Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

GEAR APPLICATIONS / INSPECTION & METROLOGY

TOOTH ROOT BENDING STRENGTH

OF LARGER-SIZED, INDUCTION-HARDENED GEARS

COMPANY PROFILE ///

Gruenberg

DECEMBER 2023
thermalprocessing.com

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DEPARTMENTS ///

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FROM THE EDITOR ///

2023 — another year in the books

The end of 2023 is here before, it seems, it even started.

On a positive note, it looks like the heat-treat industry continues on its journey to return to normal.

So, as we enter 2024 and beyond, let this not only serve as a season's greeting, but also as a promise that *Thermal Processing* will continue to explore ways to enhance our products with the ultimate goal of getting the best and latest information about the heat-treating industry in your hands — whether that be virtually or literally — just as we did this year and in many years past.

But before we say a final goodbye to 2023, make sure you take some time to discover this month's issue of *Thermal Processing*, which contains quite a bit of information.

December's topics are gear applications as well as metrology and inspection.

With our sister publication being *Gear Solutions*, it only makes sense that we tackle how those gears need some type of heat treating before they are able to perform their delicate, often complex, tasks.

In our cover article, Holger Cermak, Dr. Thomas Tobie, and Prof. Karsten Stahl, with the Gear Research Center of the Technical University of Munich, investigate the tooth root bending strength of larger- sized, induction-hardened gears.

Inspection can cover a variety of issues, and so does our next feature article from Honeywell Thermal Solutions. In the article, Honeywell's Dale Smith looks at 10 steps for accelerating thermal process decarbonization.

Also, be sure and check out this month's company profile and Q&A.

In the profile, we shine a spotlight on Gruenberg, and how it has offered standard and custom industrial drying ovens, pharmaceutical dryers, and sterilizers to a wide range of industries for more than 90 years.

In our Q&A, I had the pleasure of chatting with Wisconsin Oven's vice president of sales, Mike Grande, where he discusses the advantages of a horizontal spray quench furnace.

You'll find that and much more in our December issue. And keep in mind that we are always looking for interesting and educational editorial content, so if you have a technical paper or other heat-treat-related articles you'd like to see published, please contact me. I'd love to hear from you and be given the opportunity to share your unique knowledge with our readers.

Happy holidays from all of us at *Thermal Processing*. Stay safe, and, as always, thanks for reading!

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

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OPERATIONS

Each recently shipped Wisconsin Oven horizontal quench furnace has a maximum temperature of 1,250°F, and capacity to heat and support a 4,500-pound gross load. (Courtesy: Wisconsin Oven)

Wisconsin Oven ships two horizontal quench systems

Wisconsin Oven has shipped two electrically heated horizontal quench systems to the semiconductor industry. The systems will be used for the annealing and rapid cooling of various high-purity alloy parts.

The operating procedure for each horizontal quench system includes loading the product on a work grid located on the loading platform. Once the load is lifted into place, a pusher/extractor mechanism located at the front of the quench tank moves the load onto the quench lift platform, then the furnace pusher/extractor mechanism pulls the load into the furnace for annealing. After completing the heating cycle, the vertical lift door opens, the furnace pusher/extractor transfers the load onto the quench lift platform, and the load is lowered into the water quench tank. After the load has sufficiently cooled, the quench lift is raised, and the front mounted pusher/extractor mechanism pulls the load back onto the scissor lift. While the load is pulled onto the scissor lift, a blow off system removes the majority of the water from the load.

Each horizontal quench furnace has a maximum temperature of 1,250°F, and capacity to heat and support a 4,500-pound gross load. This type of equipment routinely achieves temperature uniformity of ±10°F. This customer requested a uniformity tolerance of ±20°F performed at 500°F, 900°F, and 1,200°F. The uniformity was documented for each system with a nine-point profile test conducted in an empty oven chamber under static operating conditions.

"At Wisconsin Oven, we work closely with customers to find the right solution for their specific process," said Doug Christiansen, senior application engineer. "This customer sought to make their previous manual quenching process more efficient and increase production capability, while providing a safer work environment for their operators. We exceeded their expectations on all three requests with these systems."

