Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

QUENCHING / INDUCTION HEATING

OIL QUENCHANTS FOR HEAT-TREATING PROCESSES

COMPANY PROFILE ///

Ajax Electric

JULY 2019
thermalprocessing.com

Leading the Way in On-Site Controlled Atmosphere Generators

RX® | Endothermic Gas Generators

RX® atmosphere creates the base carbon potential for Carburizing, Carbonitriding, Ferritic Nitrocarburizing, and Neutral Hardening processes

Typical chemical composition is 20% CO, 40% H_2, and 40% N_2 with trace amounts of CO_2, CH_4, and H_2O

Utilizes our patented ESA® Dew Point sensors

Built-in maintenance features

Fully tested prior to shipment

DX® | Exothermic Gas Generators

DX® atmosphere provides an inert atmosphere for many applications including Bright Annealing, Bluing, Brazing, Normalizing, Purging, Sintering, and Tempering

Chemical composition is based on air/gas ratio producing up to 87% N_2

Capacities from 1,000-30,000 cfh

Rich or lean operation for ferrous and non-ferrous materials

Fully tested prior to shipment

Our generators put you in control of your process atmosphere producing consistent, on-site RX and DX gas at lower operating costs than industrial gases. With recent design improvements and many standard options, our generators remain industry leading. Let us show you the **Value of Surface.**

Surface® Combustion

Engineered To Perform. Built To Last.

value@surfacecombustion.com
1-800-537-8980

surfacecombustion.com

CONTENTS ///

COVER PHOTO: SHUTTERSTOCK

DEPARTMENTS ///

JULY 2019 VOLUME 8 / NUMBER 7

UPDATE ///

New Products, Trends, Services & Development

Q&A ///

RESOURCES ///

Industrial Heating Equipment Association (IHEA)

METAL URGENCY ///

QUALITY COUNTS ///

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

FROM THE EDITOR ///

Looking for quenching info? You're in luck

If you picked up this issue of *Thermal Processing* looking for information on quenching, then you definitely won't be disappointed.

Quenching is a quintessential and necessary component in heat-treating, and, in this issue, we take a deep dive into various aspects of the process.

Starting with our Focus section, our cover article is by D. Scott MacKenzie, long-time contributor to our sister publication, *Gear Solutions*.

MacKenzie is senior research scientist-metallurgy at Houghton International Inc., so, needless to say, he is an expert on the subject.

Oil quenching can vary depending on the application, so it's important to make sure the correct quenching method is used. In his article, MacKenzie discusses the various methods of selecting the proper quench oil, as well as looking at the pros and cons of each.

Quenching with oil isn't the only way to quench, as shown in an article from Sergio Luevano with Baker Furnace. In the article, he looks at polymer quenchants — a hybrid of water and oil — and how this method has become a flexible and safer way to achieve mechanical properties.

But the quenching information doesn't stop there. In our Quality Counts column, Jason Schulze takes a look at understanding quench parameters in order to achieve part conformance.

If quenching isn't your thing, our July issue offers up a few more interesting articles that might get your attention.

Along with quenching, our secondary Focus topic is on induction heating. In an article featuring that subject, recent progress of induction heating technology at Baosteel is discussed.

In our company profile, I had the privilege of talking with Donna Stelman, president of Ajax Electric. The company has more than 80 years of experience in the manufacture of salt-bath furnaces. In the article, she shares her company's story as well as why a salt-bath furnace is important to the heat-treating world.

You'll find that and more in this issue. I hope you take away something you can use and maybe even learn something new. I know I always do.

Keep cool, and, as always, thanks for reading!

KENNETH CARTER, EDITOR
Thermal Processing magazine
editor@thermalprocessing.com
(800) 366-2185 x204

CALL FOR ARTICLES Have a technical paper or other work with an educational angle? Let Thermal Processing publish it. Contact the editor, Kenneth Carter, at *editor@thermalprocessing.com* for how you can share your expertise with our readers.

Thermal processing

David C. Cooper
PUBLISHER

Chad Morrison
ASSOCIATE PUBLISHER

EDITORIAL

Kenneth Carter
EDITOR

Jennifer Jacobson
ASSOCIATE EDITOR

Joe Crowe
CONTRIBUTING EDITOR

SALES

Chad Morrison
ASSOCIATE PUBLISHER

Dave Gomez
NATIONAL SALES MANAGER

Jim Faulkner
REGIONAL SALES MANAGER

CIRCULATION

Teresa Cooper
MANAGER

Jamie Willett
ASSISTANT

DESIGN

RIck Frennea
CREATIVE DIRECTOR

Michele Hall
GRAPHIC DESIGNER

CONTRIBUTING WRITERS

C.Y.WU, X.L.JIN
SERGIO LUEVANO
D. SCOTT MACKENZIE
LEE ROTHLEUTNER
JASON SCHULZE
Y.M.ZHOU

Media solutions

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

David C. Cooper
PRESIDENT

Chad Morrison
VICE PRESIDENT

Teresa Cooper
OPERATIONS

Dave Strand joined Wisconsin Oven Corporation in 1986. (Courtesy: Wisconsin Oven)

Dave Strand retires after 33 years at Wisconsin Oven

Dave Strand was hired in 1986 by Wisconsin Oven Corporation as a shop worker. In 2019, he retires as president and CEO of Thermal Product Solutions, LLC, the parent company of Wisconsin Oven. Strand has dedicated 33 years to the continued growth of Wisconsin Oven Corporation.

Strand will be remembered at Wisconsin Oven for his steadfast leadership and encouragement of employees. When he took over the position of president and CEO in 2005, he wanted to develop a culture that embraced employees and motivated them to play like champions every day. Strand created Wisconsin Oven's Work of Champions program and mission statement to inspire and reward employees for going above and beyond. This championship culture still holds true at Wisconsin Oven.

During his time at Wisconsin Oven, Strand was dedicated to giving back to East Troy, Wisconsin, and the surrounding communities. As honorary chairman of the United Way of Walworth County, he encouraged businesses to give back during the 2017 holiday giving campaign which resulted in more than $15,000 in donations. He was also focused on developing the next generation of talent and promoting careers in manufacturing through an annual scholarship to an East Troy High School graduate going into skilled trades or engineering and the creation of the Wisconsin Oven Universal Training Center (WOC-U) in 2018.

The employees of Wisconsin Oven held a retirement party for Strand on June 7 to celebrate his career and contributions to the company.

MORE INFO www.wisoven.com

Portable logger monitors curing of metal alloys at 800°F

CAS DataLoggers recently provided the oven temperature profiling solution for a manufacturer who needed to monitor its thermal curing production line. This involved large batches of metal alloys exposed to high temperatures in a long curing process. The customer's large production runs were cured in batches for hours in three large ovens running continuously. To ensure consistent product quality, it was important to have proof that the material had passed through the manufacturing process at the right temperatures for the right amount of time. The data logger solution would need to connect to Type K thermocouples and given the ovens' 800°F (426°C) temperatures, the customer also needed an especially resilient thermal barrier, all without going over budget.

CAS DataLoggers supplied the customer with a Grant Portable Oven Temperature Data Logger which featured six thermocouple input channels for use with Type T and Type K thermocouple probes and supported fast sample rates to enable fast process times up to eight samples a second. The manufacturer also opted to equip the logger with a Custom Enhanced Thermal Barrier with internal heat sink featuring advanced phase change technology for maximum protection and heat absorption. The barrier's all stainless-steel construction formed a robust and protective barrier for the data logger.

The standalone oven temperature profiling data logger formed part of a complete system for the customer's through-process monitoring, being battery-operated and easily portable. Users navigated the logger's menus through the simple three-button design via the built-in display and could also navigate them from a PC. Configuration enabled the logger to automatically start and stop recording at specific times and temperature

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.

By passing the Grant oven logger through the process along with the products, a temperature profile was produced to show exactly what was happening to the products during the cure cycle. (Courtesy: CAS DataLoggers)

levels to give users the most accurate process overview. Each reading reported the time and date, while the logger's non-volatile memory provided up to 260,000 readings of secure data.

By passing the Grant oven logger through the process along with the products, a temperature profile was produced to show exactly what was happening to the products during the cure cycle. At the end of a production run, the logger automatically gave users a percentage cure result on its integral screen. A quick unload of the data via the integral USB port allowed for further analysis, reporting, and data archival. The custom thermal barrier's phase change insert and heat sink stood up to the extreme heat, ensuring the reliability of the logger.

The manufacturer's product experienced improved quality following use of the Grant oven logger in its heat-treatment application. Additional benefits included increased efficiency, reduced energy costs, quality assurance reports for compliance and traceability, and complete quality control for the process. Additionally, the thermal barrier's solid construction offered excellent protection for a comparable price to others on the market.

MORE INFO www.DataLoggerInc.com

L&L installs electrical box retort furnace at aerospace supplier

L&L Special Furnace Co., Inc. has shipped and installed a retort box furnace to a worldwide leader of aerospace components in the southern U.S. The furnace is used to de-binder ceramic matrix composite components deployed in the aircraft industry.

The main function of the furnace is to remove all organics and other materials used in the product before placing it in a high-fire vacuum chamber. This de-bindering process is extremely important and allows for a finished product that is not only very strong but also lightweight.

The XLC524 has a work zone of 9" wide by 9" high by 18" deep. It has a temperature gradient of ±20°F at 1,100°F using six heating banks with biasing control to balance any temperature gradients.

The furnace is constructed with high-quality refractory insulation. It has a venturi cooling blower that aids in cooling, and is controlled by a Eurotherm program control with overtemperature protection. There is also a programmable flow panel to manage the nitrogen flow throughout the process.

The parts are a ceramic matrix composite (CMC), which is a series of ceramic threads that are bound together and woven by a 3D printing system. These parts can be made into very intricate aircraft sub-assemblies for the smaller units as well as large engine parts.

The parts are heated to 1,220 F in a retort chamber that is pressurized with nitrogen. The byproducts of the outgassing part are directed by pressure and flow out of the rear of the furnace. After de-bindering, the

XLC Series box furnace for ceramic matrix composites. (Courtesy: L&L Special Furnace Co.)

parts are heated in a vacuum furnace to temperatures in excess of 2,300 F. The result is a super-strong component that is more resilient and lighter than titanium.

All L&L furnaces can be configured with various options and be specifically tailored to meet thermal needs. It also offers furnaces equipped with pyrometry packages to meet ASM2750E and soon-to-be-certified MedAccred guidelines.

Options include a variety of control and recorder configurations. A three-day, all-inclusive startup service is included with each system within the continental U.S. and Canada. International startup and training service is available by factory quote.

MORE INFO www.llfurnace.com

Bill Gornicki named CEO of MTB, Diablo Furnaces

Machine Tool Builders announced the appointment of Bill Gornicki as chief executive officer (CEO) of both Machine Tool Builders (MTB) and Diablo Furnaces based in Machesney Park, Illinois. With 29 years' experience in the thermal processing industry, Gornicki brings a fresh perspective with proven results to leverage the dynamic and diversified companies' offerings of heat-treating furnaces and gear machinery forward to achieve new sales levels. Sustained improvement and long-term growth will be cultivated by Gornicki being focused in operational excellence, expansion of product breadth, and capabilities in existing and new markets.

Machine Tool Builders is a remanufacturer, recontroller, and custom-manufacturer of gear shaping, hobbing, and grinding machines. MTB also is the North American sales and service representative for Burri GmbH of Germany and Donner+Pfister AG of Switzerland. Burri GmbH manufactures generative grinders and wheel profiling machines, and Donner+Pfister AG manufactures and remanufactures gear and Maag gear grinding machines.

Bill Gornicki

Diablo Furnaces is an original equipment manufacturer (OEM) of IQF (internal quench) furnaces, tempers, box, belt, continuous, car bottom, rotary, pit, washers, and other custom heat-treating equipment required for captive and commercial heat treaters.

MORE INFO www.machinetoolbuilders.com

Increase furnace profitability with a heating chamber

The heating chamber plays a crucial role in vacuum equipment for metal heat treatment. Its condition determines the general performance of the system, power consumption and temperature distribution. Therefore, the condition of the heating chamber affects the heat treatment furnace profitability and the quality of processed details.

Modern heat treatment furnaces for metals are characterized by long lifetime and thus long-term maintenance program is of particular importance. Improper maintenance schedule or incorrect use of the furnace or even performing particularly "difficult" processes can lead to unexpected failures and unscheduled repair costs as well as equipment outage. When the heating chamber is severely worn out, the need for its replacement or overhaul becomes obvious.

Increased process cleanliness, better temperature distribution, trouble-free operation, lower heating power losses, better heating efficiency and increased safety are only some of the benefits associated with heating chamber replacement that can be summarized in two words: increased profitability. Global manufacturers of parts used in various industries who commissioned Seco/Warwick with the replacement of heating chambers have seen these benefits. Sinter Metal Technologies, global supplier and producer of ceramic components used in the automotive, power, construction, electronic, medical and transport industries, is one them. Replacement of the heating chamber in a more than 15-year-old vacuum furnace made it possible to increase its lifetime and capacity.

"Many years of cooperation with trusted suppliers, like Seco/Warwick, enable us to offer a wide range of high-quality products used in various markets around the world. Seco/Warwick is a reliable business partner which understands the needs of these industries," said Olgun Tanberk, chairman of the board, Sinter Metal.

"We provide modernizations and comprehensive overhauls both for Seco/Warwick equipment and for any other solution and equipment for heat treatment of metals developed by other manufacturers. Retrofit

of existing machinery does not only guarantee efficient operation of individual devices or entire production lines, but also ensures the highest safety level and economy of the investment. For Sinter Metal, replacement of the heating chamber was the optimum solution that will support cost reductions and improve the performance of the device in service," said Katarzyna Kowalska, managing director at Seco/Warwick Services.

MORE INFO www.secowarwick.com

EMAG induction heating system key to Elektror motor

Elektror airsystems is one of the international leaders in the production of industrial fans and side channel compressors. The company has been relying on UNI HEAT from EMAG eldec since mid-2018 for the production of the electric motors used in its fans. The system ensures quick and precise induction heating of the empty stator housing before the joining process with the motor winding. The process reliability and flexibility of the entire sequence are essential for the rapid "one-piece-flow" at Elektror.

Many industrial production processes wouldn't be possible without fans — they play a decisive role in the drying, suction, or cooling of materials. Often the stability and efficiency of the entire production process may even be dependent on the fans used.

The company headquartered in Ostfildern, Germany, with two production sites in Waghäusel (Germany) and Chorzów (Poland), produces about 60,000 industrial fans and side channel compressors per year. These are often customized solutions that stand out, for example, because of a precise pressure level, resistant materials, or a particularly low-vibration design. In the end, there are countless customization options available when designing a fan — and that obviously also applies to the devices' electric drives. That is why Elektror produces different sized motors and performance levels. Its components are configured to order and mounted within the scope of a lean process. In doing so, the ventilation specialists place the highest importance on process reliability. Fault tolerance is always set to "zero."

In this process, thermal joining of the empty stator housing and motor winding is one of the core processes. The housing is heated to a temperature of 280 to 300°C (536 to 572°F) using an induction heating system. This causes it to expand, allowing the motor winding to be inserted by hand. As it cools down, the housing contracts again and establishes a form-fitting and solid bond with the winding. In 2018, the specialists at Elektror decided it was time to replace the aging heating system.

