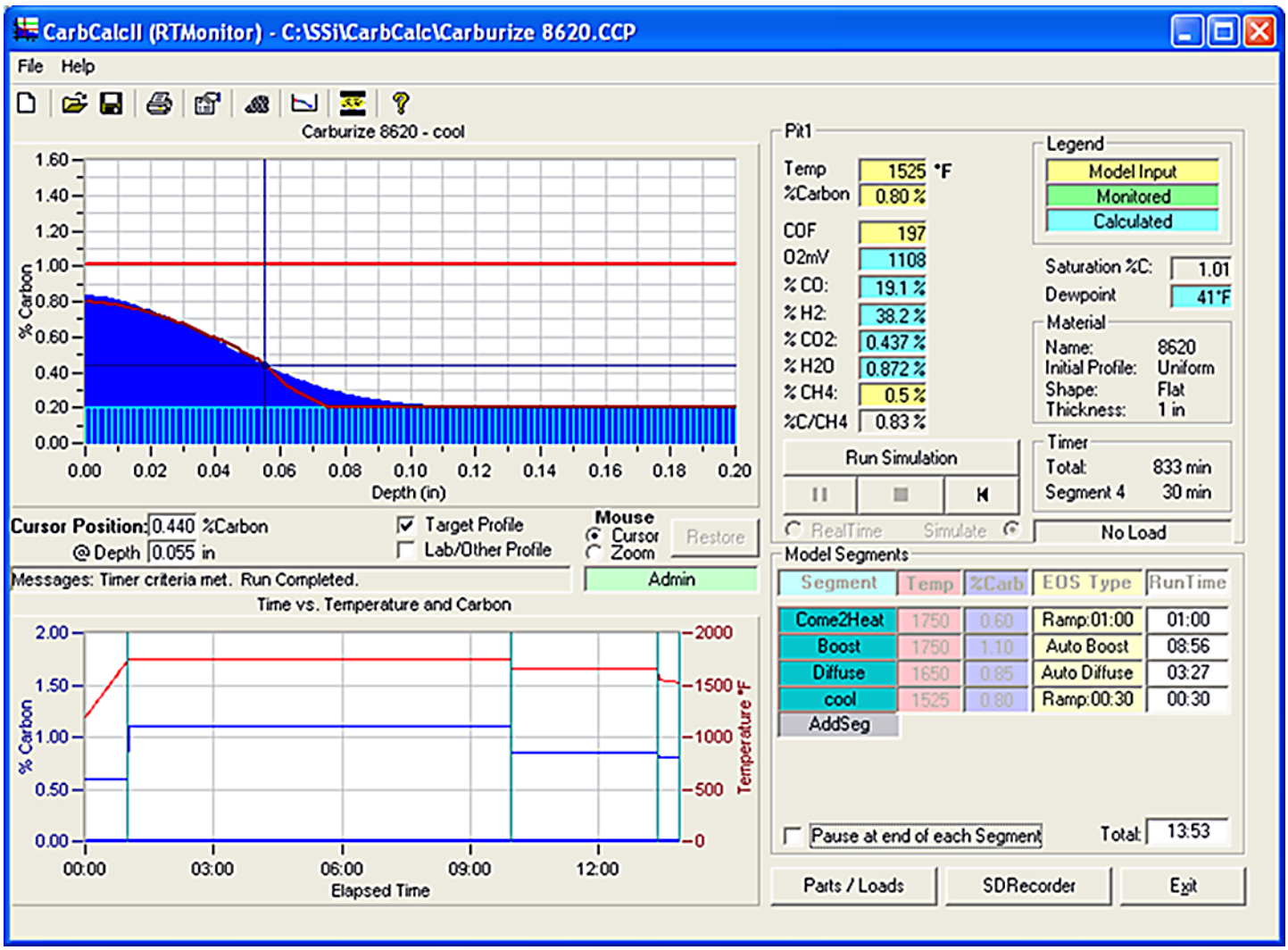

Figure 4: CARB CALC II.

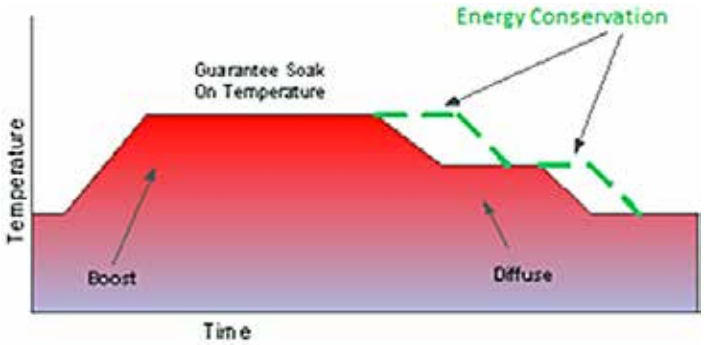

Figure 5: Energy conservation.

to run the process for a predetermined time after the furnace has reached a specified temperature, giving the parts an opportunity to achieve thermal equilibrium. Precision controls and improved processing techniques allow for quality results while enabling operations to be more energy conservative.

Software applications, such as carbon profile modeling programs, provide a predictive approach to minimizing the time in a furnace. By minimizing time, you are directly reducing the energy used in the equipment's combustion process. This reduction is accomplished by using simulation software to determine the optimal process for meeting the desired metallurgical results. By modifying temperatures and carbon potential, some cycles can be reduced by several hours. (See Figure 4)

This simulation software may be used to evaluate and control the real-time process. By taking ownership and using live values from temperature and carbon-control equipment, the software optimizes boost and diffuse segment times to achieve the desired metallurgical results. It ensures cycle times and energy use are kept to a minimum. (See Figure 5)

CONCLUSION

Energy consumption as it relates to process control is continuously improving with advancements in technology. Access to data and information, optimized controls, precise measurements and advancements in process knowledge all make contributions to the reduction of a heat treat company's energy footprint. Management and operations require an incremental payback (ROI) for control, sensor, and furnace technologies implemented on new and existing equipment. The advancement in control technology enables improved efficiency in combustions-based applications. Significant benefit also comes from operational efficiencies. These tighter process controls enable the heat-treat industry to achieve the required metallurgical results while minimizing their energy and environmental impact.

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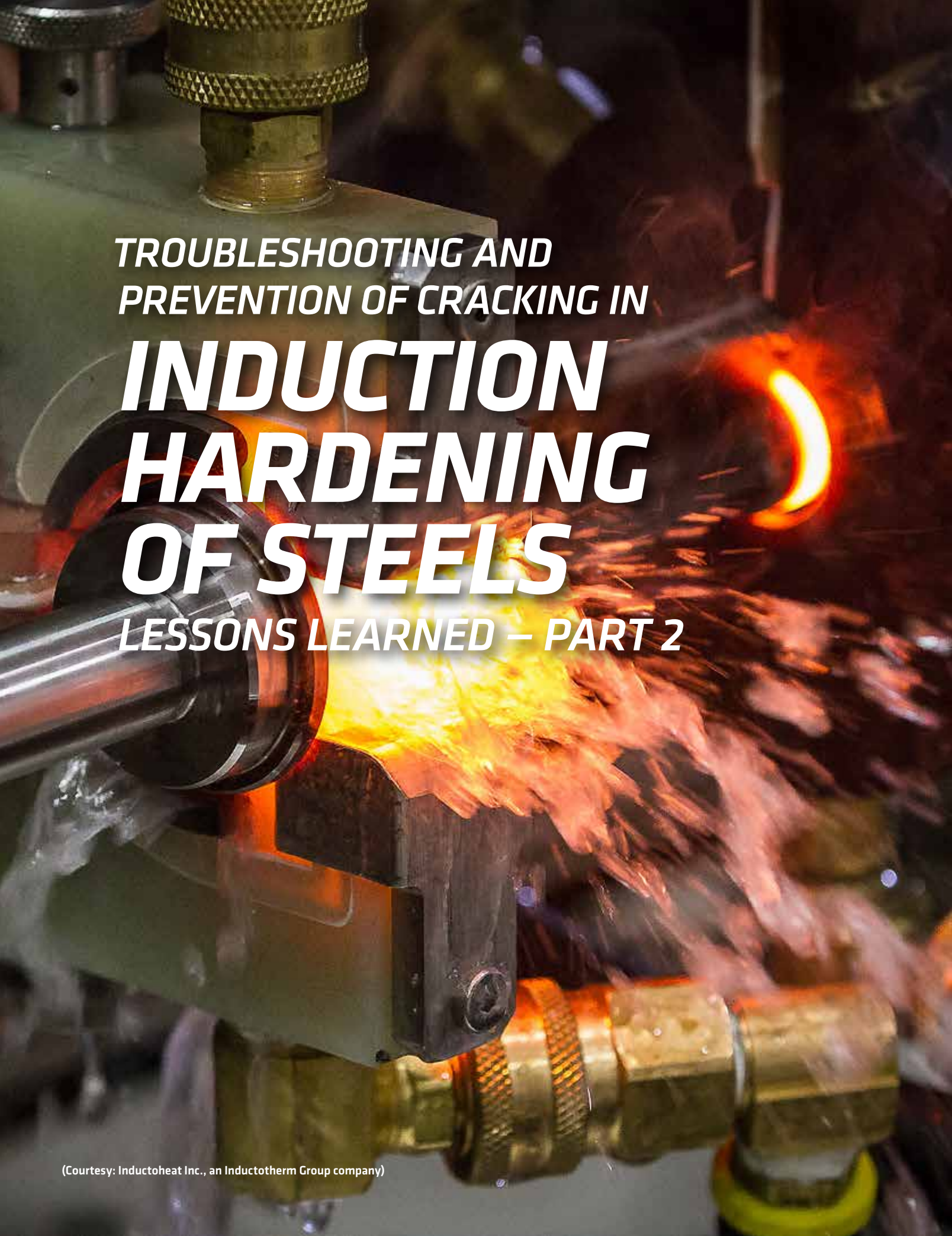

TROUBLESHOOTING AND PREVENTION OF CRACKING IN

INDUCTION HARDENING OF STEELS

LESSONS LEARNED – PART 2

(Courtesy: Inductoheat Inc., an Inductotherm Group company)

The final part of this two-part article continues a discussion on the subject of IH, providing additional troubleshooting tips and unveiling remedies to minimize a probability of cracking in industrial practice.