Unique features of these horizontal quench furnaces include:

» Two separate powered pusher/extractors; one for charging the load onto and off of the quench tank lift, and the other for pulling the load into the furnace and pushing the load out onto the quench lift.

» Hydraulically actuated scissor lift load table.

» Guaranteed temperature uniformity of ±20°F at 500°F, 900°F, and 1,200°F.

» 15,000 CFM @ 15 HP plug-mounted recirculation blower.

» Furnace and sequence control performed by PLC with 10" color HMI located in an articulating arm (to allow best field of view for operators).

» Programmable temperature controller with Ethernet capabilities.

» High limit instruments provided for product and furnace over temperature protection.

» Combination style airflow to maximize heating rates.

» Hydraulically actuated quench lift mechanism.

» Blow off system to remove the majority of water from the load after the cooling/quenching process (to minimize water spilling onto the floor around operators).

» UPS battery backup system included for PLC and controls.

» Remote manual lubrication lines for roof-mounted bearings (located at operator level for ease of maintenance).

» Chiller system to cool the quench tank water between load quenches.

MORE INFO www.wisoven.com

Lindberg ships exothermic atmosphere generator

Lindberg/MPH has shipped a gas-fired exothermic atmosphere generator to the manufacturing industry.

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.

The Lindberg/MPH HYEX exothermic atmosphere generator features an energy-efficient design that provides reliable and economic operation. The maximum exothermic gas output for this generator is 8,000 feet cubed (ft^3) per hour. (Courtesy: Lindberg/MPH)

The HYEX exothermic atmosphere generator features an energy-efficient design that provides reliable and economic operation. The maximum exothermic gas output for this generator is 8,000 cubic feet per hour.

The combustion chamber is a reinforced, water jacketed, steel shell that is insulated with a high-temperature refractory lining and uses a variable ratio tunnel main burner. The chamber includes UV flame detection and peep sight so the operator can observe the operation of the main burner. In the event of a backfire, a fire-check at the burner inlet will automatically block the mixture line and an electrically latched manual reset valve in the gas inlet line will shut down the generator in the event of low gas pressure, high gas pressure, or electric failure.

The mixing control system for exothermic gas generation uses a Waukee precision carburetor for proper blending of incoming gas and air. A gas regulator reduces and stabilizes gas pressure to the carburetor even when the main plant supply is varied. A cooling system rapidly cools the generated gas to condense out moisture. The dew point of the produced HYEX atmosphere gas is approximately 10°F above the temperature of the inlet cooling water.

"The HYEX generator design allows for varying air/gas ratios to create atmospheres specific to your process," said Kelley Shreve, general manager. "This exothermic gas generator provides an impressive 8,000 (cubic feet) per hour maximum gas output."

Unique features of this atmosphere generator include:

- ›› Energy efficient and reliable design for economical operation.
- ›› UV flame detection and peep sight.
- ›› Varying air/gas ratios create atmospheres to meet application requirements.
- ›› Variable ratio tunnel main burner.
- ›› Completely assembled unit on one base.

MORE INFO www.lindbergmph.com

NUTEC appoints Marc Carter VP North America

NUTEC Group has announced the appointment of Marc Carter as Vice President North America, Fibers Division. Carter has just relocated to the NUTEC Inc headquarters in Huntersville, near Charlotte, North Carolina. He joined NUTEC from John Cockerill, where he was head of sales for the Americas. In his previous two posts, he was business development manager at Tata Steel, and product and marketing manager at Nucor Steel.

Marc Carter

In all, Carter has spent nearly 25 years in the steel and related industries and brings with him an extensive knowledge of thermal treatment and high-temperature technologies. He is an alumnus of the University of Alabama, from where he graduated with a BSc in international marketing.

"I am honored to join the remarkable team at NUTEC, who have built a culture around the importance of being customer-focused while maintaining the highest levels of operational excellence," Carter said. "This role gives me the opportunity to be a part of a company that combines innovation, creativity, and collaboration to deliver the best customer experience in the industry. I look forward to the unique challenges this role will bring and to contributing to NUTEC's bright future for years to come."