"One of our main goals in making the investment decision was to increase process reliability around induction heating. For instance, the old system did not display

John Best, head of the motor engineering team at Elektror, inserts the motor winding into the heated (and thus expanded) empty stator housing. (Courtesy: EMAG)

the actual processing temperature that the component had reached. This led to longer throughput times in the subsequent joining operation. Furthermore, the supply of spare parts was not secured," said Roland Sand, head of the production team at Elektror. "Therefore, we were searching for a system that guarantees very precise temperatures during heating, whose operation is straightforward for any operator and whose processes consistently run. Additionally, we wanted a local supplier who could be on location immediately when servicing is required. EMAG eldec meets these requirements with its UNI HEAT technology."

Overall, a very safe and quick process is put into effect around the custom-designed UNI HEAT system: The operator grabs the empty housing with protective gloves, places it in a custom-fit workpiece carrier and pushes it inside the machine. By closing a sliding door, he starts the following process: The component moves upward into its home position. This leads the induction rod to "plunge" into the empty housing enclosure. The subsequent heating process lasts only 30 to 120 seconds, depending on the size of the component. Once it is completed, a warning lamp signals to the operator that the component can be removed. He places it in a mold, which is ready at the cooling location, and pushes the motor winding from the top inside. After a short cooling process, the motor is fully combined and ends up on a conveyor belt to the next processing step.

EMAG eldec is well-positioned to develop these core elements of a heating process: Firstly, a wide range of generators with high efficiency and precise application of energy are produced at the site in Dornstetten. Secondly, the specialists produce up to 1,000 inductors per year. They are produced within the scope of a sophisticated manufacturing process that hinges on many tiny details. Critical factors include, for example, how deep and where the heat needs to penetrate into the component. That affects the shape of the inductor and the configuration of the generator. Furthermore, EMAG eldec relies on extensive prior simulation of the process and the use of thermal imaging cameras. Lastly, every UNI HEAT overall solution is tested with the real workpiece and presented to the customer during an acceptance check in Dornstetten.

MORE INFO www.emag.com

GalvanoTechnik expands surface treatment portfolio

Family-owned heat-treatment company GalvanoTechnik in Lombardy, Italy, has expanded its surface treatment services portfolio to include Nitreg® controlled nitriding, Nitreg®-C nitrocarburizing, and ONC® in-process oxidation treatments. The company invested in a compact Nitrex system model, NXK-609, configured to process 23.5" diameter by 35.5" high (600mm by 900mm) workloads that weigh up to 1,300 lbs (600 kg). The system complies with the temperature uniformity requirements of AMS 2750E, in addition to meeting specifications ASM 2759/10, which make it possible to consistently achieve the required metallurgical and mechanical properties for controlled nitriding. Other advantages of the NXK series include a reduced footprint and a system configuration that combines three process technologies into one platform.

The move to add nitriding and nitrocarburizing to its portfolio was the result of GalvanoTechnik engaging in deeper dialogue with its customers and identifying these new needs. Six months after the successful installation and start-up of the Nitrex system, the company is now supporting customers in the defense and automotive industries with the full benefit of the Nitreg brand technologies to solve unique challenges related to wear and corrosion resistance as well as aesthetic surface finishes. Applications range from firearms components, such as magazines and barrels, to automotive components, with recipes tailored to meet the exact requirements of each part. Working with GalvanoTechnik, the Nitrex research and technology team designed and tested process recipes to find the right match. All control recipes are stored to the Nitrex system process library, and the operator simply selects the process for the specific application. The control system then takes over, automatically monitoring and adjusting parameters such as time, temperature, atmosphere composition, Kn nitriding potential, and many more.

Nitrex Metal is a worldwide 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, aluminium extrusion, defense, gears, tool and die, plastics, machinery, and other industries.

MORE INFO www.nitrex.com

The space simulator is a fairly standard piece of equipment for Tenney, but each simulator can be customized to meet the customer's unique process needs. (Courtesy: TPS)

Tenney ships refurbished space simulator

Tenney Environmental, a division of Thermal Product Solutions, recently announced the shipment of a refurbished space simulator to the aerospace industry. The space simulator is a fairly standard piece of equipment for Tenney, but each simulator can be customized to meet the customer's unique process needs.

The refurbished Tenney space simulation chamber uses a cascade cooling system and has a temperature range of -60°C to 90°C. It is constructed with a thermal shroud and thermal platen which will perform the thermal conditioning function. This vacuum chamber has an extremely low maintenance oil sealed style roughing pump and a helium cryopump high vacuum system.

Tenney provided an in-stock fluid chiller solution system with this refurbished space simulator in order to get it up and running as quickly as possible, per the customer's request. Along with this fluid chiller solution, Tenney is also designing and building a custom larger chiller and refrigeration system that will be supplied at a later date to provide the customer with faster transition rates.

"This customer came to me asking for an extremely fast turnaround on a new system. The request was impossible for a new unit from any manufacturer, so I informed them of this used space simulator that we could refurbish and add a fluid conditioning system to provide a fast, inexpensive, very reliable system," said Rick Powell, vacuum products manager.

Features of this refurbished space simulation chamber include:

- Thermal platen supports 10 pounds mass load.
- 5.0 x 10-6 Torr vacuum range.
- -60°C to 90°C temperature range.
- Two 1.0 horsepower hermetic recipro-

cating type compressors.

› Low-maintenance roughing pump.

› Cryopump high-vacuum pump.

MORE INFO www.thermalproductsolutions.com

Wisconsin Oven ships soluble mandrel curing oven

Wisconsin Oven Corporation recently announced the shipment of one electrically heated soluble mandrel curing oven to a manufacturer in the aerospace industry.

The curing oven has a maximum oven operating temperature of 400°F and work chamber dimensions of 12'0" wide x 12'0" long x 20'0" high. Guaranteed temperature uniformity of ±10°F at set points 150°, 200°, 250°, 300°, 350°, and 400°F was documented with a 15-point temperature uniformity survey in an empty oven chamber under static operating conditions.

This batch oven has sufficient capacity to heat 8,000 pounds of steel and 20,000 pounds of soluble material from 80° to 350°F at an average rate of 0.1°F per minute. To maximize heating rates and temperature uniformity of the product, horizontal and vertical upward airflow were featured in this oven.

"Our ability to customize our standard lines of equipment is part of the reason we have so many repeat customers. They know that we will be able to meet all of their requirements and that our quality and customer service is unbeatable," said Nick Toci, sales engineer.

Features of this soluble mandrel curing oven include:

› Temperature uniformity of ±10°F at 150°, 200°, 250°, 300°, 350°, and 400°F.

› Two 11,000 CFM @ 10 HP plug mounted blowers, 22,000 CFM @ 20 HP total.

› 576 kW heat input with SCR power control.

› 3,100 CFM @ 1.5 HP exhaust blower.

› Bi-parting, side-hinged, horizontal swing doors.

› Digital Eurotherm 3504 temperature controller.

› Eurotherm 6100A paperless digital recorder with 5.5" graphic touch screen display.

› Ethernet communication capabilities.

This batch oven has sufficient capacity to heat 8,000 pounds of steel and 20,000 pounds of soluble material from 80° to 350°F at an average rate of 0.1°F per minute. (Courtesy: Wisconsin Oven)

This batch oven was fully factory tested and adjusted prior to shipment from our facility. All safety interlocks were checked for proper operation and the equipment was operated at the normal and maximum operating temperatures. An extensive quality assurance check list was completed to ensure the equipment met all Wisconsin Oven quality standards.

MORE INFO www.wisoven.com

Rudnev delivers lecture on induction heat treatment

Dr. Valery Rudnev, IFHSTE Fellow and director of science and technology at Inductoheat, Inc., an Inductotherm Group company, delivered the William Woodside lecture at the ASM Detroit Chapter's end of the year chapter meeting in May. The Woodside Lecture is named for William P. Woodside, the founder of ASM in Detroit in 1913.

Rudnev spoke on "Recent Theoretical and Practical Novelties in Induction Heat Treatment." He is considered by many as one of the leading global figures in the induction heating and heat-treating industry with more than 40 years of experience. He is known within the ASM International and among induction heating professionals as "Professor Induction."

Thermal processing by means of electromagnetic induction continues to grow at an accelerated rate replacing alternative processes. Today's metal working and heat-treating industry must quickly adjust to a rapidly changing business environment, maximizing cost effectiveness, process flexibility, and energy efficiency, yet satisfy continuously increasing demands for higher-quality products, equipment longevity, and environmental friendliness.

Dr. Valery Rudnev

Induction heating is a multifaceted phenomenon comprising a complex interaction of electromagnetics, heat transfer, circuit analysis, power electronics, and metallurgical phenomena that are tightly interrelated.

Novel designs have appeared quite regularly. Rudvev's presentation focused on recent theoretical and practical novelties in induction heat treatment. Common mispostulations associated with induction heating and frequently overlooked metallurgical

subtleties will be unveiled here as well.

Rudnev has been elected as a Fellow of both ASM International and International Federation for Heat Treatment and Surface Engineering (IFHTSE). His credits include a great deal of know-how, more than 50 patents and inventions (U.S. and International), and more than 250 engineering/scientific publications.

MORE INFO www.asminternational.org

Seco/Warwick has new technology for case-hardened parts

Automotive manufacturers have joined other industries facing the dual challenges of compressed time to market and compliance with strict industry standards in exploring new strategies for achieving their goals.

The Industry 4.0 approach to modern manufacturing addresses these challenges using automation and technologies that produce high-quality products with repeatable results while reducing operating costs by eliminating waste and cycle time with a focus on quality. By approaching old problems with new thinking, Seco/Warwick's new technology for high-volume production of case-hardened parts (UniCase Master®) is helping progressive companies save billions in operating costs.

In traditional heat treatment, distortion of components post-treatment is the historic problem that generates additional costs due to rejected parts and additional machining to correct these problems. Seco/Warwick, winner of Intelligent Development Award, has developed an innovative UniCase Master system, which can replace outdated heat-treatment methods by using a fully automated system that revolutionized how gearbox components are loaded and quenched using the single-flow case hardening system.

The system, simply defined, continuously loads parts that individually enter the heat-treatment process, and when complete, enter 4D quench for precision cooling that is key to eliminating component distortion. The transfer systems in and out of the furnace are designed to maintain the integrity and surface quality of each component, even at high volumes.

The fully automated UniCase Master system offers users a system technology that achieves repeatable results for high-volume heat treatment, eliminating human interventions throughout the process. A sophisticated control system proven throughout thousands of installations controls all options within the system complete with pre-programmed cycles for the Seco/Warwick signature technologies including FineCarb® vacuum carburizing and tempering and isothermal quenching. Seco/Warwick provides a comprehensive technical service package offering, Seco/Predictive, an advanced control option that can detect potential failures before they occur.

It reduces the distortion of gears in continuous production that challenges conventional case-hardening methods with a single flow, precision case-hardening system for high-volume manufacturing.

Learn more about the process by viewing a video interview with Maciej Korecki. (https://www.youtube.com/watch?v=q9-zQ91mJm4&feature=youtu.be)

MORE INFO www.secowarwick.com

UniCase Master® is Seco/Warwick's new technology for high-volume production of case-hardened parts. (Courtesy: Seco/Warwick)

TPS ships cleanroom truck-in ovens to medical industry

Thermal Product Solutions, a global manufacturer of thermal-processing equipment, announced the shipment of three Gruenberg cleanroom truck-in ovens to the medical industry.

These Gruenberg walk-in ovens have maximum temperature ratings of 71°C and work chamber dimensions of 42" W x 48" D x 72" H. The ovens were constructed from a structural steel frame that supported the 304L stainless steel interior chamber liners and the exterior 304 #4 polished stainless-steel faces with the remainder primed and painted. All interconnecting struts are non-continuous which keeps the exterior cool.

The front-loaded truck-in ovens use horizontal airflow, which maximizes heating rates and temperature uniformity of the product load. A circulation blower located in a conditioning plenum chamber on the top of the oven directs air through perforated panels on one side of the chamber and flows horizontally across the product. The air exits the work chamber on the opposite wall back through the steam coil for reheating and recirculation.

"Gruenberg products are designed to meet the highest standards of safety specifications. These truck-in ovens were designed to accommodate the customer's loading trucks and trays for the drying of very sensitive medical devices encased in pouches," said Denny Mendler, Gruenberg product manager.

MORE INFO www.thermalproductsolutions.com

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

IHEA celebrates 90 years during its 2019 Annual Meeting

A celebratory toast to IHEA's 90th Anniversary.

Association annual meetings are once-a-year events that allow members to come together, exchange ideas, learn from expert speakers, work on committee initiatives, and network with others in the industry. But this year, IHEA's 2019 Annual Meeting held at the Lido Beach Resort in Sarasota, Florida, was a special one.

This year's meeting that brought members together for three days was IHEA's 90th Anniversary as an association; 90 years is a remarkable milestone! There aren't many associations around today that can claim they are 90 years old. The meeting included a series of outstanding presentations that were very highly rated by those in attendance:

› Speaker Bob Sherlock addressed an important subject for the membership about learning the power of selling value over price. Members picked up a variety of important tips from Sherlock.

› Omar Nashashibi of the Franklin Group gave an interesting presentation on what's happening in Washington today, giving us a sneak preview of what lies ahead as we move into an election year in 2020.

› Scott Bishop of Alabama Power helped members understand how and why they should work more closely with utility companies.

› IHEA staff member James Moore, along with Chris Della Mora of Hub International Risk Services, discussed cyber-security issues and why everyone is at risk. Members agreed that this discussion could have lasted longer.

IHEA memorabilia was on display.

Surface Combustion staff members receive a special recognition award for being an IHEA member for 90 years.

› Finally, IHEA's economist Chris Kuehl, a perennial favorite, gave his economic update, which is always interesting and entertaining.

"The energy level at this year's meeting seemed to be at an all-time high," said IHEA Executive Vice President Anne Goyer. "I think it was a combination of our 90th anniversary, great speakers, wonderful camaraderie, and social activities that brought a higher level of liveliness at this year's meeting."

Certainly, the highlight of the meeting was IHEA's gala banquet. Memorabilia from IHEA's past was on display and a special presentation that honored Surface Combustion for being an IHEA member for all 90 years made for remarkable and memorable moments. IHEA members old and new enjoyed the photos, stories, and memories shared.

B.J. Bernard, Surface Combustion's president, said he was "honored to receive an award recognizing Surface's long-time membership" and he noted that Surface has, and continues to be, committed to IHEA and serving the thermal-processing industry.

The event ended with a toast to IHEA's 90th Anniversary and cheers to a bright future.

IHEA 2019 CALENDAR OF EVENTS

AUGUST 28–29

The Powder Coating & Curing Processes Seminar

The day and a half Introduction to Powder Coating & Curing Processes Seminar will include classroom instruction and hands-on lab demonstrations.

› Alabama Power Technology Center | Calera, Alabama

SEPTEMBER 24–25

IHEA 2019 Safety Standards & Codes Seminar

This seminar is intended to help the attendee become better acquainted with the newly updated NFPA 86 – Standard for Ovens & Furnaces.