By GARY DOYON, DR. VALERY RUDNEV, RANDALL MINNICK, and TIM BOUSSIE

One of the most common applications of induction heat treatment is the hardening of steels, cast irons, and powder-metallurgy materials, developing an attractive blend of engineering properties [1]. In some applications, it may be desirable to obtain a certain combination of hardness, wear resistance, and contact-fatigue strength at the surface or near-the-surface areas without affecting the core microstructure (e.g., surface hardening of gears and axle shafts). Other cases might require an increase of hardness and strength of the entire cross section of the part, and induction through hardening can help to accomplish the desired industrial characteristics.

There are thousands of highly successful induction-hardening machines that produce millions of parts supplied to various industry segments. Among the components that routinely undergo induction hardening (IH) are such parts as camshafts, crankshafts, gears, sprockets, transmission shafts, ball studs, pins, toothed racks, wheel spindles, bearing races, fasteners, working tools, track shoes for earth-moving machines—the list is essentially endless. As an example, Figure 1 shows a small array of geometries that are routinely induction hardened.

Figure 1: A small array of components that are routinely induction hardened and hardness patterns.

Several aspects associated with a troubleshooting and prevention of cracking in IH of steel components has already been discussed in the first part of this article [2] published in the September issue of *Thermal Processing*. This includes the following subjects:

› Impact of a component's geometry on a part's susceptibility to cracking upon hardening.

› Steel overheating and grain boundary liquation (incipient melting).

› Factors related to inadequate equipment selection and improper process recipes.

› Initial, transient, and residual stresses and their impact on crack initiation and growth.

› Fishbone diagram of troubleshooting cracking and prevention.

› Case studies.

The second part of this two-part article continues a discussion on this subject, providing additional troubleshooting tips and unveiling remedies to minimize a probability of cracking in industrial practice.

FIRST THINGS FIRST

If cracking has suddenly occurred with equipment that has been running crack-free for some time, then the first questions to ask are "Has everything remained the same until the cracking problem appeared? What was different?" Many times, what might appear to be seemingly insignificant factors such as an installation of a new inductor, refurbished quench assembly, re-tooled fixtures, or newly-replaced quench media might give you an essential clue regarding possible cause(s) of a sudden appearance of cracking. Other questions to ask include:

› Did the workpiece, tooling, or fixture recently have an accidental contact with an inductor or quench device? Check positioning of the workpiece.

› Did your power supply recently encounter an erratic operation, faults, or were limits reached? Check the tightness of all control and power connections, capacitor hardware, transformer tapping hardware, and so on.

› Did the monitoring/control system reveal an inductor ground fault lately or was arcing noted?

› Did a process recipe need to be adjusted or modified?

› Have you or someone else noticed a discoloration or missing pieces of magnetic flux concentrator (if applied)? Make sure that the structural degradation of concentrators did not take place and flux concentrators have not shifted during heating due to ever-present magnetic forces.

› Did your quenchant look or smell differently than normal? Check its concentration, temperature, etc.

› Is there an evidence of excessive dirt accumulation, unexpected

discoloration, or an occasional appearance of flame and/or smoke during heating?

Answering those simple questions may reveal vital clues, and remember that the three senses: vision, smell, and hearing can be important assistants.

FACTOR OF STEEL'S INCOMING CONDITION

Cracking that occurs during IH often exposes failures taken place during earlier processing stages. This includes the steel defects, as well as defects caused by shaping, machining, trimming, etc. It is imperative to verify the quality of incoming steel. For example, some micro-cracks may be formed during a trimming operation when forging flash is removed. Those micro cracks can advance further during heating and/or quenching. Therefore, validate that the material's prior microstructure is free of cracks and microcracking did not develop prior to IH.

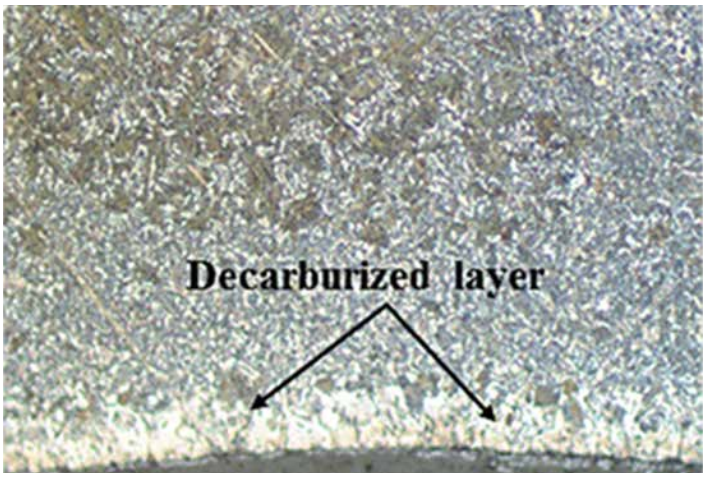

Figure 2: An example of a decarburized surface layer (light color region indicates a depletion of the surface carbon).

Initially, decarburized steels are another example of a problem that might be associated with the quality of incoming material. Decarburization indicates the loss of surface and near-surface carbon content (carbon depletion) from the steel after being exposed to sufficiently high temperatures in an oxidizing atmosphere, such as air (Figure 2). The depth of the decarburized layer is a complex function of several factors [1].]

A considerable amount of decarb is commonly present when dealing with as-hot rolled bar stock, as well as as-forged, annealed, or normalized steels. The presence of decarburized layers at the surface of "green" parts exhibits a significant problem for IH since those layers will remain within the as-quenched structure, worsening strength, wear resistance, fatigue life, impact and bending properties, etc.

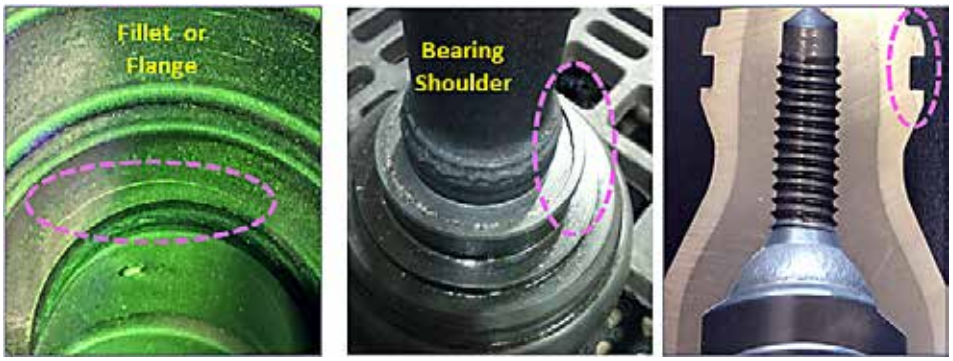

Figure 3: Typical fractures due to underestimating the eddy current flow, applying inappropriate hardening techniques, coil designs, and/or inadequate process protocols.

Carbon content determines the achievable steel's hardness level, therefore, a "soft" surface caused by a decarburization can lead to not only localized severe hardness and strength reduction, but it may even reverse the residual stress distribution, forming undesirable localized tensile surface stresses, which in turn can cause delayed cracking or premature failure of components during their service life.

Figure 4: Examples of parts containing various holes: longitudinal (axial), transverse, and cross holes.

With its short process time, induction hardening itself does not typically produce any measurable amount of decarb. Incoming decarb cannot be repaired during rapid IH under normal processing conditions. Thus, decarburization, as well as some other undesirable conditions resulting from the steel prior processing (e.g., seams, laps, etc.), excessive oxide scale buildup at the surface, intergranular oxidation, and burns should be avoided.

It is not realistic to expect that a certain grade of steel, having the exact chemical composition, will always be supplied. Steel has become a globally sourced commodity, which raises the need for the heat treaters to have a clear understanding of what kind of deviations might be expected when dealing with different suppliers or using certain steel grades in different applications.