"We are really excited to have Marc joining our U.S. team; his background in a number of leading international companies is clearly a really good fit for us, and we are expecting him to take us to the next level," said Gerardo Muraira, president/DG of NUTEC Fibers Division.

MORE INFO www.nutec.com

Leybold USA names Scala regional sales manager

Joseph Scala of Appleton, Wisconsin, has been named regional sales manager VTS-Midwest, by Leybold USA.

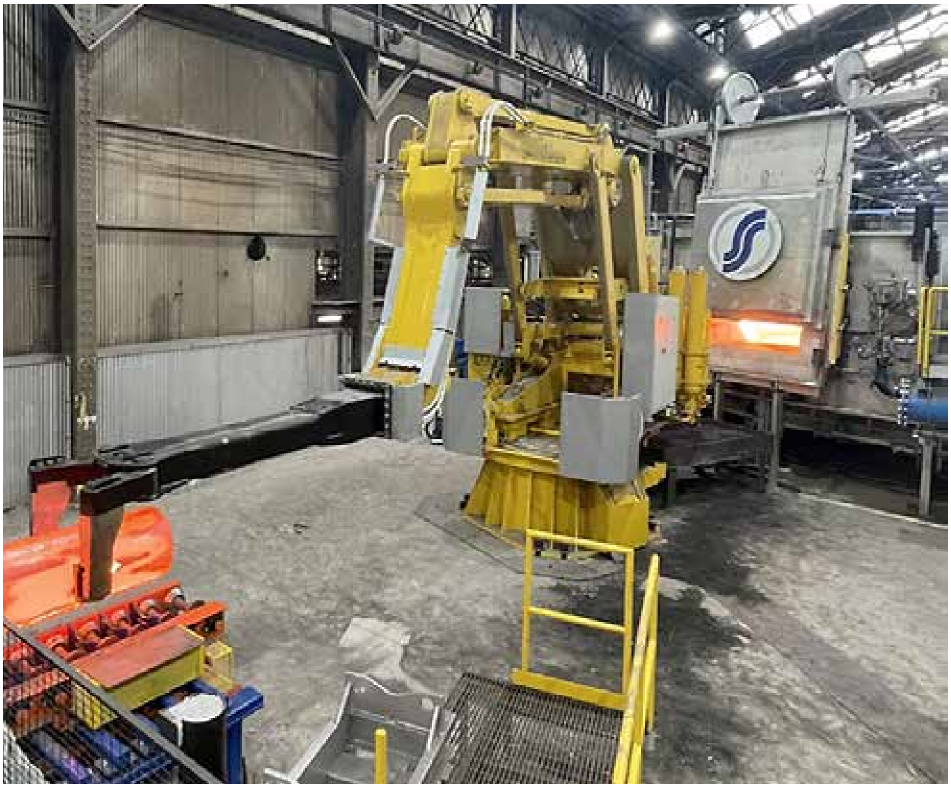
Leybold is an Export, Pennsylvania-based leader in vacuum technology, offering a broad range of advanced vacuum solutions for use in manufacturing and analytical processes, as well as research purposes.

In his role, Scala will work with applications engineers, product engineers and account managers to design and present Leybold service and solutions to help customers maintain and improve their process efficiencies. He will act as the service sales liaison between Leybold factory and customer, and develop/assist in the company's marketing and presentation campaigns.

In addition to his sales and marketing accomplishments, Scala was named 2021 Corporate Volunteer of the Year, nominated by the Alzheimer's Association.

Since 1850, Leybold has been developing and supplying vacuum pumps, systems, standardized and customized vacuum solutions, and services for various industries worldwide.

MORE INFO www.leybold.com



The new reheat furnace from Can-Eng is equipped with energy-saving, low emission regenerative burner technology. (Courtesy: Can-Eng)

Solar Atmospheres of Michigan begins relocation move

Solar Atmospheres of Michigan has commenced the relocation of the first of eight existing vacuum furnaces from the old Vac-Met premises. The first 38" wide by 28" high by 72" deep vacuum furnace, decommissioned from the Fraser, Michigan, plant, is now fully operational in the Chesterfield, Michigan, facility. The migration of the next seven vacuum furnaces and other ancillary equipment, originating from both the Fraser and Warren plants, is occurring every two weeks. By the end of 2023, the transferred assets will join the new existing Solar vacuum furnaces to form a new state-of-the-art vacuum thermal treating facility in Michigan.