› InterContinental Hotel Cleveland | Cleveland, Ohio

SEPTEMBER 24–25

IHEA 2019 Combustion Seminar

The industry premier seminar for industrial process heating professionals, this two-day event offers attendees the chance to learn the latest in combustion technology and visit with industry suppliers. The IHEA Combustion Seminar is designed for persons responsible for the operation, design, selection and/or maintenance of fuel-fired industrial process furnaces and ovens.

› InterContinental Hotel Cleveland | Cleveland, Ohio

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

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

P.O. Box 679 | Independence, KY 41051

859-356-1575 | www.ihea.org

LEE ROTHLEUTNER
PRINCIPAL DEVELOPMENT ENGINEER /// THE TIMKEN COMPANY

Process evaluations can help narrow down the causes of NMTP formations that can reduce component performance.

Combatting undesirable NMTP formations

Whether formed during a conventional quench and tempering process, carburizing, or induction hardening, non-martensitic transformation products (NMTP) are widely considered undesirable microstructural features. However, both the cause of NMTP formation and the extent to which NMTP impairs component performance are points for deliberation.

IDENTIFICATION

By definition, NMTP comprises all microstructural features other than martensite that transform from austenite upon cooling when a fully martensitic microstructure is intended. The fact that NMTP forms during transformation from austenite upon cooling is an important distinction, particularly in highly dynamic processes such as induction hardening. If an induction-hardened process is not optimized, it can result in both retained and transformed non-martensitic constituents, with only the latter truly being considered NMTP. Retained constituents such as ferrite result from insufficient temperature and/or time at temperature to fully transform the microstructure to austenite before cooling. Identifying retained versus transformed constituents is critical in effectively improving the specific heat-treating process.

Figure 1 shows an optical micrograph of a 1045 steel in a region of an induction-hardened case that was intended to be fully martensitic. The dark etching features are readily identifiable as non-martensitic constituents; however, not all are easily identified as NMTP. Understanding the processing used to generate the microstructure and/or higher magnification imaging is usually required to distinguish between retained and transformed non-martensitic constituents.

Figure 2 shows a higher magnification secondary electron image of a region adjacent to the micrograph shown in Figure 1. Arrows indicate the microstructural features in question. Based on the sharp ferrite morphology and carbide precipitation behavior, the constituents appear to have formed upon cooling, confirming their designation as NMTP.

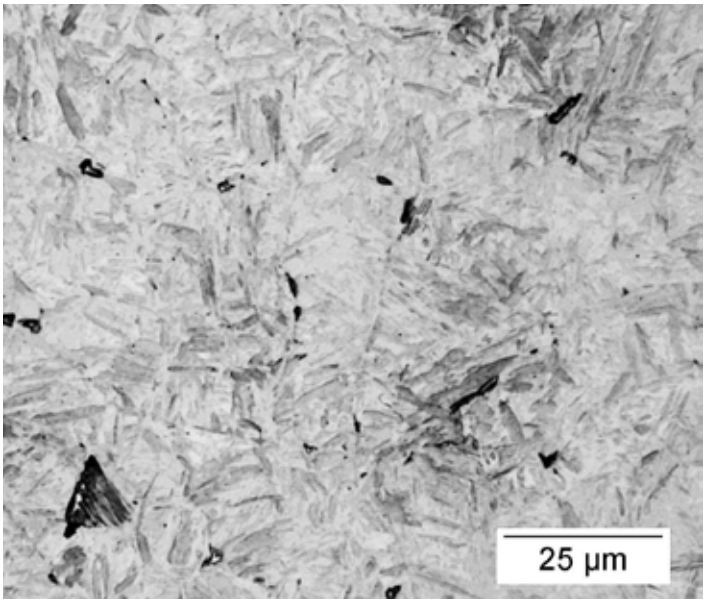


Figure 1: Optical micrograph of a region within the induction-hardened case of a 1045 shaft showing NMTP as dark etching features [1].

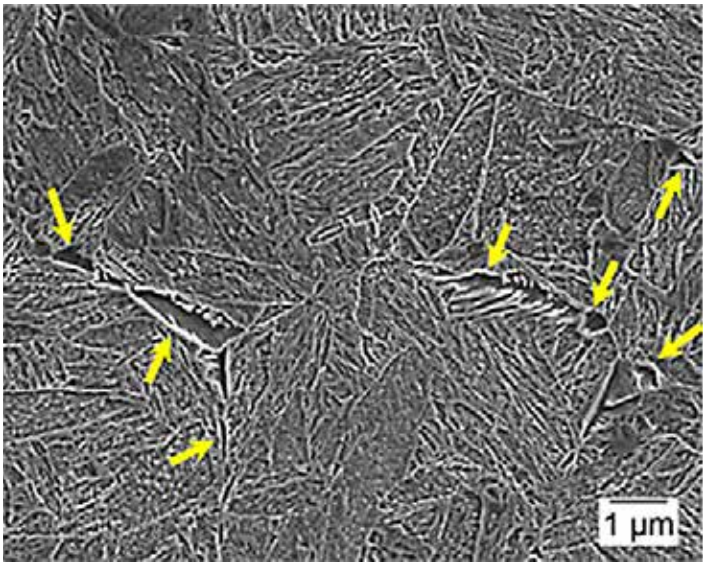


Figure 2: Scanning electron microscope secondary electron image of NMTP identified by arrows [1].

POTENTIAL CAUSES

In most cases, NMTP formation is caused by an unexpected change in process. A "change in process" can be narrowed to anything that alters the austenitizing cycle (e.g., temperature and/or time at temperature) or the cooling characteristics (e.g., cooling rate and quench severity) of the component. Potential causes include, but are not limited to, the following:

Change in Performance of Fixed Assets and Tooling

In both furnace and induction heat treating, preventive maintenance is critical. Ensuring the equipment and tooling are performing as intended is key to a stable and capable process.

Change in Part Stacking or Spacing of Batch-Processed Parts

Operator-controlled factors such as part stacking consistency and spacing during batch heat treatment can result in significant pro-

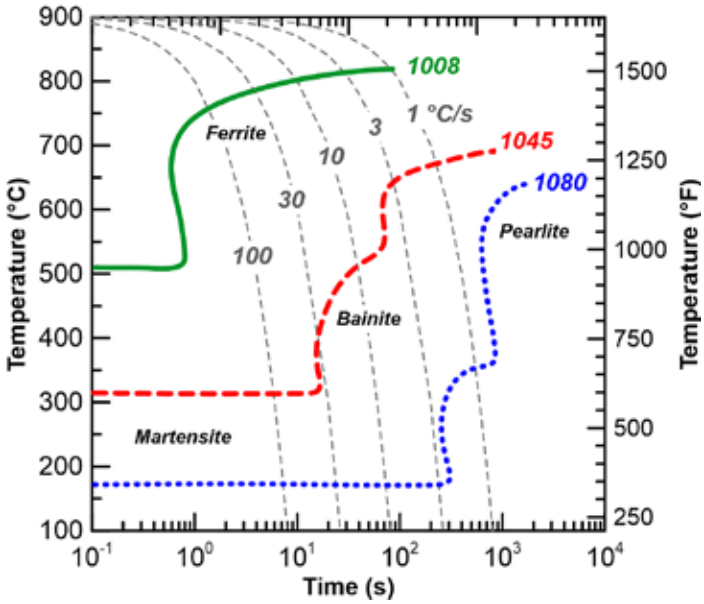


Figure 3: Continuous cooling transformation diagrams for 1008, 1045, and 1080 plain carbon steels, indicating the initiation of austenite decomposition into different phases and constituents (in this case, 1-percent transformed). A range of cooling rates is shown for reference. Developed using data from EWI [3].

A component containing microstructural features with lower strengths than martensite, such as NMTP, would likely accumulate fatigue damage at an accelerated rate and would ultimately nucleate a fatigue crack.

cess variations, especially with regard to cooling characteristics. In addition, each part geometry usually requires a slightly different configuration to achieve the desired results. Having well-established procedures, clearly documented work instructions, and adequate operator training minimizes inconsistencies.

Change in Heat-Treating Atmosphere

During austenitizing, it is critically important to have precise control of surface oxidation. Changes in alloy chemistry localized at the surface, such as decarburization and alloy depletion, can result from oxygen exposure during heat treatment. One well-known example of this phenomenon is intergranular oxidation (IGO), which can occur during gas carburizing. IGO has been observed to reduce the hardenability of the matrix adjacent to the oxides by depleting the region of alloying elements such as manganese (Mn), resulting in NMTP [2].

Change in Quenchant Characteristics

The reduction of cooling rate and quench severity can be specific causes of NMTP formation. Following quenchant supplier-recommended maintenance procedures helps ensure acceptable results.

Although many of the scenarios that can result in NMTP are listed here, a conceptual understanding of the factors controlling NMTP formation is often more useful when actively troubleshooting a process. Figure 3 shows continuous cooling transformation (CCT) diagrams for three plain carbon steels: 1008, 1045, and 1080. For the sake of simplicity, only the 1 percent transformed locus for each phase or constituent is shown. This figure clearly shows the relationship between carbon composition and transformation behavior for a given cooling rate. As carbon content increases, transformation temperatures decrease, as does the cooling rate required to achieve a specific microstructure.

For example, one hypothesized scenario in which this figure is useful is under-heated 1045 steel ("under-heated" meaning insufficient temperature or too little time at temperature during austenitization). In this case, it is unlikely that all the carbon will go into solid solution, resulting in regions that may exhibit transformation behavior analogous to steels of lower carbon composition and shift the CCT to slightly higher temperatures and shorter times (more toward a 1008 steel). Consequently, a higher cooling rate is required to achieve a fully martensitic microstructure.

Figure 3 also shows the importance of cooling rate control. For both the 1045 and 1080 steels, the bainite "nose" has a nearly vertical region where the cooling rates are close to the critical cooling rate (i.e., the minimum cooling rate required to create a fully martensitic microstructure). This behavior indicates that these steels can exhibit significant amounts of NMTP with only minimal reduction in cooling rate.

INFLUENCE ON PERFORMANCE

Qualitatively, there is no doubt that NMTP decreases performance in components that are intended to be fully martensitic [2]. However, there is little literature quantifying the deterioration of properties such as strength, ductility, and fatigue performance as a result of NMTP. Nevertheless, the concept of fatigue performance reduction due to the presence of NMTP is relatively straightforward. In general, the fatigue limit of steels scales with tensile strength [4]. Therefore, a component containing microstructural features with lower strengths than martensite, such as NMTP, would likely accumulate fatigue damage at an accelerated rate and would ultimately nucleate a fatigue crack at lower cycles than a fully martensitic component.

CONCLUSION

NMTP can be an indication of a variety of issues. Identifying the root cause often requires a systematic evaluation of the process, but having a good understanding of the fundamentals of NMTP formation can help narrow the focus more quickly.

REFERENCES

[1] L.M. Rothleutner, "Assessment of the microstructure and torsional fatigue performance of an induction hardened vanadium microalloyed medium-carbon steel." Ph.D. diss., Colorado School of Mines. Arthur Lakes Library, 2016.

[2] G. Krauss, Steels – Processing, Structure, and Performance, 2nd Edition, ASM International, Materials Park, OH, 2015.

[3] Edison Welding Institute, "TTT and CCT Prediction," accessed March 10, 2017. http://calculations.ewi.org/vjp/secure/TTTCCTPlots.asp.

[4] G. Dieter, Mechanical Metallurgy, Vol. 3. New York: McGraw-Hill, 1986.

This article is from the May/June 2017 issue of *Thermal Processing.*

ABOUT THE AUTHOR

Lee Rothleutner is a principal development engineer with The Timken Company. He received his Ph.D. in Metallurgical and Materials Engineering from the Colorado School of Mines. He can be reached at lee.rothleutner@timken.com.

JASON SCHULZE
METALLURGICAL ENGINEER /// CONRAD KACSIK

To achieve part conformance, it's crucial that quality representatives understand the quench parameters and the process.

A technical guide to quenching

From a quality perspective, verification of the conformance of quench requirements can be accomplished by examining a furnace chart that shows the quench trend. While this method may enable the quality personnel to determine conformance to quench parameters has been met, it does not mean the quality personnel are prepared to understand the quenching process itself.

In the following, I will attempt to explain the technical side of quenching which should enable quality personnel to better associate the technical aspects of quenching with the quality review and approval.

THE PROCESS OF QUENCHING

The process of quenching is intended to alter the microstructure of metals in conjunction with a thermal process. For example, the purpose of quenching A356 Al castings is to keep the Mg2Si from forming precipitates. If done correctly, this yields maximum strength and good elongation in castings.

Quenching of steel is generally accomplished by immersion in water, oil, polymer solution, or salt, although forced air is sometimes used. As a result of quenching, production hardware must develop an acceptable as-quenched microstructure and, in critical areas, mechanical properties that will meet minimum specifications after the parts are tempered. The effectiveness of quenching depends on the cooling characteristics of the quenching medium as related to the ability of the steel to harden. Thus, results may vary by changing the steel composition or the agitation, temperature, and type of quenching medium.

The design of the quenching system and the thoroughness with which the system is maintained contribute to the success of the process. The design of the part also contributes to the mechanical properties and the distortion that will result from the quench. There are several important steps in the quenching process that should be considered.

QUENCH STAGES

In general, there are three different stages during quench:

- Vapor stage (Stage A).
- Boiling stage (Stage B).
- Convection stage (Stage C).

Stage A: The vapor stage initializes when the material is immersed in the quench medium. The metal is surrounded by a blanket of vapor. What little heat transfer occurs is done through the vapor blanket. Proper agitation will remove this stable vapor blanket to ensure stage B is reached as quickly as possible.

Stage B: The boiling stage is when the vapor begins to dissipate, and the quench solution touches the metal surface. Once in contact with the metal surface, the quench solution begins to boil.

This is the fastest stage of the process and, in consequence, increases the heat-transfer characteristics.

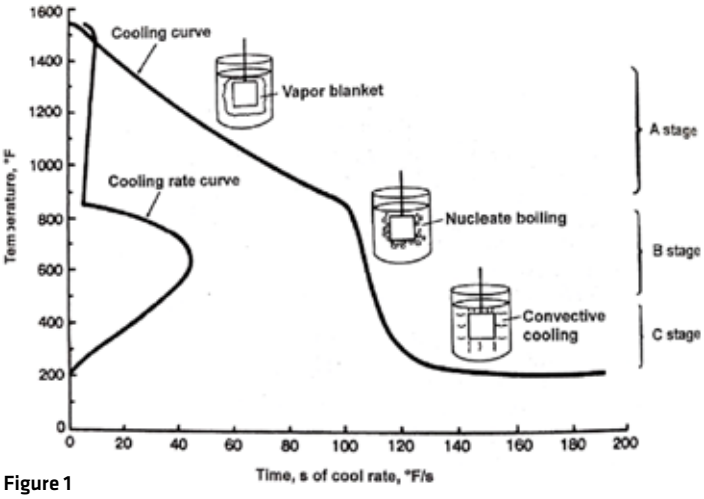


Figure 1

The boiling stage stops when the quench solution in contact with the metal falls below the quench medium's boiling point.

Stage C: The convection stage occurs when the boiling has ceased. The remainder of this stage consists of heat transfer. This stage yields the slowest cooling rates. Typically, this is the stage where the majority of distortion originates.