Also, due to a variety of factors related to steel making, even different batches of steel of the same grade and produced by the same steel supplier will not have an identical chemical composition. Acceptable ranges are specified and standardized. For example, according to the Heat Treater's Guide [3], it is not unusual even for plain carbon steels to have a carbon content variation in the range of about 0.05 percent and higher. Extreme variation in carbon content alone can produce a respected deviation in obtainable surface hardness and the ability of the steel to be hardened to a certain depth (hardenability) [1]. If insufficiently small "safety" factors were used in developing IH-process protocols, then this variation may trigger "cracking-non-cracking" outcomes of hardening. Steels with a higher carbon content are often

associated with an increased tendency for crack initiation, assuming the rest of the heat-treating conditions remain the same.

Although the percentage of carbon content by far provides the greatest influence on the properties of hardenable steels, there are a number of other chemical elements that, depending on their amount and mutual interactions, can also notably affect the results of hardening. This includes a crack sensitivity and steel brittleness; the extent of which depends on the amount and combination of elements present. Some of these additional chemical elements happen to be in steels as traces or residual impurities contained in the raw materials; others were added during melting for the development of certain conditions during the steelmaking process (e.g., deoxidation, melting specifics, etc.).

Though plain carbon steels are widely used in the industry, there are many industrial applications where their properties are not suitable for meeting certain industrial requirements or a combination of needed and often conflicting engineering properties. This is why an appreciable amount of alloying elements might be purposely added to the steel for developing certain properties. Thus, potential deviations of chemical elements should be taken into consideration during developing process recipes of IH.

An unfavorable combination of alloying elements and residual impurities could promote brittleness and crack sensitivity. For example, in most cases, it is preferable to minimize sulfur and phosphorus residuals. Sulfur reacts with iron, producing hard, brittle iron sulfides (FeS) that have a tendency to become concentrated at grain boundaries and increase the sensitivity to intergranular cracking [1, 2]. FeS in carbon steels is suppressed by the addition of an adequate amount of Mn to form MnS, creating a less brittle microstructure. The amount of Mn should be sufficient to prevent the forming of FeS. "Mn-to-S" ratio of about 5:1 or so is quite commonly specified for carbon steels. Therefore, it is important to make sure that not only an amount of particular elements is within the accepted range, but also their ratios. In addition to sulfur, excessive levels of phosphorus, tin, and copper also can worsen cracking susceptibility in steels.

Thus, the use of lower-than-specified quench temperatures and concentration, as well as higher-than-specified quench flow rates and pressures can initiate cracking with an excessive amount of some residuals, particularly if geometrical stress risers are present. Thus, steel's composition and quench parameters should be verified if cracking suddenly occurs.

The real-life existence of the hardenability band (having upper and lower hardenability limits) is associated with a permissible, yet extreme, variation of steel's chemical composition. This means that even for perfectly repeatable heating and quenching cycles, the surface hardness, hardness pattern, as well as formation, distribution, and magnitude of transient and residual stresses could be affected to a certain degree, depending on the steelmaking practice, the raw materials, precise steel composition, and a number of other factors. This makes it beneficial to use H-steels that have a tighter control on hardenability limits compared to steels with a normal composition variation. Unfortunately, not all hardenable steels are available as H-steels.

Regarding the subject of the composition control, it is important to notice an enormously powerful impact of a very small amount of boron (less than 0.005 percent B) on steel hardenability enhancement [3]. However, this beneficial quality of boron may introduce some challenges emphasizing the need of its tight control, because even seemingly very small variations of boron content (e.g., ±0.0005 percent B) might have a measurable impact on steel hardenability and hardness pattern. A similar phenomenon takes place when dealing with plain carbon steels having variable residuals of Mo and Cr. It is important to be aware that, in some cases, an increased hardenability may cause a crack initiation [1].

Steelmaking operations have continuously improved, and the steels produced today will often have a relatively consistent chemistry with a reduced (but not eliminated) composition variation. Therefore, a potential variation of chemical composition should be taken into consideration when developing process protocols or trying to determine a root cause of the sudden appearance of cracking.

It might be beneficial to remember: "If, for some reason, a steel part does not respond to heat treatment in an expected way and cracking develops, then one of the first steps in determining the root cause for such unexpected behavior is to make sure that the steel is sufficiently clean and has the proper chemical composition, specified initial prior microstructure with minimal segregation."

Figure 5: Examples of cracking appearing within the proximity to holes.

HARDENING SHAFT-LIKE COMPONENTS

The hardening of flanged shafts, output shafts, planet carriers, yoke shafts, axle shafts, drive shafts, and other shaft-like components represents a sizable market for IH. Certain geometrical features such as flanges, diameter changes, shoulders, grooves, splines, etc. may distort the magnetic field generated by an inductor, causing temperature deviations, a mixture of "hot" and "cold" spots, excessive thermal gradients, undesirable stress states, and grain boundary liquation [1] that may trigger subsequent cracking. As an example, Figure 3 shows several typical fractures that occurred due to an undesirable combination of inappropriate hardening techniques, coil designs, and/or inadequate process protocols.

There are several regions of concern when hardening the flanged shafts. One such area where a circumferential surface fracture may occur is the radius (fillet) between the shaft portion and the flange (Figure 3, left). Coarser initial grains and a deeper case depth increase a probability for cracking. For example, a hot upset flange may exhibit a considerably coarser initial grain structure compared to hot-rolled bar stock of the shaft. The concern of cracking is particularly alarming in applications of through-hardened flanges or when a hardened case depth occupies a substantial portion of the flange thickness.

Thus, the reduction of the peak temperatures in the flange and the case depth (if permitted) can help to eliminate crack initiation.

Another area of concern is located in the proximity to a bearing shoulder (Figure 3, center). Sharp shoulders, corners, and large diameter changes can considerably distort the eddy current flow and may produce a measurable temperature surplus forming undesirable microstructures susceptible to a crack development. Those cracks are also typically circumferential. Higher temperatures and deeper hardness case depths in that area increase the likelihood for a surface fracture.

The third region of concern when hardening flanged shafts (e.g., axle shafts) is a shaft's area adjacent to a flange. Shafts with small flange radii or no radii as well as thin-walled hollow shafts are particularly susceptible for a formation of a crack. Depending upon a hardness pattern, material's strength, ductility, and toughness, a circumferential fracture may be initiated in the surface (more typical) or subsurface. In other cases, a component can fracture internally in a transverse or longitudinal direction [4]. Internal cracking is more frequently associated with "as-cast" or "as-hot forged" materials or materials with an undesirable grain flow, kink-band formation, excessive presence of inclusions, their unwanted morphologies, composition, distribution, orientation and size, or any other combination of factors that may result in reduced ductility and toughness as well as overlapping of peaks of tensile stresses.

If improperly addressed, such geometrical discontinuities such as machined grooves, slots, undercuts, keyways, snap rings, teeth, etc. can also cause cracking [1, 4, 5]. As an example, Figure 3, right, reveals some local fractures. Heat surpluses and unequal metal expansion/contraction in a combination with excessive quench severity were causes of those fractures. Improved inductor profiling, process recipe, and modified quenching can help to eliminate cracking.

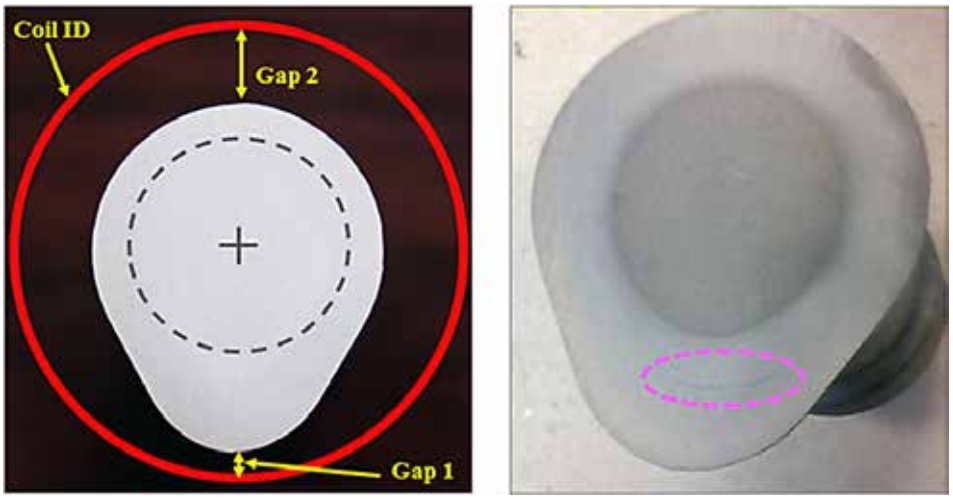

Figure 6: Variation in electromagnetic coupling between the coil inside diameter (Coil ID) and different regions of the cam lobe (left) and subsurface thumbnail cracking (right) [8].