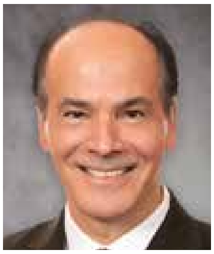
"To have all of our operations under one roof is a massive step for our employees and our company," said Bob Hill, president of Solar Atmospheres of Michigan. "Ownership of the vacant lot next to us gives the opportunity to grow the business more efficiently in one location. We are excited to get through this transition phase and look forward to 2024 and beyond."

MORE INFO www.solaratm.com

Scala receives Outstanding Lifetime Philanthropy award

The Association of Fundraising Professionals of Northeast Wisconsin has named Joseph Scala of Appleton their "Outstanding Lifetime Philanthropy" Award Recipient. Scala received the award at the AFP event celebrating National Philanthropy Day on November 16.

Scala was nominated by Commander Dave Mix of the Menasha VFW, for whom he has served as a volunteer for more than 15 years, including singing the national anthem, "God Bless America," and "America the Beautiful" at numerous events, as well as spearheading many successful fundraising efforts.



Joseph Scala

This award is presented to an individual or family, either in honor or memory, who are recognized widely as community philanthropists and have a long and proven record of making a significant impact in their community through financial support and volunteerism/leadership for a variety of organizations.

Scala is regional sales Manager VTS-Midwest at Leybold USA.

Chiz Bros. opens Detroit ceramics warehouse

Chiz Bros., a provider of custom solutions for refractory and high-temperature applications in a wide range of industries, including metals, power, glass, and ceramics, has opened a warehouse in suburban Detroit.

The facility at 36082 Industrial Road in Livonia carries the same inventory as the company's Pittsburgh-area location. Those products include ceramic fiber blanket, papers and felts, boards, and modules. The Detroit warehouse will also provide local support for routine and emergency needs.

"As one of the country's largest Alkegen (formerly Unifrax) distributors, we are always looking for ways to better serve our core markets in the industrial heartland and Rust Belt with 'Made in the USA' ceramic fiber products," said Mark Rhoa Jr., vice president of Chiz Bros. "With that purpose in mind, we opened the Detroit warehouse under the leadership of Mike Klauk, our regional manager."

"I am pleased to be responsible for the activities at our Detroit warehouse," said Klauk, who came to Chiz Bros. after more than a decade at Unifrax, where he held sales engineer and applications engineer positions. "I look forward to providing our customers with the products and technical assistance they need exactly when they need them."

MORE INFO www.chizbros.com

Can-Eng has rotary hearth reheating furnace order

The first hot ingot mults from a recently commissioned 20 ton/hour rotary hearth reheating furnace were delivered to the 4 Anvil rotary forge at a central Pennsylvania steel works.

The Can-Eng scope of supply included nearly 400 feet of in-line roller conveyor that feeds cut ingot mults from four horizontal band saws to the reheat furnace, a pedestal mounted charging/discharging furnace manipulator, and a high-speed in-line roller conveyor to deliver 2,300°F hot mults to a new rotary forge machine.

Each ingot mult weighs approximately 2.2 tons. The entire cell is located in a completely revamped production hall on the grounds of North America's oldest forge shop. The new line will replace a walking beam furnace and associated rotary forge machine that has been in production for more than five decades. The new reheat furnace is equipped with energy-saving, low emission regenerative burner technology. Full ramp-up to production capacity is anticipated in Q4 2023.

MORE INFO www.can-eng.com

Gruenberg ships two truck-in sterilizers for medical industry

Gruenberg, a leading industrial oven and sterilizer manufacturer, has shipped two truck-in sterilizers for the medical industry.