QUENCH PARAMETER REVIEW/VERIFICATION

Quench parameters should be clearly identified on suppliers' internal procedures/work instructions. This not only enables the operators to ensure the hardware is processed correctly, but also allows the quality representative verifying the quench to clearly understand the quench variables. These variables will include quench medium (water, water/polymer mix, oil, salt, etc.), agitation, quench delay, quench temperature, as well as quench solution volume vs. part size.

SUMMARY

Conformance to quench parameters is essential to achieve overall conformance. Understanding the technical aspects of quenching should help in the review process and also give quality representatives more confidence when issues may arise.

ABOUT THE AUTHOR

Jason Schulze is the director of technical services at Conrad Kacsik Instrument Systems, Inc. As a metallurgical engineer with 20-plus years in aerospace, he assists potential and existing Nadcap suppliers in conformance as well as metallurgical consulting. He is contracted by eQualearn to teach multiple PRI courses, including pyrometry, RCCA, and Checklists Review for heat treat. Contact him at jschulze@kacsik.com.

The Solution

ALD Thermal Treatment, Inc.

Global Service Centers

- Limbach-Oberfrohna Germany
- Port Huron, Michigan USA
- Ramos Arizpe, Coahuila Mexico

www.aldtt.net

MOTION+POWER TECHNOLOGY EXPO

Visit us at Booth 3200

High Tech is our Business

ALD is a leader in vacuum process technology and Heat treatment services.

LEADERS IN THE CONTROL OF DISTORTION

+ Low Pressure Carburizing
+ High pressure gas quenching
+ Gas Nitriding
+ Ferritic Nitro-Carburizing
+ Plasma Carburizing
+ Normalizing
+ Hardening
+ Annealing
+ Brazing
+ Cryogenic Treatments
+ Engineering services and process development
+ Prototype and trials

Enrique Lopez – Sales and Marketing
Email: sales@aldtt.net
Phone +1 (810) 357-0685

ALD Thermal Treatment, Inc.
2656 24th Street
Port Huron, MI 48060, USA

ALD is a subsidiary of AMG Advanced Metallurgical Group N.V.

SELECTION OF OIL QUENCHANTS FOR HEAT-TREATING PROCESSES

Discussing the various methods – as well as the pros and cons – of selecting a quench oil for various applications.

By D. SCOTT MACKENZIE

Modern quenching oils offer a wide range of capability and performance. The selection of the proper quench oil is critical for proper heat-treating operations. The quenchant selected must provide consistent quenching the first time, as well as over the life of the quenchant. Improper selection of quench oil can result in short oil life, or soft parts. Improper maintenance of the quench oil can result in stained parts. This paper will illustrate the selection factors in choosing a quench oil to ensure proper quality parts.

INTRODUCTION

It is not known how long oils have been used in the hardening of ferrous alloys. Many types of oils have been used, including vegetable, fish, and animal oils, and, in particular, sperm whale oil have been used for quenching operations [1]. The first petroleum-based quenching oils were developed around 1880 by E.F. Houghton in Philadelphia. Since that time, many advancements have been made in the development of quenching oils to provide highly specialized products for specific applications.

A wide range of quenching characteristics can be obtained through careful formulation and blending. High quality quenching oils are formulated from refined base stocks of high thermal stability. Selected wetting agents and accelerators are added to achieve specific quenching characteristics. The addition of complex anti-oxidant packages is included to maintain performance for long periods of continued use — particularly at elevated temperatures. Emulsifiers may be added to enable easy cleaning after quenching.

METHODS OF QUENCH OIL SELECTION

The steel composition, component section thickness, and the type of quenchant all have a major influence on the properties obtained in the heat-treated condition. The selection of quench oil is dependent on the part, type of furnace, and cost.

The part requirements are critical. The alloy must be considered to achieve the proper hardness and required mechanical properties. Geometry and section size are influenced by the hardenability of the alloy. This limits the section size for through hardening. The geometry of the part also influences the residual stress state and distortion. Non-uniform section sizes, sharp radii, and complex shapes can contribute to distortion and potential part cracking. The oil must be chosen, as well as the method of fixturing, to minimize the potential of distortion and quench cracking.

The furnace also influences the choice of quenchant. If the agitation in the quench tank is poor, then fast oil must be chosen. If the part is prone to distortion, then the furnace and quench tank must be capable of heating the oil to the proper temperature for martempering.

If the part is press-quenched, then an oil must be chosen that is tolerant of the presence of the inevitable infiltration of hydraulic fluid. It also should provide some lubricity to prevent excessive wear to the quench die fixtures. It also should have an excellent anti-oxidant package to provide repeatable quenching of high surface volumes with limited quenchant volumes.

The cost of the quenchant is also important. Unfortunately, this is often the only variable considered. The initial cost and in-use costs, as well as the final end-of-life costs of disposal and environmental cost must be considered.

The initial costs are influenced by the quality of the base oil stock chosen and the quality and robustness of the additive package. The additive package consists of speed improvers and anti-oxidants. The quality of the anti-oxidant package also influences the in-use cost.

The in-use cost is influenced by the maintenance costs associated with the quench oil. The cost of testing to ensure repeatable testing must be considered. Other maintenance costs such as filtering should be included in the calculation. The cost of additive packages (usually not required by quality quench oils) added to the quench tank as the quench oil ages is not usually added to the cost calculations because this usually falls under the maintenance budget. However, it should be added to understand the total cost of the quench oil selected.

The steel composition, component section thickness, and the type of quenchant all have a major influence on the properties obtained in the heat-treated condition. The selection of quench oil is dependent on the part, type of furnace, and cost.

One additional factor not usually included is the cost of cleaning the parts. Finally, the oxidative stability of the oil should be considered. If the oil tends to oxidize rapidly, this will increase the cost of cleaning and require replacing the oil more often. This is especially true of oil used in martempering applications.

Consumption of the oil by drag-out should also be considered in the quench-oil calculations. Higher viscosity oil will tend to drag out more, as will high surface area parts. The method of racking parts can

cause the retention of higher-than-normal quantities of oil. Attention to racking and proper drain times can reduce consumption.

In general, there are three different situations for the selection of quench oil:

› Existing operation wanting a different quench oil because the life of the existing oil has been depleted; dissatisfaction with current supplier; or cost of existing quench oil.

› New operation similar to existing process, such as the addition of a new line for increased capacity, or a new facility at a different location processing similar parts.

› New operation or new process with new or different configuration parts or parts of a different alloy.

The selection of quench oil can be accomplished by one or more methods: Comparative Cooling Curves; Hardening Power, or by the Grossman H-Value of the quenchant. In each case, not only must the quenching characteristics be considered, but the thermal stability of the oil should be considered.

Variable	Method				
	ISO 9950	AFNOR NFT-60778	JIS K2242	Z8 E 45003	ASTM D6200
Country	International	France	Japan	China	USA
Probe Alloy	Inconel 600	Silver 99.999% Pure	Silver 99.999% Pure	Silver 99.999% Pure	Inconel 600
Probe Dimensions	12.5 x 60	16 x 48	10 x 30	10 x 30	12.5 x 60
Vessel Dimensions, mm	115±5 dia.	138 dia. X 99 high	300 ml beaker	300 ml beaker	115±5 dia.
Oil Volume, ml	2000	800	250	250	2000
Oil Temperature ºC	40 ± 2	50 ± 2	80, 120, 160	80 ± 2	40 ± 2
Probe Temperature, ºC	850 ± 5	800 ± 5	810 ± 5	810 ± 5	850 ± 5

Table 1: Comparison of Cooling Curve Test Methods (after Liscic et al) [2].

COMPARATIVE COOLING CURVES

When an existing process requires new oil, the new quenchant must be metallurgically equivalent. This means the cooling curves or the quenching path should be similar. The cooling curve is measured by several different methods described in Table 1 [2]. It should be mentioned that it is very important the same cooling curve methodology be used. Different methods of cooling curve measurements are not directly comparable [3].

When testing oil for comparison purposes, only new oils should be chosen. This is because old oil will show oxidation and appear faster than the new oil. Further, the oil must be tested by the same method and preferably at the same time by the same testing laboratory to eliminate inter-laboratory testing variation.

As a general rule, oils are considered to be metallurgically equivalent if the Maximum Cooling Rate is ± 14°C/second; the temperature at the Maximum Cooling Rate is ± 14°C, with similar viscosities and flash point. This is illustrated in Figure 1. Tabular data from the cooling curves are listed in Table 2. As a general rule, if the oils meet these criteria, similar metallurgical results will be obtained.

This is by far the most common method of comparing and selecting quench oils. However, many other factors besides the cooling curve behavior are important to select the proper quench oil.

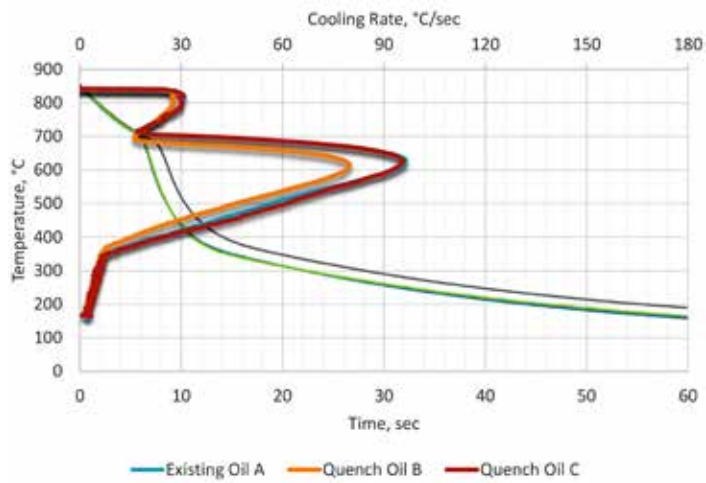


Figure 1: Comparison of three different oils by cooling curve measurement to ASTM D6200.

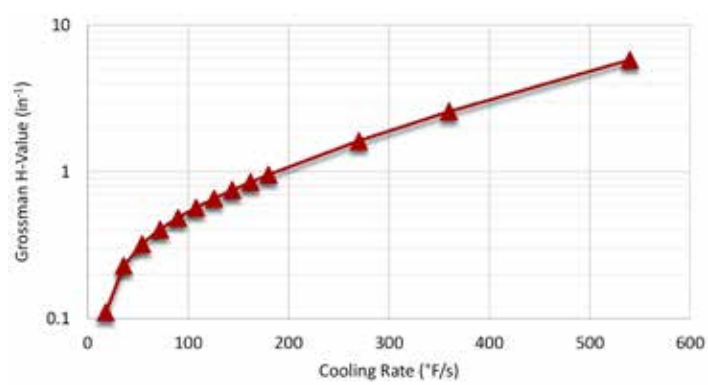


Figure 2: Grossman H-Value as a function of cooling rate (°F/s) at 1,300°F.

HARDENING POWER

Alternatively, quenchants can be compared using cooling curve analysis by using the Hardening Power of the quenchant [4]. In this method, three characteristic points of the cooling curve, measured by the method described in ISO 9950, are used in a formula derived by regression analysis to describe the hardening power of oil quenchants. This hardening power for unalloyed steels, HP, is expressed as a single value in Equation 1:

$$HP = 91.5 + 1.34T_{VP} + 10.88CR - 3.85T_{CP}$$ **Equation 1**

where T_{VP} is the transition temperature between the vapor phase and the boiling phase (in °C); CR is the cooling rate at 550°C; and T_{CP} is the transition temperature between the boiling phase and the convection phase.

This method allows oils to be selected by comparing the relative hardening power of each of the oils. However, for new installations, it is necessary to know the necessary cooling rate required to achieve part properties.

This method was further developed for the hardening of carburizing steels in hot oils [6] [7]. Using the methodology described in ISO 9950, it was determined that only two critical points from the time-temperature and cooling rate curves had any significance for the measured hardness. The addition of the hardness of the Jominy End Quench at 6.5 mm increased the accuracy of the hardness prediction. In this experiment, the core hardness when martempering

Property	Unit	Existing Oil A	Quench Oil B	Quench Oil C
Maximum Cooling Rate	C/s	98.12	81.26	97.36
Theta 1	C	714.28	693.72	713.9
Temp. at Max. Cooling Rate	C	612.04	597.34	607.78
Temp at Start of Boiling	C	715	693.2	714.82
Theta 2	C	409.43	429.35	403.98
Temp at Start of Convection	C	370.8	372.08	347.9
Flash Point	C	177	186	182
Cooling Rate at 300 C	C/s	6.35	5.26	5.35
Time to 850 C	s	0	0	0
Time to 600 C	s	7.2	8.78	7.28
Time to 400 C	s	11.21	14.05	11.06
Time to 200 C	s	43.93	55.39	45.92
Cooling Rate at 705 C	C/s	22.8	16.7	23.0
HP-IVF (oils)		465.41	312.43	567.3

Table 2: Tabular data of measurements comparing three different quench oils [5].

Agitation	Air	Oil	Water	Brine
No circulation	0.02	0.25-0.30	0.90-1.0	2
Mild Circulation	-	0.30-0.35	1.0-1.1	2-2.2
Moderate Circulation	-	0.35-0.40	1.2-1.3	-
Good Agitation	-	0.40-0.50	1.4-1.5	-
Strong Agitation	0.05	0.50-0.80	1.6-2.0	-
Violent Agitation	-	0.8-1.10	4	5

Table 3: Typical Grossman H-Values [10].

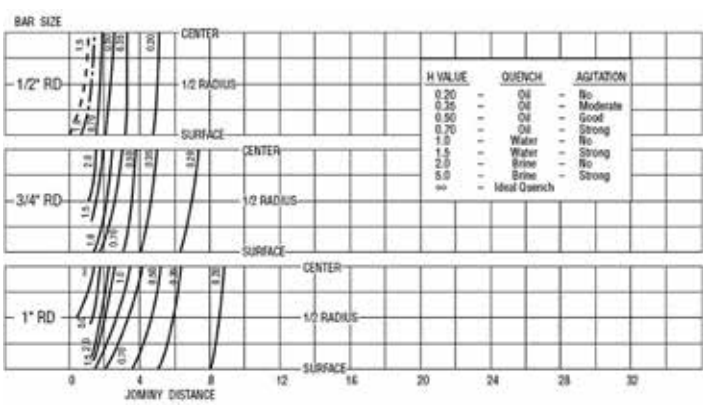


Figure 3: Chart for predicting the approximate cross section hardness of quench round bars using Jominy test results [16].

yielded Equation 2:

$$HV30 = 135 + 0.56CR_{500} - T_{20} + 5HRC_{J=6.5} \qquad \text{Equation 2}$$

where CR_{500} is the cooling rate at 500°C; T_{20} is the temperature (°C) after 20 seconds; and $HRC_{J=6.5}$ is the hardness at a Jominy distance 6.5 mm from the quenched end. It was shown that this method accurately predicted the core hardness.

It is important to realize that different steels have different cooling requirements, and that the Hardening Power equation was based on unalloyed carbon steels. Different alloys will require different regression constants [8]. However, this method has been shown to be effective in determining the relative ranking of oils for quenching. However, the Hardening Power equation should be used with caution when comparing different steels or for general hardness predictions. Alternative equations for making hardness predictions and ranking of oil quenchants have been made by Chen and Zhou [9].