Figure 7: A CamPro® machine that uses SHarP-C™ (left), multi-lobe inductor design (center), and hardness pattern (right). (Courtesy of Inductoheat Inc., an Inductotherm Group Company)

It is not unusual for modern shaft-like components to contain longitudinal (axial) and/or transverse holes (Figure 4) as well as angled or cross holes. Those holes result in an eddy-current flow diversion potentially resulting in an appearance of "hot" spots and, if not properly addressed, crack-initiation sites (Figure 5).

Temperature deviation around the hole may produce a corresponding non-uniform hardness pattern. This is particularly so when dealing with angled holes, where there might be an appreciable variation in heat generation and case depth in obtuse vs. acute angles compared to a straight hole.

It should be noted that temperature surplus alone might not result in crack development. There are other factors that can complement the heat surplus. For example, inappropriate quench intensity and distribution, as well as positioning holes in the proximity to the forging-parting line can increase the propensity to cracking, just to name a few. The repositioning of quench holes further away from the parting line is a step for making parts friendlier to IH. Drilling holes after hardening (if possible) might be another consideration to avoid oil-hole cracking.

Angled holes exhibit considerably different cooling intensities during quenching. With conventionally designed inductors, quenching devices, and recipes, an acute-angle area experiences more severe cooling intensity compared to an obtuse region complementing the heat surplus. This combination makes an acute-angle region to be susceptible to crack initiation.

A complex stress state in the oil-hole vicinity takes place during heating and quenching. There are a number of helpful practical solutions available for heat treaters to enhance the stress state and dramatically reduce or even eliminate the propensity of angled holes for cracking.

Several patented designs were invented during the development of the non-rotational crankshaft hardening technology (CrankPro® hardening machines), allowing selective control of the heat-source distribution in the oil-hole proximity by providing preferable channels for eddy-current flow and intentionally modifying quench profiling.

Experience shows that, in many cases, the proper choice of design parameters (electrical frequency, power density, inductor profiling, etc.) allows one to obtain the required hardened pattern around holes free of cracks. For example, even such complex-shaped parts as a ball bearing cage, which consists of a number of closely located large holes, can be induction hardened instead of using time- and space-consuming carburizing processes. Figure 4, bottom, shows several complex geometry shaft-like components that have been successfully IH, even though, initially, it might seem like an impossible task.

Some parts have multiple closely-positioned holes [4]. The size and orientation of holes may call for a particular induction-hardening technique. As a general rule, if multiple holes are positioned longitudinally, then a single-shot inductor might be a preferred choice compared to scan hardening. On the other hand, if holes are posi-

tioned circumferentially, then the use of scan inductors might be more appropriate compared to a single-shot hardening.

Space does not permit a detailed discussion on electromagnetic and heat-transfer subtleties, eddy-current flow in the oil-hole vicinity, an impact of chamfering characteristics, and a selection of process parameters to minimize the probability of cracking. These and other subjects are discussed in [1, 4, 7].

PREVENTION OF CRACKING IN CAMSHAFT HARDENING

Electromagnetic induction is a popular method for heat treating a variety of automotive components including camshafts. Camshafts belong to a group of irregularly-shaped parts consisting of several sets of cam lobes and bearings. The number of lobes, their size, profile, positioning, and orientation depend upon the camshaft type and engine specifics and can vary to great extent [8].

In the past, IH of camshafts commonly require their rotation. Unfortunately, because the nose of the cam lobe has a closer electromagnetic coupling with the coil, this approach was associated with noticeably deeper case depths in the nose compared to its base circle (the heel). As an example, Figure 6, left, illustrates a typical variation in electromagnetic coupling between the coil inside diameter (coil ID) and different regions of the cam lobe. Deeper case depths are associated with reaching higher temperatures.

An attempt to provide a minimum required hardness case depth in the poorly coupled base circle/heel region may result in an overheating of the nose that could not only worsen the camshaft's characteristics including its straightness, but it can also produce an undesirable stress state, severe grain coarsening, and incipient melting, potentially causing surface or subsurface cracking (Figure 6, right). When IH low toughness materials (e.g., high carbon steels, cast irons, etc.), even seemingly insignificant increases in the hardness case depths may be sufficient to initiate cracking.

In order to dramatically minimize a probability of cracking, a non-rotational SHarP-C™ technology has been effective for contour hardening of cam lobes. Figure 7, left, shows a CamPro® machine that uses SHarP-C™ technology, a multi-lobe inductor design (Figure 7, center), and a hardness pattern (Figure 7, right). Experience shows that a CamPro® machine can not only exhibit reduced energy consumption, but it also can produce much straighter camshafts. Some users of CamPro® machines have reported almost undetectable camshaft distortion, an elimination of the entire straightening operation. and measurable scrap reduction [8].

COMMON REMEDIES TO MINIMIZE THE PROBABILITY OF CRACKING

The existence of an endless variety of components that are routinely induction hardened has educated us with various remedies to minimize a probability of cracking. If cracking has occurred, a thorough investigation should be conducted applying principles and general practices of failure analysis [5], and it should take into consideration subtleties of a particular IH application. It is important to remember that a cracking problem is often application-specific. Therefore, the collection of reliable background data and heat-treat history is imperative.

Certain part geometries and materials grades might be prone for a particular failure mode. As an example, Figure 8 shows an appearance of a variety of cracks when heat treating gears and gear-like components. Even a brief look at Figure 8 reveals a complexity of factors, an ambiguous nature of cracking and its root cause(s)

related to just gear-like parts.

Over the years, the industry has developed a number of general remedies that might help to eliminate cracking issues in IH. Some of those remedies are listed below (when applying remedies associated with modification of a process recipe, always make sure that hardness levels and patterns are within the required "min-max" range and discuss your actions with the OEM):

› Determine when the cracking occurred (for example, during heating or quenching, before or after tempering or perhaps it is a post heat-treating fracture that appeared after grinding/straightening).

› Proper metallographic examination [5] should be conducted assessing crack morphology, a possible relationship with a microstructure, determining the fracture mode and the most probable cause of fracture.

› Verify anticipated prior microstructure and chemical composition of an incoming material. Its cleanliness, degree of heterogeneity/segregation, grain coarseness, presence of imperfections (e.g., laps, seams), as well as the type of non-metallic inclusions, their composition, shape, size, and distribution (ASTM E45 or ISO 4967). Non-metallic inclusions may or may not affect cracking — it depends. Remember that steel cleanliness affects not only quality of end-use products (in particular fatigue life of highly stressed transmission components) but it may also affect cracking sensitivity [1]. If the steel's initial structure is appreciably different than expected, then this issue must be addressed to your steel supplier. Appropriate measures should be taken in improving a friendliness of a material's initial structure prior to IH. For example, in order to refine the structure of hot-forged parts (e.g., hot upset forged flanges or splines); it might be beneficial to normalize it prior to machining and IH.

› Validate that the microstructure of a "green" part is free of cracks and microcracking developed prior to induction hardening.

› Make sure that the workpiece has an anticipated geometry, and it is properly positioned during heating and quenching. A part's unspecified positioning, self-reallocation, and tilting during IH, as well as its slippage and excessive wobbling during rotation should be avoided. Thin, elongated components should not fit snugly, allowing expected part growth during heat treating.

› Verify that adequate inductor and process recipe have been used. Have any abnormal electrical limits, ground faults, arcing, or other parameters been detected by process monitoring devices?

› Make sure that spray quench orifices are not plugged, resulting in unspecified quench nonuniformity. Verify that the quenchant has the required conditions and there is no obstruction for the spray quench to reach the part's surface.

› Do not compromise, instead use appropriate induction equipment that would allow true optimization of a process recipe by having a capability to not only adjust power and scan rate/heat time, but electrical frequency as well.

› Reduce temperature of austenitization by applying slightly lower power (< 1-3%).

› Apply quench delay (0.25-0.75 sec).

› Increase quenchant temperature approx. 2-3°F.

› Increase quenchant concentration (approx. 1-3%).

› If specified, tempering (oven or induction, whatever is specified) should be done as soon as possible. Long delays between hardening

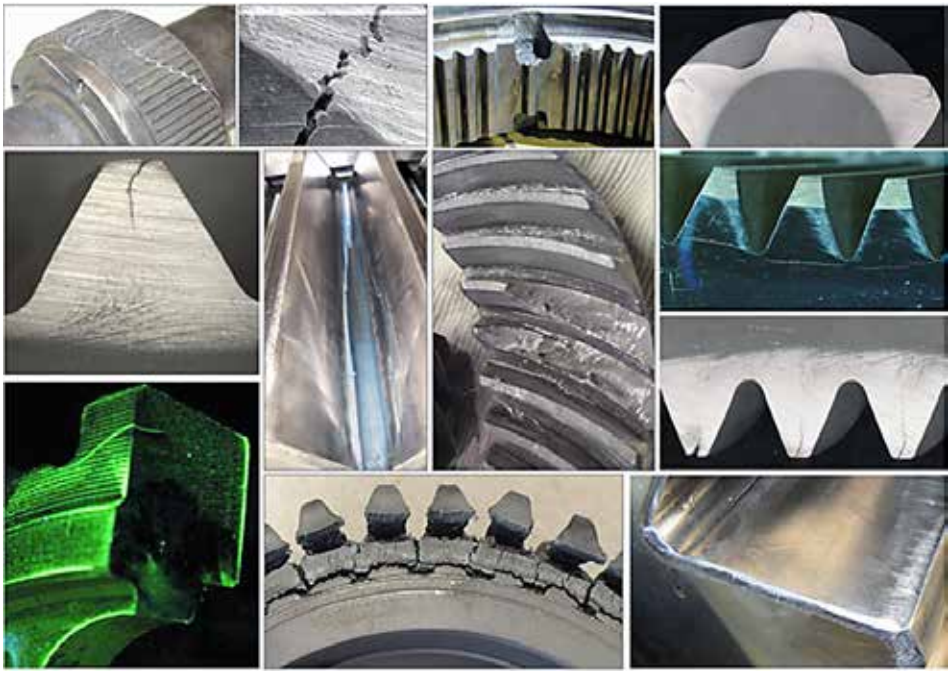

Figure 8: An appearance of cracking in the heat treating of gears and gear-like components.