The truck-in sterilizers have a maximum temperature rating of 232°C and interior dimensions of 30” W x 59” D x 79” H. The two units will be placed side by side at the customer’s facility so one unit is designed with a right-hand hinged door and right-side mounted control console, and the other unit with a left-hand hinged door and left-side mounted control console.

The sterilizers use electro-mechanical door locks to prevent the door from being opened when the sterilizer is processing, protecting product loads from being damaged due to accidental disruptions in the process occurring when someone opens the door. These sterilizers also feature uninterrupted power supply (UPS) systems which will supply power to the control circuits for a brief period in the event of a power loss. This allows the sterilizer to potentially restart and also allows the temperature controller to continue to record temperature data to help identify quality issues with that batch of product.

The truck-in sterilizers are designed with high-volume, horizontal airflow systems to ensure uniform heat distribution throughout the sterilizer chambers and optimize efficiency. The circulation motors include variable frequency drives and soft starts. The air intake/exhaust systems use fiberglass media filters to filter the air entering and leaving the chamber. The system provides pressurized air, ventilation and cooling with a pressure intake blower and air intake blower that uses variable frequency drives for speed adjustments during heating and cooling cycles.

The control panels are UL-certified, and each has a communications module with a USB port, an Ethernet port, and a 120V outlet. The temperature for each sterilizer is controlled by an Allen Bradley CompactLogix PLC with Ethernet capabilities, HMI technology, a user-friendly touch screen, and the ability to store up to 10 recipe profiles. Temperature uniformity within the chamber of ±3°C at 121°C and 163°C was documented with a 12-point profile test after a 60-minute soak.

“The electro-mechanical door locks on these Gruenberg sterilizers are a protective measure to prevent accidental disruptions in the process from someone opening a door,” said Mike Schneck, Gruenberg product manager. “If the door is opened mid-process, the product load would be damaged and result in lost product and production time.”

Unique features of these Gruenberg truck-in sterilizers include:

- Temperature uniformity of ±3°C at 121°C and 163°C .
- Electro-mechanical door lock.
- Uninterruptible power source (UPS).
- Allen Bradley CompactLogix PLC .

» Allen Bradley Panelview Plus 7 HMI.

» High-flow intake and exhaust air filtration system.

MORE INFO www.gruenberg.com

Graphalloy bushings successful in plastic thermoforming

Graphite Metallizing Corporation, the manufacturer of self-lubricating Graphalloy® bushing materials, announced the success of their bushings in a high-temperature plastic thermoforming application.

Their customer uses thermoforming to manufacture custom plastic designs. They specialize in plastic trays used for material packaging, shipping, and handling for a variety of industries including automotive, electronic, medical, and food packaging.

The application is light load and slow speed, with an operating temperature of 350-400°F. This temperature creates a problem for oil or grease-lubricated rolling element bearings. In 2013, they purchased Graphalloy bushings to allow operation at this higher temperature, since Graphalloy bushings are self-lubricating and can withstand temperatures from minus-450°F (minus-265°C) to 1,000°F (535°C).

A Graphalloy sales rep followed up with the company to see how the Graphalloy bushings were working, and the plant manager said they were working very well. He said he installed the bushings originally in early 2013 and the spares were still on the shelf.

Graphalloy bushings offer solutions in places where traditional bearing lubricants will not work, including high-temperature applications, clean environments, submerged operation applications, and more. Graphalloy, a graphite/metal alloy, is a unique self-lubricating bearing material that offers superior performance in hundreds of mechanical and electrical applications.

Graphalloy standard and custom-designed products provide lifetime cost savings and significant operating advantages over conventional bushings and bearings.

Features and benefits include:

» **Self-lubricating.** Requires no grease or oil. Permits continuous operation and eliminates downtime.

» **Dimensionally stable.** Does not cold flow or deform under pressure. Maintains its size and shape.

» **Chemically resistant.** Insoluble in most industrial liquids. Works in acids, alkalies, hydrocarbons, water, and liquid gases.

» **Low coefficient of friction.** Constant, low coefficient of friction. Not just a surface layer, solid throughout.

» **Linear motion.** Maintains lubrication during linear motion. Lubrication is not drawn out and dust is not pulled in.