If the Hardening Power of the quenchants considered is within approximately 25 percent, then the quenchants are generally considered to be equivalent.

GROSSMAN H-VALUE

The classic method related to the ability of a quenchant to harden steel is to determine the Grossman H-Value [10] [11] or Severity of Quench. The H-Value is defined in Equation 3 [12]:

$$H = \frac{\alpha}{2\lambda} \qquad \text{Equation 3}$$

where α is the average heat-transfer coefficient at the surface of the part, and λ is the thermal conductivity of the steel. For most steels, the thermal conductivity does not change appreciably over temperature or from alloy grade to grade, so it is directly approximate to the average heat transfer of the quenchant. A summary of the Severity of Quench for different media is shown in Table 3.

The Grossman H-Value is determined experimentally by quenching a series of round bars. After quenching, the bars are sectioned, polished, and etched. The 50 percent martensite region is determined. This is readily achieved because the transition in etching between dark and light etching corresponds to 50 percent martensite.

Although, this method has been used in the industry for many years, it is not without problems. The biggest issue with the application of the Grossmann H-Value is the difficulty in quantifying agitation rates. There is really no understanding of what is meant by "mild" or "violent" agitation. Further, the different methods of quenching such as spray quenching have no equivalent to the Grossman H-Value. This method is only focused on the ability of the quenchant to harden steel and gives no indication regarding distortion.

However, the terms describing the agitation are not quantifiable and can result in errors. Since most oils are tested without agitation, this results in a very narrow range of possible oil values. Further, when the original testing was done, the oils used in the original paper were straight oils, devoid of speed improvers. Modern oils achieve much higher quench rates (nearly double) than those tested in the original paper. Previously, there has been no way to correlate cooling curve data to Severity of Quench (H).

However, Otero [13] determined the Grossman H-Value from the cooling rate at 1,300°F (705°C) by use of the Kondratjev [14] dimensionless number. Correlation of the Grossman H-Value as a function of the cooling rate at 1,300°F (705°C) is shown in Figure 2. Typical values for several common quenchants are shown in Table 4.

The calculations show a good similarity to the classical H-values of Grossman. Further testing is needed to verify that the calculated results correspond to Jominy data and predicted hardness distributions in quenched bars [15].

To achieve equivalence to the data presented in Jominy End Quench testing, the H-Value only refers to the quench rate at a very narrow temperature range of 705°C (1,300°F). To ensure the proper cooling rate and microstructure is achieved, it is necessary to refer to Continuous Cooling Diagrams (CCT) for the steel of interest.

Quenchant	Cooling Rate at 705°C	Cooling Rate at 1300°F	H in^{-1}
Water	117	211	1.30
Houghto-Quench K	60	108	0.65
Houghto-Quench G	37	67	0.43
Houghto-Quench 105	24	43	0.30
Houghto-Quench 100	22	40	0.28

Table 4: Calculated Grossman H-values from cooling curves of commonly used quenchants.

This method makes possible the calculation of the critical size in terms of a standardized quench and calculation of the critical size from a single test. Using charts, it is possible to predict how a known steel with a specific Jominy curve would behave and predict the hardness distribution within the bar. Using the concept of equivalent rounds, the hardness distribution can be predicted. An example of charts to predict hardness distribution based on hardness correlation to round bars is shown in Figure 3. Using this method, the hardness was predicted for SAE 4130 at the minimum and maximum hardenability for different size rounds for the cooling curves. The results are shown in Figure 4.

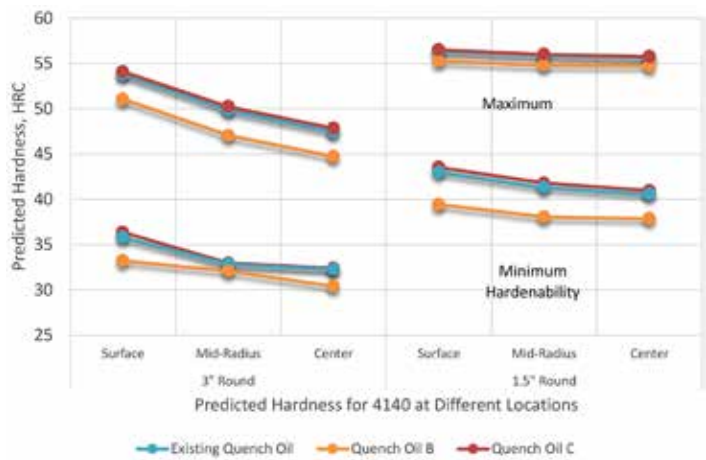


Figure 4: Predicted hardness for SAE 4140 using the Grossman H-Value calculated from cooling curves.

HEAT-TRANSFER CALCULATION

Lastly, a relatively newer method to predict hardness and microstructure has been developed by IVF Swerea in Sweden using the IVF SmartQuench Integra [17]. In this method, the heat-transfer coefficients as a function of surface temperature are calculated using the inverse-method [18]. After entering the TTT diagram of the desired material (or using the database), the CCT curve is calculated. From there, the microstructure and hardness are calculated. This last method is more accurate, as it encompasses the entire quench path of the quenchant. Examples of the heat transfer as a function of the surface temperature for the cooling curves are shown in Figure 5. The calculated hardnesses for SAE 4140 and different size round bars are shown in Figure 6.

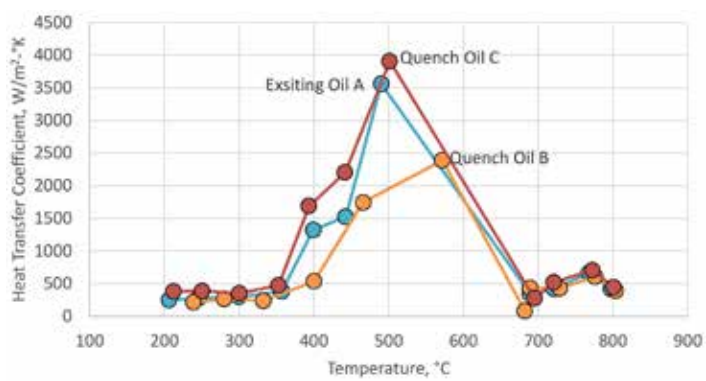


Figure 5: Comparison of heat transfer coefficients as a function of surface temperature on a series of cooling curves.

However, similar physical properties and quenching characteristics will not mean the oil will perform over time in a similar fashion. The thermal stability of the oil, measured by its oxidative stability, must also be considered [19]. However, due to space constraints, the oxidative stability of oils will be discussed in a later article.

CONCLUSIONS

In this article, the various methods of selecting a quench oil for various applications are described. Each of the different methods has merits and shortcomings. The cooling curve method is typically conservative, as the oils are not agitated during cooling curve measurement. This method is also the simplest method and offers a visual indication of the similarity or difference between different quenchants. The hardening power is an extension of the cooling curve test and is an additional method of showing similarity of different quench oils. However, it is only as good as the cooling curve measurement. Using the cooling curve and determining the Grossman H-Value is a quick method of predicting hardnesses for different size bars. It does not provide any information regarding microstructure. Another limitation is that the agitation is typically not determined, and only one point on the cooling curve is used for the determination of the average heat-transfer coefficient.

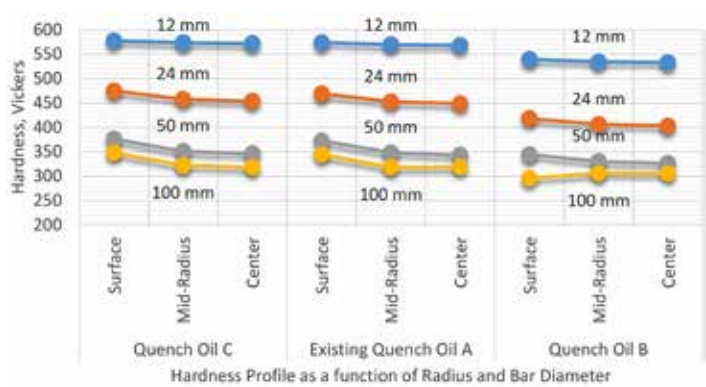


Figure 6: Predicted hardness of different size round bars of SAE 4140, as calculated from surface heat transfer coefficients.

The last method, using calculated surface heat transfer coeffi-

cients and calculation of microstructure and hardness as a function of radial distance, offers the most comprehensive method of comparing quenchants. However, it is limited to simple round bars. It is also limited by the accuracy and availability of TTT curves.

REFERENCES

[1] D. S. MacKenzie, "History of Quenching," Journal of Heat Treatment and Surface Engineering, vol. 2, no. 2, pp. 68-73, 2008.

[2] B. Liscic, H. M. Tensi, L. C. Canale and G. E. Totten, Eds., Quenching Theory and Technology, Boca Raton, FL: CRC Press, 2010.

[3] G. Totten, C. Bates and N. Clinton, Eds., Handbook of Quenching and Quenchants, Metals Park, OH: ASM International, 1993.

[4] S. Segerburg, "Classification of quench oils: A method of comparison," Heat Treating, vol. 20, no. 12, pp. 30-33, 1988.

[5] D. S. MacKenzie, "Metallurgical Aspects of Distortion and Residual Stresses in Heat Treated Parts," in 23rd IFHTSE Heat Treatment and Surface Engineering Congress, April 18-21, Savannah, GA, 2016.

[6] E. Troell, H. Kristofferson, J. Bodin, S. Segerberg and I. Felde, "New Tool for Calculation of Heat Transfer Coefficients, Microstructure and Hardness from Cooling Curve," in IFHTSE 5th International Conference on Quenching and Control of Distortion, Berlin, Germany, 2007.

[7] H. Kristofferson and S. Segerberg, "Designed Experiments to Study Distortion, Hardness and their Variation in Hot-Oil QUench Carburizing," Heat Treatment of Metals, vol. 2, pp. 39-42, 1995.

[8] L. C. Canale, X. Luo, X. Yao and G. E. Totten, "Quenchant Characterization by Cooling Curve Analysis," J. ASTM, vol. 6, no. 2, pp. 1-29, 2009.

[9] C. Chen and J. Zhou, "Discussions on Segerberg Formula Concerning Hardening Power of Quenchants," J. Shanghai Jiaotong Univ., vol. 36, no. 1, pp. 78-82, 2002.

[10] M. A. Grossman and M. Asimov, "Hardenability and Quenching," Iron Age, vol. 145, no. 17, pp. 25-29, 1940.

[11] M. A. Grossman and M. Asimov, "Hardenability and Quenching," Iron Age, vol. 145, no. 18, pp. 39-47, 1940.

[12] A. V. Reddy, D. A. Akers, L. Chuzoy, M. A. Pershing and R. A. Woldrow, "A Simple Method Evaluates Quenches," Heat Treating Progress, vol. 1, pp. 40-42, 2001.

[13] R. Otero, "Calculation of Kobasko's Simplified Heat Transfer Coefficients from Cooling Curve Data Obtained with Small Probes," J. ASTM, vol. 4, no. 2, pp. 30-36, 2012.

[14] N. Kobasko, "Optimized Quenched Layer for Receiving Optimal Residual Stress Distribution and Super-strength Material," in 3rd WSEAS International Conference on Applied and Theoretical Mechanics, Barcelona, Spain, December 14-16, 2007.

[15] J. L. Lamont, "How to Estimate Hardening Depth in Bars," Iron Age, no. 10, pp. 64-70, 1943.

[16] Timken, Practical Data for Metallurgists, 17th Edition, North Canton, OH, 2014.

[17] Swerea IVF AB, SQIntegra Product Brochure, Monldal, 2012.

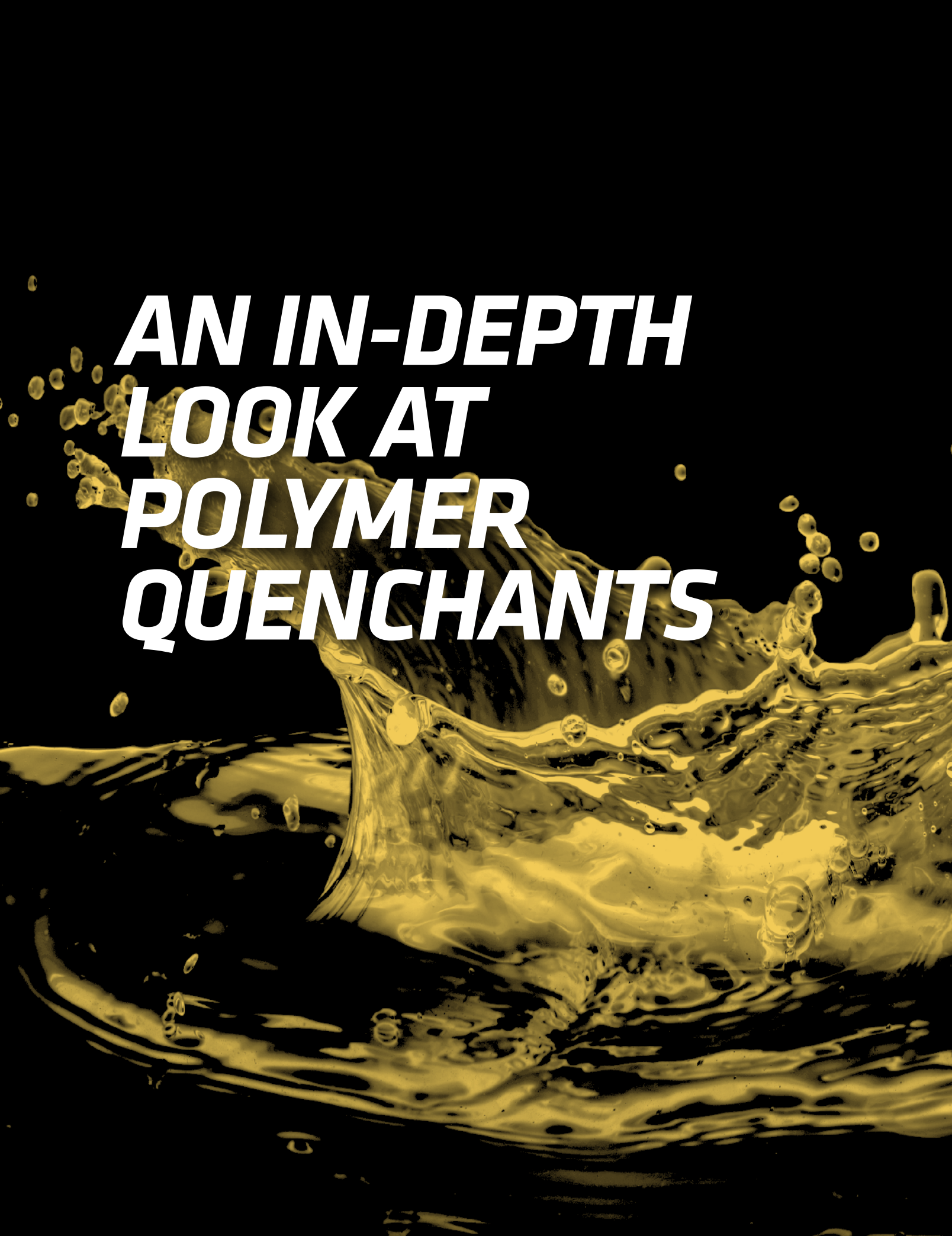
[18] I. Felde and T. Reti, "Evaluation of Cooling Characteristics of Quenchants by Using Inverse Heat Conduction Methods and Property Prediction," Materials Science Forum, vol. 659, pp. 153-158, 2010.