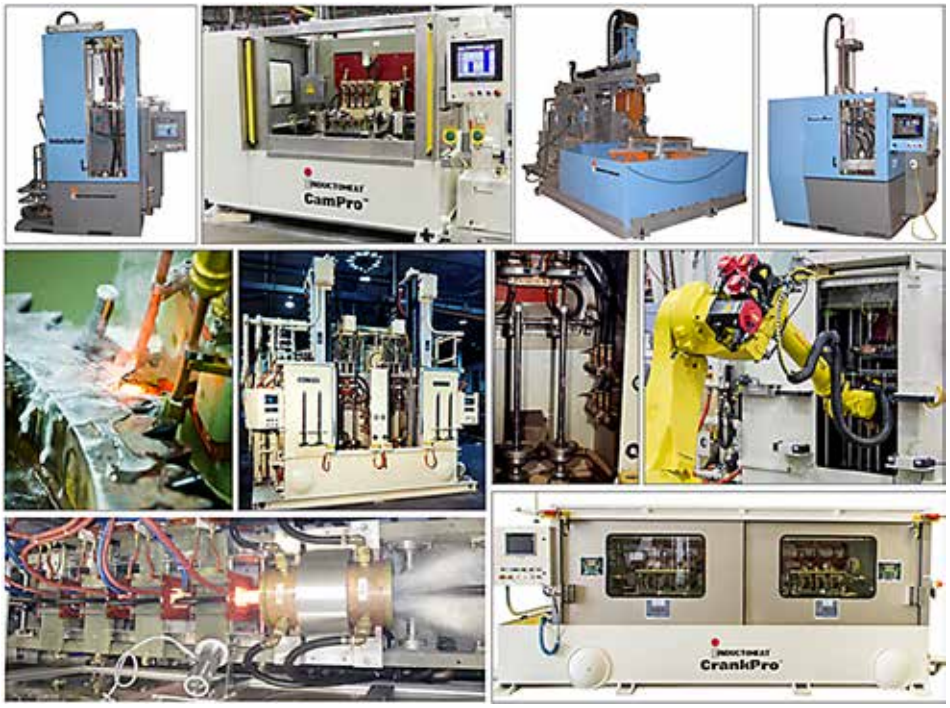

Figure 9: Examples of induction heat-treat machinery that have become undisputable standards for the modern induction heat-treat industry. (Courtesy of Inductoheat Inc., an Inductotherm Group Company)

and tempering may result in the delayed cracking, which could be caused by several factors. It is particularly beneficial to position the tempering operation immediately after the hardening machine or at least in the same building when dealing with low-toughness materials and high-hardness levels.

› Shorten duration of the quench cycle and apply some self-tempering (if applicable). If possible, apply a combination of self-tempering and multi-pulse induction tempering.

› Increase time of tempering (if applied), using low values of tempering power and/or frequency or applying IFP technology or multiple heat-soak cycles at low-power levels and reduced frequencies.

› Increase the time prior to the final cool-down stage (time between the end of tempering and the beginning of the eventual cooling down for the part's safe handling).

› Some cracks that occur very infrequently are so rare, they may be considered as a statistical event. It is much easier to determine the root cause of cracking if it can be turned "on" and "off" by modifying the process parameters.

› It is difficult to over-emphasize that if a fracture occurs, it is imperative to determine after which process stage it appears (after heating, quenching, part transportation to tempering, after tempering or post heat-treat operations such as grinding or part identification). Final grinding, straightening, and part identification can have a noticeable impact on both: residual stress distribution as well as cracking. Abusive grinding is known to be responsible for altering as-hardened microstructures and the residual stress state and could promote notch sensitivity and fractures. Stamping or laser carving the identification number into the part should be done outside of the heat-treat areas. The same rule should be applied for electro-etching and other part-identification techniques.

It is worthwhile to repeat that if an attempt to eliminate cracking by any of the previously described actions isw used to modify a process recipe, it will be necessary to make certain that the full customers' heat-treat specifications are still met.

CONCLUSION

IH is a proven technology, and many thousands of induction machines are in service worldwide. The popularity of this technology continues to grow, and inventions and innovations are appearing quite regularly. Induction equipment is energy efficient, flexible, reliable, robust, and environmentally friendly, producing components with enhanced metallurgical quality. As an example, Figure 9 shows equipment that has already reached undisputable standards in modern heat-treat industry.

Unfortunately, as with any process, heat-treat professionals occasionally may encounter some cracking issues. Each part has its own "personality" that affects the outcome of heat treatment. Even a cursory look at the "fishbone" diagram of cracking [2] unveils the intricacy and challenges in determining the root cause and the consequential factors associated with cracking.

In real-world needs, manufacturers of IH equipment should have the experience and analysis necessary to help heat-treat practitioners with specific problems. Understanding a broad spectrum of factors associated with various failure modes is an important step in designing new products and developing crack-free processes. Mutual cooperation of designers and equipment manufacturers are vital for success.

Finally, we would like to share the statement that is popular among heat treat professionals: "In the beginning there is PRICE, at the end there is COST. The difference is QUALITY. This quality ensures the ability of heat-treat professionals to avoid unpleasant surprises by using past experience, engineering expertise, computer modeling capability, and awareness of the latest advances in theoretical knowledge."

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ABOUT THE AUTHORS

Gary Doyon, Dr. Valery Rudnev, Randall Minnick, and Tim Boussie are with Inductoheat Inc., an Inductotherm Group company.

OPTIMIZING TEMPERATURE MEASUREMENT

IN HEAT-TREATMENT OPERATIONS

Thermocouple extension cables are used when the process control instrumentation or recording device is at an extended distance. They complete the thermocouple circuit back to the reference junction or "cold junction," which exists inside the instrumentation. (Courtesy: TE Wire & Cable, LLC.)

Specifying thermocouple wire, extensions, and thermocouples.

By MARC STRINGER

Quality and efficiency in heat-treatment operations requires accurate temperature measurement. Specifying thermocouple wire and thermocouples carefully will lead to greater temperature measurement accuracy and less scrap or re-work.

First, consider whether the need is for thermocouple cable or for thermocouple extension cable. Thermocouple cable is made to survive inside the furnace and may be used to form the measuring junction or "hot junction." It requires insulation and jacketing material that can withstand the process temperatures. It must be used where the temperatures are extreme.

Thermocouple extension cables are used when the process control instrumentation or recording device is at an extended distance. They complete the thermocouple circuit back to the reference junction or "cold junction," which exists inside the instrumentation.

A thermocouple connector makes the transition between the thermocouple cable and its extension. The "true" or "high-temperature" thermocouple cable is wired into the plug (male) half of the connector. The extension grade cable is wired into the jack (female) half of the connector. All components need to be of the same type; that is for a Type K thermocouple, the cable and connector must be type K, and the extension cable must be type KX.

EXTENSION CABLES

Because thermocouple extension cables are away from the furnace; where temperatures are at or close to ambient, they are made with PVC (105°C) or FEP (200°C) or other relatively low-temperature insulation materials. See Table 1 for the relative properties of FEP vs. PVC in harsh environments for guidance on which insulation and jacket material is right for your application.

Extension cables are not subjected to the extreme temperatures and temperature cycling that cause calibration drift and do not require frequent replacement. Extension cables simply carry the Seebeck EMF generated back to the instrumentation. Where best practices require limited life and routine replacement of thermocouples measuring high temperature due to calibration drift, it is not necessary to replace their extensions on the cold side of the connector. Only the high temperature "true" thermocouple cable on the hot side of the connector is replaced. Extension grade thermocouple conductors are not calibrated above 400°F (204°C) or 212°F (100°C) for TX) — again, since these are only run through ambient environment.

Extension cables are still part of the thermocouple circuit and carry the Seebeck EMF generated at the measuring junction back to the reference junction existing within the instrument. So, the conductor alloy must be compatible with that of the thermocouple. For base-metal thermocouples, this means thermocouple types T, J, E, K, or N must only be extended with extension grades TX, JX, EX, KX, or NX respectively. For these base thermocouple circuits, the alloy metals of the extension grade conductors [1] are substantially the same as thermocouple grade alloys and have approximately the same thermoelectric properties. However, they are not calibrated above 400°F as stated earlier.