» **FDA accepted.** Accepted for food services. No lubrication to drip or cleanup. Easily steam cleaned.

MORE INFO www.graphalloy.com

INTERNATIONAL FEDERATION OF HEAT TREATMENT AND SURFACE ENGINEERING

Lesley Frame elected vice president of IFHTSE 2024-2026

Lesley Frame, assistant professor, Materials Science and Engineering, University of Connecticut, recently was elected IFHTSE vice president for the 2024-2026 term in Yokohama and will serve as president 2027-2029.

Frame got her undergraduate degree at MIT and completed her PhD at the University of Arizona. She was a Fulbright Scholar at Cardiff University in Wales. She spent five years at Thermtool Corp., leading product development, materials characterization, and customer education for the company. After Thermtool, she decided to return to academia, and joined the faculty at the University of Connecticut. Her primary research focus is on structure-processing-property relationships for materials manufacturing and processing-performance relationships for material durability. She has been active in ASM and has been serving as the vice president and now president of the HTS board for the past four years.

Lesley Frame is assistant professor, Materials Science and Engineering, University of Connecticut.

ASM HEAT TREATING CONFERENCE A SUCCESS

The ASM Heat Treating Conference, as part of IMAT, was in Detroit, Michigan, October 16-19. The total attendance for the events (Heat Treat/IMAT/and MPT Expo) was more than 4,500 attendees, with more than 27 countries represented. There was a total of 337 oral presentations and 22 posters for both IMAT and HTS. More than 300 exhibitors were present for the entire event.

CONFERENCE UPDATE

5th International Conference on Thermal Process Modeling and Simulation (5th ICTPMS)
April 17-19, 2024

The 5th International Conference on Thermal Process Modeling and Simulation will be held together with the 4th Mediterranean Conference on Heat Treatment and Surface Engineering (MCHTSE 2024). These two IFHTSE conferences will be in Lecce, Italy, April 17-19, 2024.

The two conferences aim at providing a forum where engineers, scientists, researchers, and production managers can review and discuss fundamentals, new challenges, recent progress, and emerging topics in the fields of advanced heat treatment and surface engineering technology.

TPMS-5 aims at covering all aspects of modeling and simulation of thermal processes.

»**More info:** www.aimnet.it/eng/manifestazione.php?id=789&idc=4

2nd Bosphorus International Heat Treatment Symposium
April 25-26, 2024

BHTS'2024 — 2nd Bosphorus International Heat Treatment Symposium will be in Istanbul, Halic Congress Center April 25-26, 2024, in cooperation with MISAD — Heat Treatment Industrialists Association and METEM-UCTEA Chamber of Metallurgical and Materials Engineers' Training Center.

With the scope of this symposium, a space will be created where the challenges in advanced heat-treatment technologies, current R&D studies, new developments, and different ideas will be discussed. Within this framework, local, foreign, and international companies are invited that want to exhibit their products, services, and exemplary applications to support them as participants. The symposium is in Turkish and English. Turkish-English simultaneous translation will be provided in all sessions.

Deadline for papers is January 19, 2024.

»**More info:** www.bhtsheat.com/en

29th IFHTSE Congress
September 30-October 3, 2024

The ASM Heat Treating Society (HTS) and the International Federation for Heat Treatment and Surface Engineering (IFHTSE) present the 29th IFHTSE World Congress, a premier global event dedicated to advancing the fields of heat treatment and surface engineering. It will be co-located with ASM's Annual Meeting, IMAT 2024, and is scheduled for October 1–3, 2024, in Cleveland, Ohio.

The 2024 IFHTSE World Congress revolves around the theme "Innovations in Heat Treatment and Surface Engineering for a Sustainable Future." Emphasizing the critical role of these technologies in shaping a sustainable world, the event will explore the latest

The total attendance for Heat Treat/IMAT/MPT Expo 2023 was more than 4,500 attendees, with more than 27 countries represented.

developments, breakthroughs, and practices that can enhance the efficiency, performance, and environmental impact of heat treatment and surface engineering processes. In addition, traditional heat treating topics will be offered.