[19] K. Funatani, "Distortion control via optimization of cooling process and improvement of quench oils," in IDE 2008, Bremen, Germany, 2008.

ABOUT THE AUTHOR

D. Scott MacKenzie, Ph.D., FASM, is senior research scientist-metallurgy at Houghton International Inc. For more information, go to www.houghtonintl.com.

AN IN-DEPTH LOOK AT POLYMER QUENCHANTS



The flexibility and safety surrounding the use of polymer quenchants makes this hybrid method one of the best ways to achieve mechanical properties.

By SERGIO LUEVANO

Quenching of various alloys to achieve mechanical properties has been an area of scientific research for many years. Using polymer quenchants has proven to be one of the best methods to achieve mechanical properties due to its flexibility and safety. There are three major stages of polymer quenching: vapor phase, boiling phase, and convection phase. What happens in these three phases will determine the mechanical properties of the material.

The vapor phase is the first major stage, which happens when the part enters the quench medium (water, polymer, oil, etc.). As soon as the part enters the quenching medium, the metal is surrounded by a thin film around the surface. Since the liquid is a cooling medium, there is heat transfer at this point. The heat is transferred through radiation and conduction during the vapor phase. The latent heat of vaporization is critical at this stage.

The boiling phase is the second major stage and follows immediately after the vapor phase. The vapor film disappears in the beginning stages of the boiling phase. The disappearance of the vapor film allows the quench medium to come in contact with the hot metal being quenched, causing the surrounding quench medium to boil. During this phase is when the highest heat extraction rate occurs. The surface tension is critical and the quench medium properties become a factor.

The last major phase is the convection phase. During the convection phase, the boiling has completely stopped. As the name of this phase states, the heat is removed slowly by convection into the liquid. The rate of convection cooling is determined by the liquid properties only, and the viscosity of the medium is critical.

QUENCH MEDIUMS

There are three popular quench mediums: water, oil, and polymer quenchant.

Water has the highest cooling rates, which range between 2,000°F/sec to 10,000°F/sec. The vapor film phase depends primarily on the surface finish (Figure 1). The cost is inexpensive, easy to maintain, and has a very low safety risk. Water offers very high flexibility, being that only temperature can be adjusted to change quench characteristics. Due to the variation in cooling rates, the parts exhibit the highest distortion and cracking rates of all mediums. Soft spots on the component surface can develop due to an increase in temperature in the water, causing a longer vapor phase. The high cooling rates on steels during the martensitic transformation temperature will result in high residual stresses, excessive distortion, and increase the probability of potential cracking. From a maintenance perspective, there is a high potential for bacterial growth if not properly agitated and filtered.

Oil is considered a favorite of the steel industry (Figure 2). Oil quenches can be found in three categories: normal, medium, and high-speed grades. Normal speed quench has a slower rate of cooling, thus, alloyed material and tool steels are typical. Medium speed quenching oils are used when medium to high hardenability is required. High speed quenching oils are used for carburized and carbo nitriding applications. Oils are favorites when large, thick parts are required. Although very popular, there are some disadvantages. Parts that have been quenched in oil have a need for alkali cleaners or solvent degreasers. There are also significant safety risks. Water must be avoided as much as possible. Less than 1 percent of water can have an effect on soft spots, distortion, and cracking. The foaming of water molecules during quenching can cause fires or explosions. Sludge content in the tanks can cause part staining and changes in mechanical properties. Oils also exhibit a change with usage as well. Oils with use have a loss of volatile components, oxidation of compounds, depletion or loss of additives, and thermal degradation.

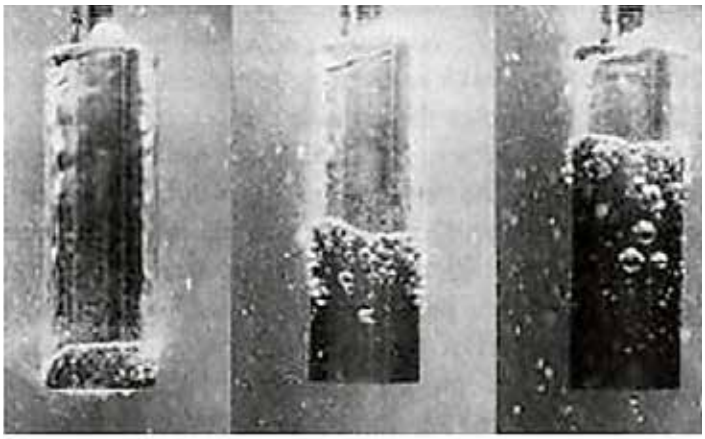


Figure 1: Simulated water quench. Vapor/boiling/convection phase left to right.

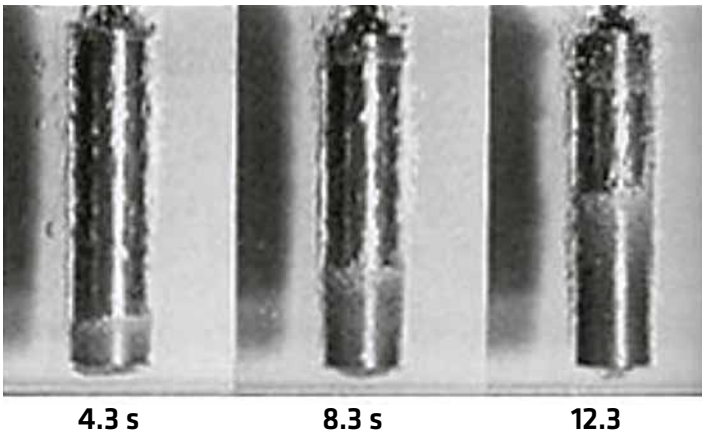


Figure 2: Simulated oil quench. Vapor/boiling/convection phase left to right.

Polymer quenchants are a hybrid of both water and oil. They are soluble in water and are clear at room temperature. As an aqueous solution of a liquid organic polymer, it can come with a corrosion inhibitor. When shipped from a manufacturer, there is 40- to 50-percent water

in most occasions. Only water needs to be added to a system to get the required concentration. In general, they have a higher molecular weight, higher viscosity, and lower thermal/oxidative stability.

There are various polymer quenchants, including Polyalkylene Glycol (PAG). PAG is unique in that it can be separated. This is possible because water hydrogen bonds with the PAG, giving the mixture seen in a tank. When a PAG is taken above 167°F, the hydrogen bonds are disrupted, causing cloudiness that is referred to as the cloud point. The mixture at this point is in two phases.

Looking at three stages of quenching for a PAG will give insight on how a polymer quenchant is unique and flexible (Figure 3). A water vapor blanket will form around the part when quenched, as in any other medium. A PAG can have different rates of diffusion of water to surface based on the concentration. When the temperature of metal drops and the PAG heats up, the boiling phase and the critical heat flux begin. At this point, the polymer layer is disrupted, which allows a water rich concentration to interact with the surface of the metal. After the metal temperature has dropped below boiling, some of the liquid around the metal may still be above the cloud point. This leads to a high viscosity boundary layer allowing for convection heat transfer.

There are several factors that affect the heat transfer rate in polymer quenchants to the parts. The quench concentration plays a major role. The higher the concentration, the slower the cooling due to the viscosity and film thickness. The thicker the film, the harder it is to break the film, allowing the part to cool for a fraction of a second longer before the water hits the part. Agitation of the quench tank also plays a major role (Figure 4). Agitation reduces the thermal gradients and has direct correlation on timing of film rupture/breakage. The higher the agitation, the faster the cooling. Temperature control is also critical. Higher bath temperatures will lower the cooling rates. For aluminum, it is very common to see the temperature inside of a tank between 70°F to 90°F where higher cooling rates are acceptable. This is in contrast to steel, where the temperatures tend to be between 90°F to 140°F.

Polymer quench tanks require maintenance and checks that water and oil do not. Daily concentration analyses are recommended and, in some cases, required per specifications. Concentrations are performed by a BRIX refractometer (Figure 5). A BRIX refractometer displays readings in the BRIX scale. BRIX is a unit of measure, which is related to the sugar content of a sugar solution and can be used for quenchants. All manufacturers will provide you with a chart to determine the concentration of your tank based on the reading. Quarterly testing by viscosity is recommended to compare with daily numbers. Large differences between concentration by BRIX method and viscosity indicates a problem with the polymer quenchant. It could mean contamination or polymer degradation. Periodic bacterial dipsticks can be used to minimize the risk of bacterial growth. The beauty of using a polymer quenchant is that if you have hydraulic fluid or other oil contaminants enter the bath there is a possibility that you will not need to drain the tank. The agitation system can be stopped and when all settles the oil can be skimmed from the tank. Filtration on the tank is similar to that of water, where a bag filter of at least 50 microns will prevent solids from being agitated in the tanks.

PAG quenchants allow for thermal separation. This process is done to remove water-soluble impurities such as salt contamination, degraded polymer, or foaming agents. Thermal separation is performed by taking the bath to 180°F and agitating the tank. After being at temperature for about an hour, turn off the agitation and heat. Let it sit for a while. The tank will be left with a water layer on top and PAG layer on bottom. Pump off the upper layer (water) and add water/PAG as needed to return to desired concentration. On large tanks, the entire solution is pumped out and separated in holding tanks, where it is then sent back as reclaimed glycol.

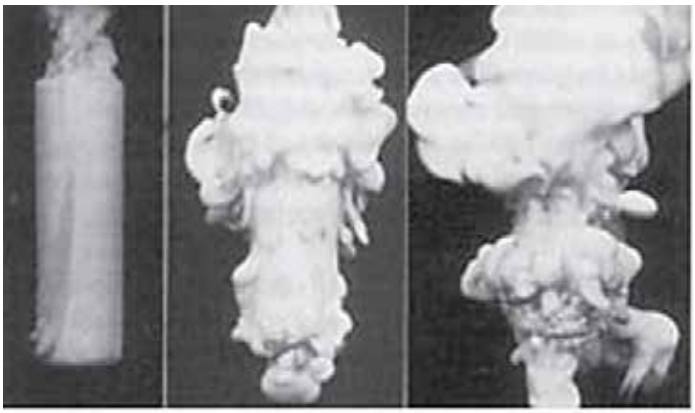


Figure 3: Simulated PAG quench. Vapor/boiling/convection phase left to right.

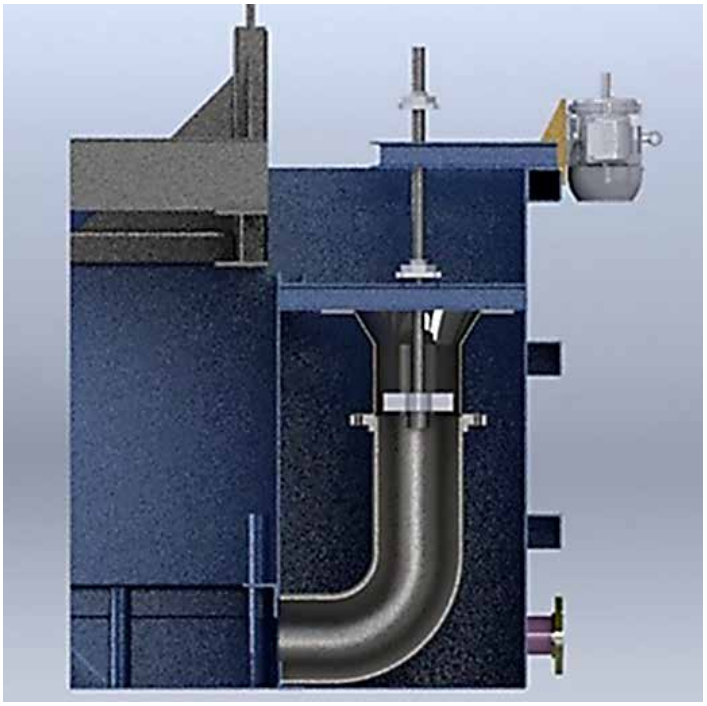


Figure 4: Cut out view of typical agitation system.

POLYMER QUENCHANTS AND SAFETY

The unique and most appealing part of polymer quenchants is the safety. Most PAG quenchants have FM approvals. A common type of PAG used in the industry is a Tenaxol UCON A. It has an FM rating of zero and a National Fire Protection Association rating of zero for health, flammability, and reactivity. This in turn reduces risk, which can lower insurance premiums. This is the major advantage and the main reason many shops are doing conversions of oil systems to polymer quenchants. Compared to oil, there are no fire hazards, no soot, and no smoke. Environmental safety is also significantly increased; in the event that there is a spill, it can be easily cleaned up.

Compared to oil quenchants, polymer quenchants do require slight upkeep. Tank agitation and bath temperature require better analysis for initial set-up. However, due to advances in technology, the upkeep is almost neglible compared to the safety risks involved with oil.

The old method of manually logging through BRIX method described above is slowly becoming obsolete. A recording device is

Figure 5: BRIX refractometer.