PVC AND FEP RELATIVE SUITABILITY TO HARSH CONDITIONS

	PVC	FEP
Typical High Temperature (Continuous)	105C	200C
Typical Low Temperature (Continuous)	-20C	-70C
HARSH CONDITION – (AT AMBIENT UNLESS STATED)		
Abrasion Resistance	F-G	E
Acid Resistance	G-E	E
Alcohol Resistance	G-E	E
Alkali Resistance	P-F	E
Benzol, Toluol, Etc. (Aromatic Hydrocarbons) Resistance	P-F	E
Degreaser Solvents (Halogenated Hydrocarbons) Resistance	P-F	E
Electrical Properties	F-G	E
Flame Resistance	E	O
Gasoline, Kerosene, Etc. (Aliphatic Hydrocarbons) Resistance	P	E
Heat Resistance	G-E	O
Low Temperature Flexibility	P-G	O
Nuclear Radiation Resistance	F	F
Oil Resistance	F	F
Oxidation Resistance	E	E
Ozone Resistance	E	E
Underground Burial	P-G	E
Water Resistance	F-G	E
Weather, Sun Resistance	G-E	O

P=Poor, F=Fair, G=Good, E=Excellent, O=Outstanding

These ratings are based on average performance of general-purpose components. Any given property can usually be improved by the use of selective compounding. Ratings are relative and qualitative, based on comparison to other plastic cable jacketing materials.

Table 1: Typical thermocouple extension cable insulation and jacketing materials

NOBLE METAL THERMOCOUPLE EXTENSION

Noble metal thermocouples type R, S, or B are used when measuring higher temperatures. Their extension grades are still referred to as types RX, SX, or BX respectively. However, here the alloys differ from the noble-metal thermocouple but still have approximately the same thermoelectric properties. Common copper instrumentation cable must not be used as thermocouple extension cable for the reasons given above.

CABLE LISTINGS — ELECTRICAL CODE REQUIREMENTS

Extension grade thermocouple cable is typically run where the circuit is relatively long and might be permanently installed in cable tray, conduit, or other raceways. As such, it is subject to the regulations governing all instrumentation and control wiring for the facility, probably the National Electrical Code (NEC, NFPA 70) Article 725 or Article 300. This in turn requires the cable to be listed by a nationally

recognized testing laboratory (NRTL). The cable listing requirements are either PLTC (Power Limited Tray Cable, Article 725) for 300V cable raceways and enclosures; or TC (Tray Cable, Article 300) for 600V cable raceways and enclosures. The voltage rating has more to do with the facility infrastructure and where the thermocouple extension cables will be routed and terminated than with the thermocouple circuit itself. It may be run alongside other cables. NEC installation practices require all cables rated 600V and higher cables be segregated. This is why a facility may require 600V rating on thermocouple extension cables — because that is their infrastructure. The circuit voltage will still be only down at signal levels. Most thermocouple extension cables are listed as PLTC, which technically rates them for 300V, although, again, the actual circuit voltage will be only at signal levels. The voltage rating is not printed on PLTC cables, per UL marking rules. In ambient temperature and benign environments (which is typical), the insulation and jacket are PVC or other low-temperature materials, and the cables are usually listed as type PLTC. In extreme or harsh environments where PVC may not be suitable, fluoropolymer FEP insulation and jacket materials can be selected. FEP is excellent relative to PVC and other plastic materials where exposure to harsh environments such as solvents, acids or alkali, gasoline, direct sunlight, water, or direct burial conditions are possible. Cables in such harsh environments may be deemed special-application cables, and NEC listings may not apply. Table 1 indicates the relative suitability of PVC and FEP in harsh environments.

Extension cables are 22AWG minimum size; however, larger sizes 20AWG, 18AWG, and 16AWG are also common. The minimum size requirement is so they may be listed as National Electrical Code (NEC) cable type PLTC. This may mean the extension is a larger wire size than the thermocouple itself, which runs to the measuring junction. The larger wire size is better suited to the relatively longer portion of the circuit since it will have a lower resistance for circuit length. So, an increased size may be for circuit design purposes, and not only to meet the requirements of PLTC.

ELECTRICAL NOISE

Extension cables are subjected to electrical noise. Pairs should be optimally be twisted, and the cable should be shielded. These cables are usually longer cable runs through the factory. They may be alongside electrically noisier power, control, and instrumentation cables operating at higher voltages. They may be run past any number of generators, motors, lights, or other sources of electrical noise. All this electro-magnetic noise could interfere with very low voltage thermocouple signal. For this reason, thermocouple extension cables should be shielded. When a cable is comprised of multiple pairs, each pair should be twisted. Twisting the pairs defeats common-mode noise. Shielding is typically an aluminum-foil tape that absorbs outside noise and a tinned copper wire that "drains" the foil and carries the noise away as electrical current to ground. The drain wire is terminated to ground at one end of the cable run. The aluminum foil tape is polyester on one side, which serves two purposes: The polyester layer adds strength and insulation. The strength is needed for cable processing (manufacturability) and handling. The insulating property is needed so that in multi-pair cable, the pair shields can be isolated from each other. Where individual pair isolation is specified, the foil side will face in, and the drain wire will be inside the tape in order to be in contact with the aluminum foil. There will be one drain wire per pair in this case, and this is the most common configuration. An overall foil shield and drain wire is also normally included for additional shielding effectiveness. (For more detail about the sources of noise and solutions, see "Noise in Instrumentation Circuits"; *Thermal Processing* March/April 2018.)

CONVENTIONAL MINERAL INSULATED CABLE CONSTRUCTION

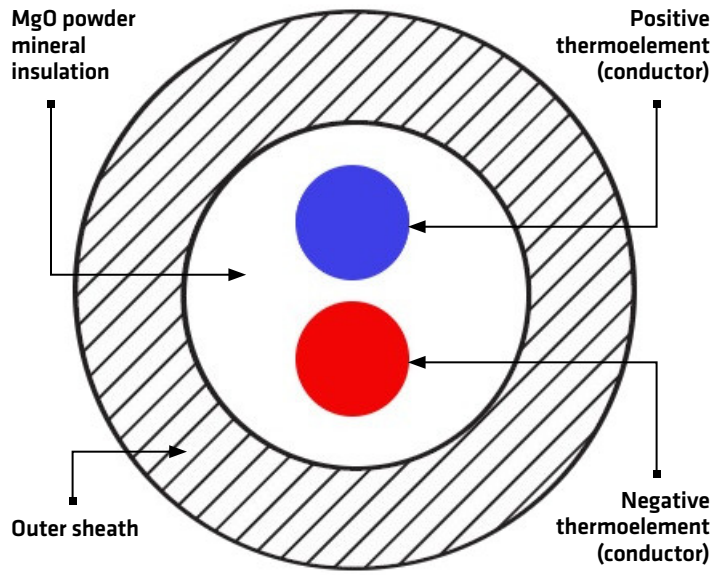

Figure 1: Conventional construction design for Mineral Insulated Metal Sheathed (MIMS) cable.

LOW DRIFT, DUAL-WALL TYPE MINERAL INSULATED CABLE CONSTRUCTION

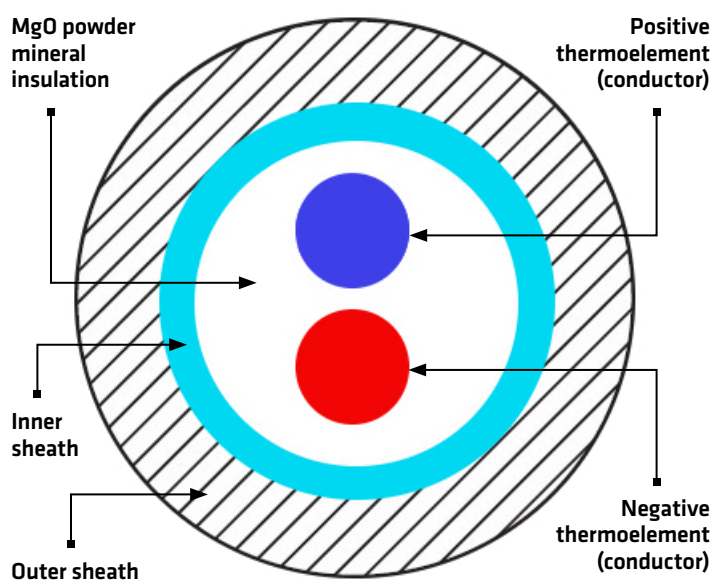

Figure 2: New construction design for Low-Drift Dual-Wall Type Mineral Insulated Cable.

THERMOCOUPLE CABLE

Thermocouple cable that will be exposed to process temperatures and thermal cycling, such as that used to manufacture expendable thermocouples for uniformity surveys and system accuracy testing, must be designed for those temperatures. The PVC or FEP insulation and jacket materials used for extension cables would not survive first use. The alloys used for the conductors are calibrated up to the design temperature. To differentiate from extension cable, these are sometimes called "true" thermocouple cables.