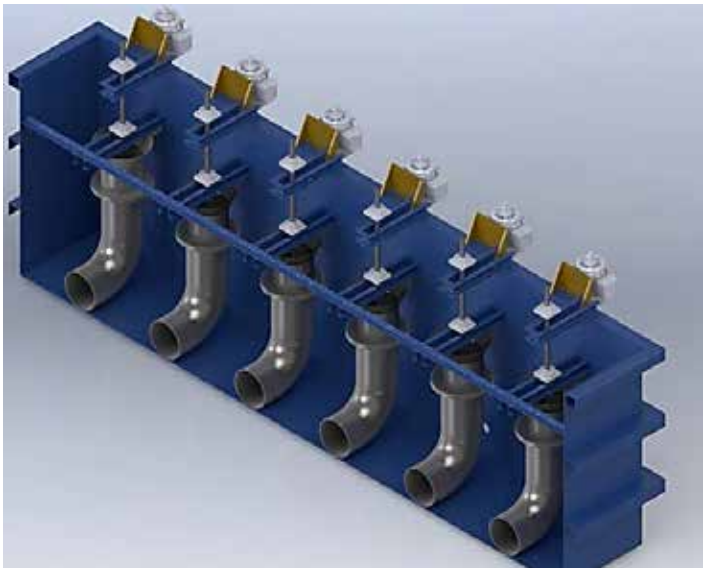


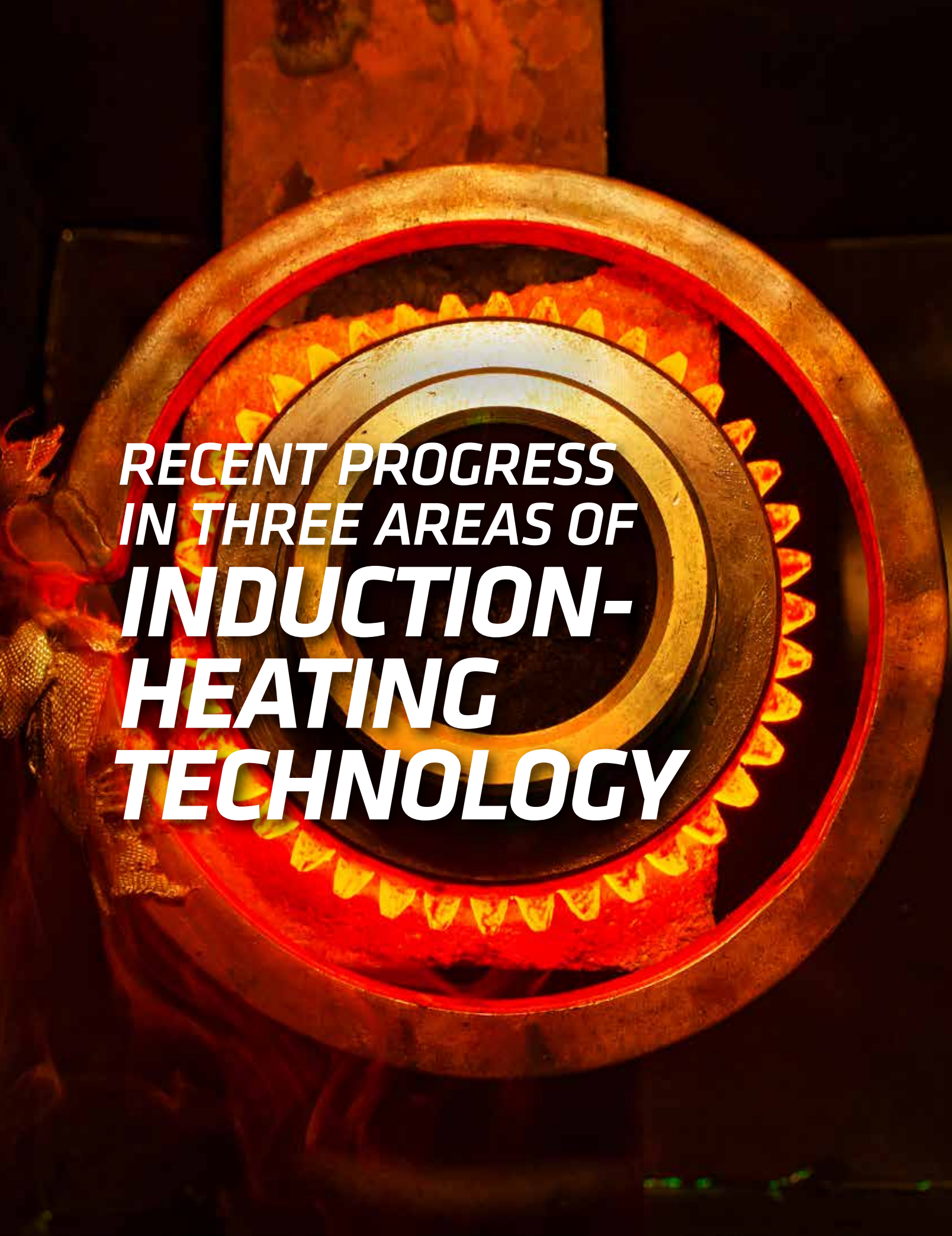
Figure 6: Cutout view of a polymer quench tank for steel parts.

continuously recording concentrations. If the concentration gets above or below a baseline, the system will force an alarm to go off. This method ensures that the concentration is correct throughout the day. Using a tank farm and thermal separation, the tank can be cleaned out. With a touch of a button, a tank can be drained, separated, and replenished automatically. A PLC will add water and glycol as needed to replenish the tank when maintenance or clean-out is performed. This is extremely helpful to commercial heat treaters who run multiple parts that need multiple concentrations and agitation speeds. Agitators that are running on variable frequency drives can be easily changed with simple PLC programming. Prior disadvantages for polymers are proving to be advantages, due to greater flexibility of its use (Figure 6).

As the industry continues to grow, the use of polymers will grow alongside it, not only for its flexibility for desired mechanical properties, but, more importantly, for safety to the workers.

ABOUT THE AUTHOR

Sergio Luevano is with Baker Furnace.



RECENT PROGRESS IN THREE AREAS OF INDUCTION-HEATING TECHNOLOGY

While researching induction-heating technology at Baosteel, attention was focused on the improvement of heating efficiency and heating effect.

By C.Y.WU, X.L.JIN, and Y.M.ZHOU

This paper introduces recent research progress of induction heating technology at Baosteel, specifically the development of full coil static induction heating technology of the backup roller, the development of induction hardening technology of steel pipe, and research on sparking phenomenon during edge induction heating. A computer simulation method has been established and used in these research subjects, which can precisely calculate the whole heating processes and the system parameters. Based on experimental tests and verification, the simulation model has been greatly improved, and the corresponding computed results can be directly used as guidance for the production process, which makes these research works more efficient and accurate.

INTRODUCTION

Efficiency, quality, and cost are the three primary concerns of steel companies, while EPM technologies mostly deal with matters related to product quality. Regarding induction heating technology, maintaining the output of a power source in a stable state and obtaining a desired temperature value are the two most important objectives. The heating process and uniformity of temperature distribution are the most prioritized objectives in the application of induction heating technology, which mainly depends on reasonable designing of the induction coil structure and precise controlling of the heating process parameters. With the development of computer simulation technology, the accurate calculation of the induction heating process becomes possible, which makes the application of this technology faster and more efficient. In addition, it is easy not only to obtain the heating temperature but also the induction heating system parameters by computer simulation [1-3].

Recently, the EPM team at the Baosteel Research Institute successfully developed a full coil static induction heating technology for a large forged backup roller, an inner scanning induction heating technology for large steel pipe, and the edge heating technology for hot rolled steel plate. This paper gives a brief introduction to the development process and main difficulties of the previously mentioned induction heating technologies. Three research topics during the induction heating process — the end-effect and its countermeasures, the precise control of the heating temperature, and the electromagnetic field analysis under complicated working conditions — have been explored and will be discussed.

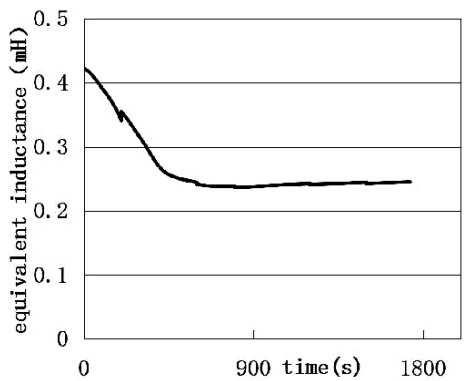


Figure 1: Calculated equivalent inductance curve over time.

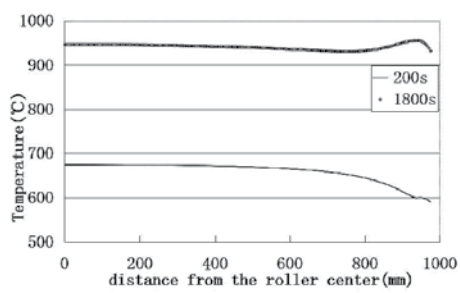


Figure 2: Calculated temperature curves along the axial direction of the roller surface at a different temperature.

1. FULL COIL STATIC INDUCTION HEATING TECHNOLOGY OF THE BACKUP ROLLER

A full coil static induction heating technology was developed for the induction hardening of the backup roller where a solenoid coil with multiple turns covers all the working surface of the heated backup roller during heating [4]. The roller rotates to improve circumferential temperature uniformity, while it is kept relatively static to the induction coil in the axial direction. Compared to conventional heat treatment technologies, the full coil static induction heating technology has an advantage of a much deeper hardened layer and a larger hardness value when used for heat treating of the backup roller. With this technology, wear resistance and service life of the treated roller can be improved to reduce production and maintenance costs. Since a backup roller usually has a diameter larger than 1.5 meters and a height higher than 2 meters, it inevitably takes a much longer heat-treating time than that of conventional induction heating. Moreover, the difference of temperature distribution along the whole roller surface is restricted within ±10°C. These requirements make the industry application of this technology hard to realize, unless we can precisely calculate the induction heating system parameters and control the heating process [5-7].

In this study, the backup roller is heated from 450°C to more than 900°C, which has a greater change of physical properties during the heating process and leads to a remarkable fluctuation of the heating system load. This phenomenon makes it difficult to precisely control the heating process. As shown in Figure 1, the equivalent inductance drops with an increase of temperature and then finally reaches a stable value. Furthermore, the initial inductance is almost twice as much as that of the high temperature, which causes the heating frequency to increase almost 50 percent during the entire heating process under the condition that the load capacitance remains constant. This phenomenon not only greatly influences the stable running of the induction heating system, but it also has an important effect on the temperature distribution. Since the thickness of the induction heated layer is required to be more than 100mm, the heating frequency is usually under 100 Hz. On the other hand, the parameters of the induction system change with the size of the backup roller and its corresponding heating coil, which makes designing of the induction system parameters and control of the heating process more complicated.

Regarding the temperature distribution, it is relatively easy to obtain a desirable temperature distribution at the radius direction. However, the end effect inevitably occurs when using a solenoid-type induction coil during the heating process, which makes the roller surface temperature difficult to control [8]. As can be seen in Figure 2, the roller surface temperature along the axial direction presents different features of nonlinear distribution over time, which mainly depends on the coil structure, roller height, and coil-to-roller space. When the roll surface temperature is lower than the Curie temperature, the temperature at the end part of the roller is much lower than that of the center part. However, when the roll surface temperature exceeds the Curie temperature during induction heating, the temperature at the end part of the roller will rise rapidly and exceed that of other parts. This means simply changing the induction heating parameters cannot improve the uniformity of the temperature distribution. To solve this problem, an effective way has been proposed and conducted that adjusts the heating-coil currents separately based on the surface temperatures of the corresponding heated roller parts.

Regarding the hurdles mentioned earlier, a computer simulation used to accurately simulate the induction heating process and temperature distribution. The simulation model was first verified and optimized by experiment results. The final calculated temperature distribution of the roller along the longitudinal direction is shown in Figure 3, where it can be seen that the temperature uniformity of the roller surface layer is well controlled, while the inner part of the roller remains at a relative low temperature. Results of an infrared temperature measurement show the temperature difference of the entire roll surface is less than ±5°C, as shown in Figure 4, where S1~S5 are the temperature curves measured by an infrared radiation thermometer at different locations of the roller surface during the final stage of the induction heating process. The five curves all but overlap with each other, which means a very uniform temperature distribution has been obtained at the entire roller surface.

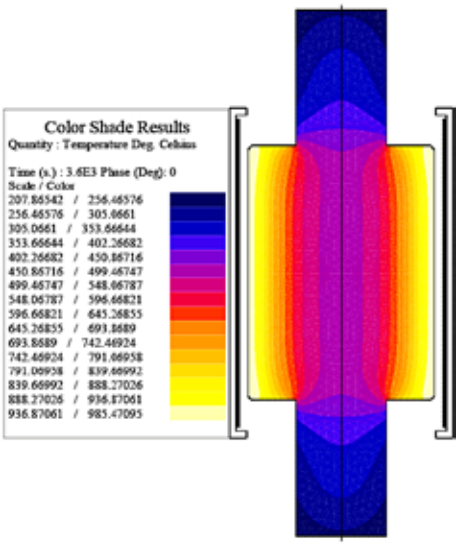


Figure 3: The calculated temperature distribution after all induction heating stages.

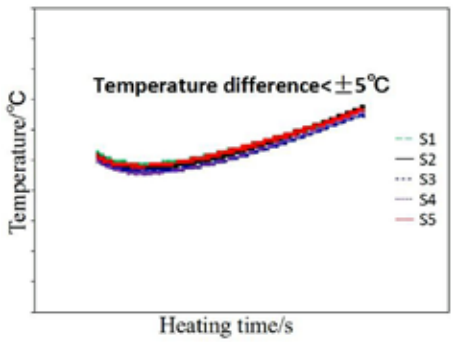


Figure 4: Temperatures measured at different locations of the roller surface by infrared radiation thermometer.

2. INDUCTION HARDENING TECHNOLOGY OF STEEL PIPE

Wear resistance is one of the key performance indexes of steel pipe when it is used for material transportation, which directly affects its service life and cost performance. In the process of steel pipe production, the use of heat-treatment technology to improve its hardness and wear resistance is an effective method, and has a wide range of applications in industry lines. However, for large diameter steel pipes used for transportation, there are many difficulties in using conventional heat-treatment methods. In this study, a scanning induction hardening technology was applied to the inner surface of the steel pipe, so as to improve its inner hardness and wear resistance. By carrying out a series of research works of composition study, computer simulation, physical experiment, temperature measurement, hardness testing, micro-structure analysis etc., a steel pipe with gradient strength distribution along the wall thickness direction has been obtained.

To improve its service life, the steel pipe is preferred to be induction hardened with more than 50 percent of its wall thickness. Since over-heating will cause grain coarsening, it is important to control the maximum temperature below a certain temperature during the heating process. This peak temperature can be controlled by the heating power, heating frequency, and the moving speed of the steel pipe. In order to precisely control the entire heating process, a computer simulation has been implemented. At a low moving speed, heat conduction becomes dominant, which makes the temperature gradient hard to obtain. As shown in Figure 5, there is a peak value of the inner surface temperature during heating, while the temperature difference along the radius direction soon becomes gentle out of the heating coil, where the temperature difference between the inner and outer surfaces is only within 20 degrees at the starting quenching position. Therefore, in order to increase the temperature gradient, the moving speed of the steel pipe should be increased.

An induction hardening experiment was implemented to study

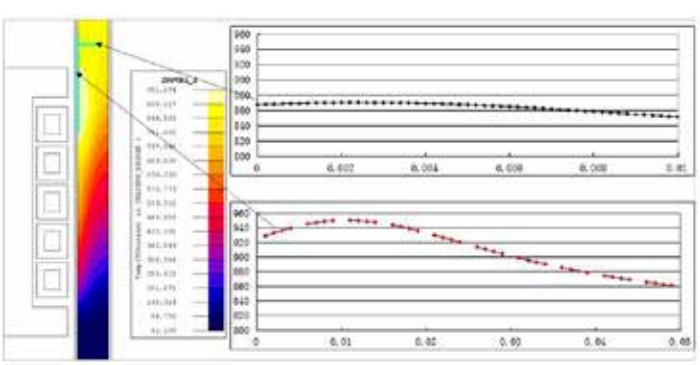


Figure 5: Computer simulation model and calculated temperature distribution curves.

Figure 6: Experimental equipment and temperature distribution of the induction-heated steel pipe.

the real heating process and the mechanical properties of the treated steel pipe. The temperatures measured by thermocouples at different locations of the steel pipe during the induction hardening process are well in accordance with the calculated results. In Figure 6, a high temperature ring with uniform temperature distribution in the circumferential direction of the steel pipe can be seen during the experiment. This ring moves with constant speed and with a stable temperature distribution during the entire induction hardening process, which guarantees a 1,400 MPa strength of 10mm thickness of the steel pipe under a suitable steel composition.