The insulation for these cables is either high-temperature tapes or braids such as fiberglass, Refrasil® [2] or CEFIR® [3]. Insulations rated up to 2,400°F are available. These cables are often not twisted and not shielded, since their use is for shorter runs where they are not exposed to electrical noise. However, both those features are available for applications where electrical noise may be present. (For more detail about these cables, see "Temperature and Accuracy. Three basic steps in selecting the right Thermocouple Wire"; *Thermal Processing* March/April 2018.) Thermocouples made with these non-metallic jackets are referred to as Expendable Thermocouples.

MINERAL INSULATED METAL SHEATHED CABLE

Another type of thermocouple cable is Mineral Insulated Metal Sheathed cable (MIMS). These cables use compacted magnesium oxide (MgO) insulation around the conductors and a metal sheath to form the cable. Sheath materials are most usually stainless steel; Inconel, an alloy of platinum and rhodium; or Nicrobel. These cables protect the conductors better from certain atmospheres and environments than non-metallic jacketed cables. The application and environment dictate the materials' selection. Where extremely high temperatures (>2,400°F) are to be measured and where Noble metal thermocouple types R, S, and B are specified, MIMS cable construction is often indicated. Thermocouples made with MIMS cable are one type of nonexpendable thermocouple. There are innovative new low-drift MIMS cable types commercially available that reduce drift, improve accuracy, and may permit a longer useful life. Figure 1 and Figure 2 illustrate cross-sections of conventional MIMS cable (Figure 1), and dual wall low-drift MIMS cable (Figure 2) available from TE Wire & Cable.

ERROR, ERROR LIMITS, AND CALIBRATION

Thermocouple wire may also be specified to have standard accuracy or special accuracy. The level of accuracy is called the limits of error and is defined for each thermocouple type. Standard limits of error for types J, K, and N, for example, are the greater of ±4.0°F or ±0.75 percent; and Special Limits of error for these are the greater of ±2°F or ±0.4°F. Special limits are also call "half limits" or "premium grade" or may be designated as (for example) 'JJ' for type J special limits of error. Some manufacturers also offer "quarter limits" or "half special limits" accuracy that would be designated JJJ for type J. (See Table 2)

All thermocouple cable will have some error. Determining the inherent error is the purpose of laboratory calibration, so readings taken can be adjusted for the inherent error in the cable at a given temperature. Depending on the seller, the actual error should be available as a laboratory-calibration report, for any spool of cable over a specified temperature range. This report can be used to calibrate the instruments or recording device.

CALIBRATION DRIFT

The thermocouple accuracy given by the manufacturer, however, will be for the thermocouple's first use only. The properties of the alloys begin to change with use, and so the EMF generated and calibration error also change. This phenomenon is called calibration drift and is the reason for limiting the number of uses of thermocouples as prescribed in SAE AMS2750. Calibration drift is most commonly called simply "drift" and is defined in ASTM MNL-12 "Manual on the Use of Thermocouples in Temperature Measurement."

THERMOCOUPLE USAGE

All thermocouples have a limited useful life and must not be re-used after a number of uses or number of calendar days after first use, depending on the temperature of the process. SAE AMS2750 is an industry standard that prescribes the limits on thermocouple usage or useful life. Depending on the temperature and process, nonexpendable thermocouples might have a longer prescribed useful life than expendable thermocouples. For example: for a consistent process below 1,200°F, AMS2750 requires that expendable thermocouples must be changed 90 days after first use or after 30 uses, whichever comes first; whereas nonexpendable thermocouples must be changed 90 days after first use or after 270 uses, whichever comes first.

Thermocouple Type/Wire	Temperature Range °F (°C)	Grade Designation	Standard Grade Limits °F (°C) whichever is greater	Grade Designation	Special Grade Limits °F (°C) whichever is greater
T	32 (0) to 700 (370)	T	±1.8 (1) or ±0.75%	TT	±0.9 (0.5) or 0.4%
J	32 (0) to 1400 (760)	J	±4.0 (2.2) or ±0.75%	JJ	±2.0 (1.1) or 0.4%
E	32 (0) to 1600 (870)	E	±3.1 (1.7) or ±0.50%	EE	±1.8 (1) or 0.4%
K or N	32 (0) to 2300 (1260)	K or N	±4.0 (2.2) or ±0.75%	KK or NN	±2.0 (1.1) or 0.4%
T*	-328 (-200) to 32 (0)	T	±1.8 (1) or ±1.5%	TT	±0.9 (0.5) or 0.8% **
E*	-328 (-200) to 32 (0)	E	±3.1 (1.7) or ±1%	EE	±1.8 (1) or 0.5% **
K*	-328 (-200) to 32 (0)	K	±4.0 (2.2) or ±2%	KK	**
Extension Wire	**Range °F (°C)**	**Designation**	**Limits °F (°C)**	**Designation**	**Limits °F (°C)**
TX	32 (0) to 212 (100)	TX	±1.8 (1)	TTX	±0.9 (0.5)
JX	32 (0) to 400 (200)	JX	±4.0 (2.2)	JJX	±2.0 (1.1)
EX	32 (0) to 400 (200)	EX	±3.1 (1.7)	EEX	±1.8 (1.0)
KX or NX	32 (0) to 400 (200)	KX or NX	±4.0 (2.2)	KKX or NNX	±2.0 (1.1)
RX or SX	32 (0) to 400 (200)	RX or SX	±9.0 (5)		
BX	32 (0) to 212 (100)	BX ***	±7.6 (4.2)		
BX	32 (0) to 400 (200)	BX Alloy ***	±6.7 (3.7)		

* Thermocouple material is normally supplied to meet tolerances above 0°C (32°F). If material is required to meet tolerances below 0°C (32°F), this must be specified. Special material selection is required.

** Suggested initial calibration tolerance. Requirements should be discussed between purchaser and supplier.

*** Copper vs. copper can be used as an extension for Type B thermocouples if the transition is below 100°C (212°F). Above 100°C (212°F), PCLW30-6 alloy should be used as the positive extension wire.

Table 2

REFERENCES

[1] Conductors are used in reference to thermoelements.

[2] Refrasil is a registered trademark of Hitco Carbon Composites.

[3] CEFIR is a registered trademark of TE Wire & Cable.

ABOUT THE AUTHOR

Marc Stringer is product manager for OEM & Metallurgy Products with TE Wire & Cable, LLC.

COMPANY PROFILE ///

ACROSS INTERNATIONAL

FULLY COMMITTED TO PROVIDING RELIABILITY, INNOVATION, AND VALUE

Across International 50L jacketed glass reactor with thermal insulation jacket. (Courtesy: Across International)

Across International is an industry leader in the manufacture of heat-treatment, vacuum, and material-processing equipment with a simple mission: to empower those advancing science by offering innovative and high-quality products, along with the best customer support.

By KENNETH CARTER, Thermal Processing editor

Across International is the product of two immigrants who dreamed big when they started shipping equipment out of a garage in New Jersey more than two decades ago.

Those humble beginnings paved the way for what has become a thriving company with locations around the world serving the heat-treating needs of multiple industries.

"We've earned the business of many respectable government agencies, universities, and Fortune 500 companies," said Anna Tykowski, senior public relations with Across International. "Some of our best customers include U.S. and Canadian labs and divisions of energy and military, industry leaders such as Byron Products and TSC EcoSolutions, and leading universities such as Georgia Tech, University of Delaware, Western Kentucky University, and many more. We work hand-in-hand with some of the brightest scientists and researchers from around the world."

The wide spectrum of customers that Across serves shows how the company can deliver quality workmanship no matter the customers' budgets, according to Tykowski.

"This is so that a start-up from a university or research lab can continue to choose our brand for a wide variety of products and sizes that will accommodate their growth and success," she said.

WIDE RANGE OF PRODUCTS

For the heat-treating industry, Across offers a wide range of furnaces that covers a spectrum of functions, according to Tykowski.

"We have a lot of different types of furnaces," she said. "We have muffle furnaces, which are good for enamel coatings, annealing, tempering, or brazing. Then we also have controlled atmosphere furnaces, and those are great for people who want to use an inert gas inside the chamber to create a controlled environment. Tube furnaces are good for small samples undergoing synthesis, purification, chemical-vapor transport, or similar processes. We carry multi-zone and single-zone tube furnaces with various tube diameters. Samples are loaded into a quartz or ceramic boat and pass through the length of the tube using a push rod. Tube furnaces are particularly useful within the semiconductor industry."

But the big draw for heat-treating is Across International's induction heaters, which heat metal by applying an electric current, according to Tykowski.

"It works with both ferrous and non-ferrous metals," she said. "Usually, people use it for preheating for welding, or they'll melt batches of precious metals. We had a dentist use an induction heater to recover the metal from old tooth fillings, for example."

In addition to Across International's induction furnace line, Tykowski also said the company offers custom coils.