3. RESEARCH ON SPARKING PHENOMENON DURING EDGE INDUCTION HEATING

An edge heater having a "C" shape connecting core is used for induction heating of hot rolled steel plate. During the application of an edge heater, a spark phenomenon often occurs, which is induced by discharge arcing between the conveyor roller and the heated steel plate. In order to avoid this, some preventive measures can be implemented, such as keeping conveyor rollers insulated to the ground, manufacturing the roller with unequal diameter, inputting the nearby coil currents with opposite direction, and so on. Because of the bad conditions at the production line, iron scurf and water mist can destroy the insulation grade of the roller. It is difficult to keep the high value of insulation for a long period of time, which brings a greater challenge to stable production and maintenance.

Analysis shows the main factors that cause the spark phenomenon include: (1) surface roughness of the roller, (2) the insulation value of the conveyor rollers, and (3) magnitude of the induced eddy current in the contact positions between the conveyor roller and steel plate. The surface roughness and the insulation value of the roller basically depend on field maintenance of the conveyer rollers, while the induced eddy current is influenced by many factors, such as the deviation of the steel plate during moving, the width of the steel plate, the relative position of the coil, the heating power, and so on. It is obvious that, if the induced eddy current at the positions of the conveyor roller in contact with steel plate is small, sparking between the steel plate and the roller is less likely to occur. In this study, the previously mentioned factors that affect induced eddy current are analyzed by numerical simulation. The numerical simulation model was verified and optimized by experiment results to improve its accuracy.

It was found there is a significant difference for different steel plate width in their current density distribution along the roller-to-plate contact line. The maximum eddy current density at the contact line of a narrow steel plate is bigger than that of a wide steel plate. This result reveals it is more likely to cause a spark when heating a narrow steel plate.

On the other hand, there are usually four coils connected in parallel on both sides of the steel plates. During the heating process, steel plates are easily shifted to one side, which cause a load-match unbalance for the induction heating power system (Figures 7 and 8). It was found that, under the same input current, the induced current on the more coil-covered side of the steel plate is larger than that on the other side. This result indicates the probability of a spark and is greatly increased when the steel plate deviates to one side of the induction coils. Moreover, the previously mentioned load-match unbalance further strengthens the uneven distribution of the input current in the coil, resulting in a great bias on the induced current in the steel plate. Thus, the steel plate will be heated to different temperatures at each side of the steel plate, resulting in uneven physical properties along the steel-plate width. Therefore, it is strongly recommended that effective measures should be taken to avoid a bias of the steel plate so as to decrease the spark phenomenon.

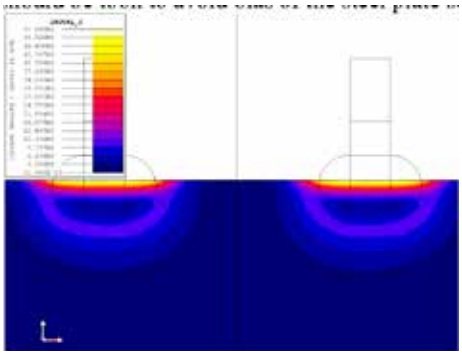


Figure 7: Current density distribution along the steel plate surface.

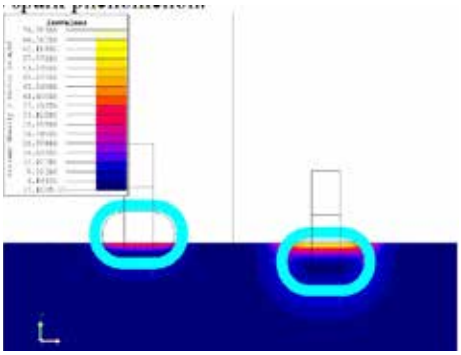


Figure 8: Current density distribution along the steel plate surface when the steel plate is off-tracking.

CONCLUSIONS

This paper mainly focuses on recent research about applications of induction heating technology in Baosteel, where three research topics related to roller, plate, and pipe have been studied. Although shapes of the treated work pieces are very simple in these cases, special requirements make the industry application of induction heating technically difficult. Through the previously mentioned research, the following conclusions can be obtained:

› Computer simulation is an indispensable way to apply modern induction heating technology, which can accurately guide the industry process.

› Sufficient attention should be paid to non-electrical factors that greatly affect the induction heating process, such as moving speed, surrounding condition, and so on.

REFERENCES

[1] Yu. A. Samoilovich, Steel in Translation, 45(2015), 73-79.

[2] S.Nobuo,M.Shinji,E.Shigeru, JFE technical report, 2008, 11, 1-6.

[3] M.Behulova,B.Masek,L.W. Meyer, Materialpruefung, 2006, 48, 217-224.

[4] Union Electric Steel, Forged Roll Heat Treatment[OL], http://www.uniones.com/the-ues-difference/forged-roll- technology/forged-roll-heat-treatment.

[5] L.Zhigang,J.Haichao,Z;Feng,et al., Heat Treatment of Metals, 36(2011): 115-118.

[6] C.Tianxiang,W.Zhanjun, Heat Treatment of Metals ,41(2016), 149-153.

[7] W.Cunyou,J.Xiaoli,Z.Yueming,Heat Treatment of Metals, 43(2018), 216-221.

[8] R.E. Haimbaugh,Practical induction heat treating[M],ASM international,2001, 50-51.

ABOUT THE AUTHORS

C.Y.Wu, X.L.Jin, and Y.M.Zhou are with the Research Institute, Baoshan Iron & Steel Co. Ltd. in Shanghai, China.

COMPANY PROFILE ///

AJAX ELECTRIC

OFFERING CONSISTENT TEMPERATURE UNIFORMITY

Ajax Electric's custom-built salt-bath furnaces use closely spaced electrodes parallel to each other, permitting electromagnetic circulation of the salt. (Courtesy: Ajax Electric)

Ajax Electric has been custom building salt-bath furnaces for decades, and with that experience, the company makes sure customers are getting the best products to meet their needs.

By KENNETH CARTER, Thermal Processing editor

When heat treaters are looking for a furnace that will fit the bill, their No. 1 priority is getting equipment with consistent temperature uniformity, and Ajax Electric's salt-bath furnaces are backed by more than 80 years of experience to ensure they meet that standard.

"That's a very important aspect to heat treaters, and we can do that," said Donna Stelman, president of Ajax Electric. "We deliver it consistently."

Ajax Electric's custom-built salt-bath furnaces use closely spaced electrodes parallel to each other, permitting electromagnetic circulation of the salt, according to Stelman.

"That was a big thing that happened back in 1936, and that's pretty much how we started," she said. "The reason why that was such an amazing thing is because of the way these electrodes made the salt circulate. It was necessary for temperature uniformity, and that was very, very important back then."

WHY SALT BATH?

And it still is today. Electric salt-bath furnaces are still at the heart of what Ajax supplies, but the company has continued to branch out over the decades.

The advantages of a salt-bath furnace are many:

› Circulation provides precise temperature control. The spacing of Ajax heating elements used for internal heating results in the automatic circulation of salt, which benefits from the uniformity of temperature and heat treatment.

› Since heat is transferred by direct contact of the work with a heating medium of high heat capacity, Ajax salt baths heat the work much faster than radiation or convection furnaces.

› Since work heats faster than in atmosphere or vacuum furnaces, smaller equipment is required for the same production level.

› With the salt bath, the work is in contact at all points with the heating medium with no distortion.

OFFERING SPARE PARTS

Ajax is also using its vast experience in salt-bath heat treating by offering a line of spare parts.

"Anything that goes along in the manufacturing process that the salt-bath furnace needs, which is usually a wash-and-rinse tank, a preheat chamber, and enclosures," she said.

That led into Ajax acquiring Central Panel, which is Ajax's subsidiary company that makes the electrical control panels that run the furnaces.

"It's like one-stop shopping here," Stelman said. "If you have a heat-treatment application or process, Ajax can help you with every form of it."

The types of industries that can benefit from Ajax's salt-bath furnaces have covered a wide range over the company's history.

SERVING MANY INDUSTRIES

Industries that use Ajax furnaces include auto and airplane manufacturers, tool manufacturers, and, more recently, pharmaceutical companies that use salt baths for their memory wire.

Since Ajax Electric's furnaces are custom built, a big part of the company's philosophy is how it races to solve each customer's special requirements, according to Stelman.

Since Ajax Electric's furnaces are custom built, a big part of the company's philosophy is how it races to solve each customer's special requirements. (Courtesy: Ajax Electric)

"We do our furnace design based on our customers' needs," she said. "We're a small company, so I can put together in a room my salesman who has talked to the customer, my engineer who designs the furnace, and my serviceman who has been to the facility and to many facilities like it and can anticipate what might go wrong. We can talk to a customer and say, 'We've done this before.'"

And with more than 80 years of experience, "we've done this before,"

Electric salt-bath furnaces are still at the heart of what Ajax supplies, but the company has continued to branch out over the decades. (Courtesy: Ajax Electric)

The types of industries that can benefit from Ajax's salt-bath furnaces have covered a wide range over the company's history. (Courtesy: Ajax Electric)

"We have all that data here. We can tell you this will work this way, and this won't work this way. Customer challenges are usually like that."

takes on even more weight in meeting a customer's challenge.

"We have all that data here," Stelman said. "We can tell you this will work this way, and this won't work this way. You might want it to do this, but it's not going to do this, or vice versa. Customer challenges are usually like that, but there's rarely something that comes up that hasn't been discussed before."

MEETING NEW NEEDS

As Ajax has entered the 21st century, it's important the company move into areas that more customers are demanding: namely, automation. Luckily, Ajax has been making inroads into that next level for years, according to Stelman.

"People used to heat treat basically in an old manufacturing plant by hand, and now companies want full automation, and we did whatever the customer wanted," she said. "That opened up a lot of things for us, and it continues to. Not only did we get into automation, now everything's robotic. They can produce product while basically sitting at a desk running these furnaces."

Stelman, who has been with Ajax for 30 years, emphasized that, even though salt-bath processing hasn't changed that much over the years, it still enjoys incremental improvements.

"It's almost like when you have this Tide laundry detergent, and they say it's new and improved, but it hasn't really changed much; we are doing the same thing we've done since we started with salt," she said. "But it's all a matter of how you do it. Now you're doing it with fewer workers, and again you have to be in tune with what your customers want. They're all going after safety aspects that were never thought of before. Safety used to be: Put a sign on it that says, 'Danger, it's hot,' you know? Now safety is where, if something doesn't work — this lever doesn't go this way — things have to shut down, just like that. And it's all in the programs; it's all in the robotics; it's all in the automation, and I think that's how you get an older company like ours that is doing business with the same kind of equipment for many years into this century."

TAKING ON THE COMPETITION

And Stelman has found that, along with the Internet of Things having an impact on her company, she also benefits from outsourcing the expertise that makes those advantages happen.

"You don't have to bring a robotics expert on site; you don't have to bring him in house," she said. "I can continue to be a very small company and outsource the things I need help with."

But being a small company doesn't mean Ajax doesn't have the teeth to compete with bigger companies, according to Stelman.

"Some of my competitors' equipment is expensive to run and takes up a lot of floor space," she said. "My equipment can compete hand over fist with those people. A salt bath is small compared to a vacuum oven or compared to a hot air oven."

With Ajax's established history — even though Ajax officially opened its doors in 1954, the salt-bath furnace it supplies has been around since 1936 — Stelman points out that the need for salt-bath furnaces will continue for many years to come, and Ajax will be available to meet those needs.

"Ajax has been here forever," she said with a laugh. "I think that's what we've got going for us. We have a customer reputation."

MORE INFO www.ajaxelectric.com

MARKETPLACE ///

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

Contact **Thermal Processing** at 800-366-2185 to feature your business in the Marketplace.

ADVERTISER INDEX ///

ADAM JACOBSON /// GENERAL MANAGER /// JN MACHINERY

"We're able to really cater to our customers' needs, as well as having the flexibility of many different ovens for many different operations."

What's a typical day like for you at JN Machinery?

We're a small company, so, it really depends on what's going on as far as projects. I'll check in with the guys, see how far we are on a project, and then start answering any emails from overnight and catch up on work from the day before. But I always try to make time to update our history because I'm always learning more about our older ovens to make it easier to buy spare parts.

What does JN Machinery offer the heat-treat industry?

The owner's father designed in-line ovens for the spring industry, and he worked for many different spring companies. He and his father are very well known in the spring industry after they had designed this process, and he made his own spring company so successful that he was able to sell it off, and then his father started this oven company. Word got out in the spring industry that this was the new way to do it, because they were all using big batch ovens before that.

We're very well known in the spring industry. That's definitely our bread and butter and always will be, but I'm excited for this sort of opportunity to get us out in front of people who don't know us.

In a lot of ways, a big driving factor for the spring industry is the way the automotive market goes. And that's always going to be our base; we're not going to abandon it. I want to get a couple other ovens outside of that industry, because they've really been refined over the years to make maintenance very easy.

The ovens are very efficient; we go a long way to make them energy efficient, and that's something that makes us pretty unique as opposed to some of the larger guys. We have an oven that's 40 inches long and 5 inches wide — a really small oven that's on one end of the spectrum. And then on the other end, last year we did our largest oven, which had a 58-inch wide opening, and it was 15 feet long, to do garage-door springs.

That's really where we try to stand out: our customer service and our ability to be able to have that flexibility and range to do ovens from all sorts of sizes.

We're able to really cater to our customers' needs, as well as having the flexibility of many different ovens for many different operations. Because even now, I'd say we're 90 percent in springs. We do have some people, especially with our larger 30-inch ovens, that they use for heat-treating. There's a big customer of ours in Nashville that just needs to heat-treat rivets, and they run them at 1,200 degrees.

How do you work with a customer when they come to you with a challenge?

We probably did 75 to 80 ovens last year, and maybe five to 10 of those were truly custom. When someone wants something custom, we usually have a good idea of what they're trying to do, for example: Do they want to do a tray oven where the motor is a step motor and each tray moves one position?

We're not afraid to go visit a customer and learn the process. But for the most part, it's pretty simple stuff: It's an oven, and springs go in it. Some of them are more custom, which has led us to our line of paint systems.

We do coatings for springs, obviously, but it works well on some other applications. It's basic rust protection.

It comes in a whole bunch of colors, and it works great for part identification. For really tiny springs, if there's a left hook and a right hook on them, the poor guy assembling this hydraulic valve isn't going to be able to tell the difference just by looking at them. But we can offer a painting system that's attached at the end of the oven, where you — for a left and right hook — paint one blue and one red. Then you know which ones go where. It makes it easier for the end user to assemble the part.

We're extremely customer service driven, that's really where we try to stand out. Obviously, you can go get an overseas oven and get overseas service, but with us you are going to get a made-in-America product with made-in-America service.

Where do you see heat treat in the next decade and your place in that future?

We're going to really try to focus on some things other industries are trying to do right now. Lights Out Operation, for example, where we're making the ovens smart enough so the maintenance guy can sit at home with their iPad and be able to see what parts are running without anybody in the building. We also want to get it to — if our customers are able to pay for it — where we can offer a monthly service where we monitor ovens. Automation is going to be the absolute future, and everyone's trying to do that right now. And they should be.

We want people to know we're different from some of the larger guys, and we do offer really small ovens — all of them are electric, and all of our ovens are mobile. That's a niche that's, in some ways, underserved in the heat-treating industry. That's where we can come in and make more of a footprint for ourselves in this industry.

MORE INFO jnmachinery.com