"We are happy to assist our customers in designing customized induction coils for targeted heating of magnetic materials at rates of up to 100°C per second, depending on samples, which enables continuous production lines and huge energy savings in the heat-treatment processes," she said. "If you have an oddly shaped part, and you're not sure what's the best way to bring it up to temperature, we can help figure out a solution. In these situations, we'll request a sample of the part being heated, as well as the desired results, and we'll do our own in-house testing to make a suitable recommendation for both the coil structure and the right induction heater for the job."

Across International AccuTemp-series 16 cubic foot multi-zone vacuum drying oven. Features 6 dedicated temperature controllers with built-in shelf heating technology. (Courtesy: Across International)

By working thoroughly with its customers, the experts at Across have discovered innovative ways to offer its services, according to Tykowski.

"In the lower-temperature chemistry R&D and production labs alike, we've found that many of our customers are continuously feeding our SolventVap rotary evaporators with a food-grade PTFE valve and evaporating volatiles for separation at impressive speeds," she said. "To accommodate their continuous throughput demands, we have expanded to offer dual main condensers (for a total of three) to maxi-

Quality control inspections being performed on a compact recirculating heater at Across International's headquarters in Livingston, New Jersey. (Courtesy: Across International)

mize surface area for re-condensation, and dual receiving flasks so that one can be drained while the other continuously receives condensate."

SAMPLE TESTING

Sample testing is a unique service Across can offer its customers, according to Tykowski.

"Sample testing is a fantastic service we provide," she said. "We have a lot of folks who try to melt very tricky things, like powders, platinum, or titanium. We encourage sample testing in those situations, to make sure everything works according to expectations. What it comes down to is providing custom solutions."

Custom solutions are an integral part of Across International's methodology when a customer approaches the company with a challenge.

"We start from scratch to create these unique solutions," Tykowski said. "If they come to us with a complicated part due to shape, size, material, or anything along those lines, we can offer sample testing to ensure our clients' success without their incurring the cost of buying a unit and conducting their own research. If they require a nondisclosure agreement, we always do our best to safeguard our customers' privacy. If we need to create an equipment customization, we can do that, too. There have been times where a customer has needed an access port for a forced air oven to insert a sensor or probe, and we were able to customize it to their specifications."

Although customizations are not always needed for Across customers, the company is ready and willing to do them, according to Tykowski.

"Our experienced engineering team is well-equipped to make custom modifications," she said. "They are wildly talented at what they do, and they love solving the challenges that come with these customizations."

Across International customizable 1,200°C PECVD tube furnace. (Courtesy: Across International)

CUSTOMER PERFORMANCE

One of Across International's main goals is to improve customer performance in the field, while minimizing heating times lost to inefficiency, according to Tykowski. Across refers to this as "targeted heating."

"That often means approaching heat treatment from a different angle," she said. "Targeted heating is one of these methods in the

individually heated and controlled racks in our AccuTemp multi-zone vacuum ovens. That's only one example. Each rack and the samples have their own individual dedicated temperature controller, and they get the same atmospheric conditions. If you have a sample that you want at 78°F, you can put it on one shelf, and if you want one at 80°F, you can put it on a different shelf. Features like this are useful if you're doing a controlled experiment with different temperature variables. We also work on decreasing time-to-temperature by having the heat applied directly underneath the sample."

Essentially, different levels of the oven can be adjusted to different temperatures, according to Tykowski, making the oven extremely versatile.

LARGE GROWTH IN A SHORT TIME

Across International is a private American company that has grown by leaps and bounds since its beginning in 1998.

In 2008, the company established its first office in Berkeley Heights, its first official headquarters in New Jersey, which is also when the company's main website was launched.

Later, in 2012, the headquarters moved to Livingston, New Jersey, according to Tykowski. In 2015, the company identified a growing need to serve its customers on the West Coast, so Across established another location in Sparks, Nevada. That same year, Across opened another location in Victoria, Australia, which serves Australia, New Zealand, and the neighboring Asian countries.

"And that's where we are today," she said. "And there are plans in the works to continue growing."

And growing it is: Across International is in the process of increasing the square footage of its facilities in Victoria, Australia and in Reno, Nevada, according to Tykowski.

"All of this is being done to help support the expansion we need to meet and exceed our customers' demands," she said.

Across has its eyes on creating solutions for larger scale production capacity and increasing the robustness of its equipment for accommodating bulk manufacturing, according to Tykowski.

"We're also working hard to build partnerships and distribution networks in new markets across the world to help bring our high-quality products to new scientists and innovators that can put them to work growing their business and innovating for their community and our modern globalized trade network," she said.

'TOP-NOTCH' CUSTOMER SERVICE

One of Across' crown jewels is the company's stellar customer service.

Tykowski stressed that Across International's customers can greatly benefit from having a team of support engineers available for long hours, whether it be by phone, email, video chat, or in person in the field. Across provides U.S.-based technical support services not only for the duration of the manufacturing warranty period, but also for the lifetime of the equipment.

"I think our customer service is just top-notch. It really is. We want to make sure our customers have the resources they need to resolve any problems," she said. "And we have a great return policy. Our tech support is lightning fast at getting back to inquiries. We're all based in the U.S. You don't have to go overseas to get help. All our parts, service, and support are here. We also can coordinate on-site repairs, if necessary. We really do our best to take care of our customers, and they mean a lot to us. We wouldn't be here without them."

MORE INFO across international.com

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JEFF MARSHALL /// VICE PRESIDENT /// METALLURGICAL HIGH VACUUM CORPORATION

"Greater efficiency, more profitability, and less assets needed to achieve results are always going to be paramount for heat-treaters, and MHV is going to be there to help them in tangible ways."

What does MHV do for the heat-treat industry?

We make our customers more competitive, which is good both for the customers and for the industry as well. If our customers become more competitive, there's more attractiveness to invest. And if there's more attractiveness to invest, there's innovation, and the industry moves forward.

What kind of challenges do heat treaters face today?

There are both technical and financial challenges. The technical challenges are that there's always a drive for lighter, stronger, and cheaper metals. That's always going to be there. The financial challenges, however, come down to what companies in any industry face, and that is they're trying to increase their return on investment. Companies choose to address this in different ways; however, there are really only two main factors that contribute to improving that return: profitability and the net assets that are employed.

The net assets employed is the amount of money that's tied up to produce a level of profit. So, if you reduce the assets that you're tying up, you're using less capital or money to get the same profitability. By increasing your profitability on the other hand, you get a higher return on the money invested. Ideally, you want to both increase profitability and reduce the assets employed. Those are really the challenges.

How is MHV helping customers deal with these challenges?

First, we remanufacture pumps, and that represents an alternative to buying new, but only if it provides the same performance as new. A remanufactured pump can, for instance, cost as little as 50 to 60 percent of the cost of a new one. When MHV remanufactures a pump, it's to the exact tolerances and specifications as newly manufactured. And we prove that performance to our customers with a drawdown test. The industry norm is to use a run test, which simply shows that the pump runs, but that doesn't show process performance. A drawdown test actually draws the vacuum down and compares it to new pump-performance curves. No one else in the industry does that, so our customers get a fair choice between new and remanufactured because performance is the same.

One of our other services we provide is we work onsite hand-in-hand with our customers to optimize vacuum systems at no cost to them. We extend pump life and reduce operating costs with improved efficiency. For instance, a pump failure that can occur during an operating cycle can cost a company to incur out-of-spec product, which is really scrap rate as I see it; it's scrap. Another possibility is that you can get premature failure in your customer's finished goods, which is going to be returned to you as a warranty item. Now both scrap and warranty are known as direct charges, which is a cost that reduces profitability. Those are some areas where we can improve a company's profitability.

When we work with our customers at their facilities, they were able to reduce pump downtime in many cases. The other thing is that — and this really addresses the asset side —many remanufacturers will outsource machining to third parties or return to original manufacturers for more complex work. But all of the remanufacturing at MHV is completed at our facility. This reduces the turnaround time because we don't have to send it anywhere. And the turnaround is critical. With one particular customer, a major heat treater, we were able to help reduce the number of spare pumps they kept in inventory from four down to two by extending their pump life and reducing that turnaround. They didn't need four anymore. A new pump is $21,500 roughly, so what we did was remove $43,000 from his inventory. So, he's using less money to get the same amount of profit now. And that's how we help our customers deal with the challenges they face.

Where do you see heat treat in the next 10 to 20 years and MHV's place in it?

The heat-treat industry is made up a number of segments. Some of the segments will be robust and others are going to follow a traditional cyclical pathway, which, depending on the served industry, will either lead or lag in economic conditions. But two prominent segments that are going to outperform the GDP are the med-tech and aerospace industries. Med tech, at this point in time, I just don't see a visible ceiling, at least in the foreseeable future.

And aerospace will remain robust for the next 10 years or so. The order backlog for commercial aircraft is at an all-time peak right now. I think there are 14,000 units on backlog. And there are about 38,000 expected to be produced globally over the next 20 years. That's huge.

But regardless of whether the industry segment is in an upward or a downward part of their economic cycle, greater efficiency, more profitability, and less assets needed to achieve results are always going to be paramount for heat-treaters, and MHV is going to be there to help them in tangible ways.

MORE INFO www.methivac.com