Important dates:

- **Submission deadline:** January 26, 2024.
- **Author notifications of acceptance:** March 29, 2024.
- **First draft of manuscript due:** May 17, 2024.
- **Editor feedback to authors:** June 14, 2024.
- **Final manuscripts due:** June 28, 2024.
- **More info:** www.asminternational.org/ifhtse-congress

SPOTLIGHT ON MEMBERS

Universidad Autónoma de Nuevo León

Universidad Autonoma de Nuevo Leon was officially established on September 25, 1933, by a vote of the Honorable Congress of Nuevo Leon. With a legacy of 89 years, it is now the largest educational institution in northern Mexico.

More than 24,000 students are enrolled in undergraduate and graduate levels.

IFHTSE is a federation of organizations not individuals. There are three groups of members: scientific or technical societies and associations, universities and registered research institutes, and companies.

IFHTSE 2024 EVENTS

APRIL 17–19, 2024
4th Mediterranean Conference on Heat Treatment and Surface Engineering (MCHTSE 2024)
Lecce, Italy I www.aimnet.it/eng/manifestazione.php?id=788&idc=4

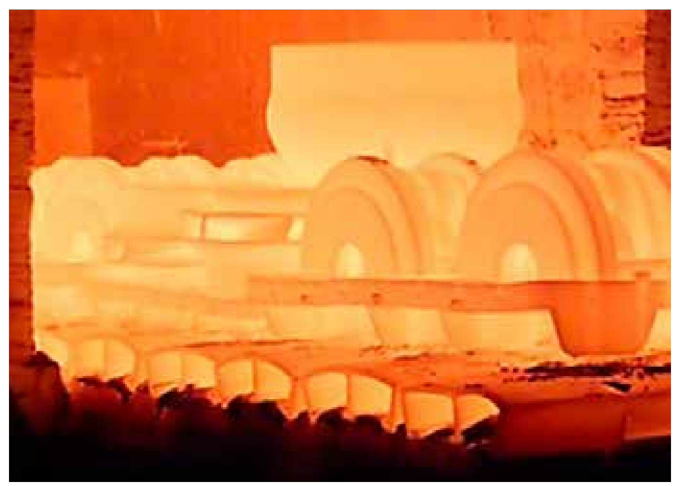
APRIL 17–19, 2024
5th International Conference on Thermal Process Modeling and Simulation (5th ICTPMS)
Lecce, Italy I www.aimnet.it/eng/manifestazione.php?id=789&idc=4

APRIL 25–26, 2024
2nd Bosphorus International Heat Treatment Symposium
Istanbul, Turkey I www.bhtsheat.com/en

MAY 6–8, 2024
3rd QDE - International Conference on Quenching and Distortion Engineering
Vancouver, Canada

SEPTEMBER 30-OCTOBER 3, 2024
29th IFHTSE Congress
Cleveland, Ohio I with IMAT and ASM's annual meeting

For details on IFHTSE events, go to www.ifhtse.org/events



IHEA COMPANY SPOTLIGHT

Algas-SDI supplies combustion equipment to heat treaters around the world

Algas-SDI is a manufacturer of liquid fuel vaporizers, natural gas backup and decompression equipment, and combustion equipment. The company deploys its products worldwide through its network of distributors.

Algas manufactured its first direct fired propane vaporizers in the 1930s. In the 1990s, Algas merged with Sam Dick Industries (SDI), which was owned by Eclipse, Inc. at the time.

Algas-SDI has a long history of using packaged burners in water bath vaporizers. A combustion products division was created in 2021 due to supply-chain challenges and given the long business history with Eclipse, Inc.

In addition to the Simple Heat packaged burners used on water bath vaporizers, the company also supplies Velocity Heat direct fired furnace burners for higher temperature applications.

In 2022, the company moved to a new facility in Kent, Washington, in order to support its continued growth.

Phoenix Velocity Heat Direct Fired Burner provides 3,000,000 BTU/hr. Typical applications for the VH burners include batch and continuous furnaces for heat treating, thermal oxidizers, and non-ferrous melting furnaces.

Becoming a member of IHEA was considered a good fit for Algas-SDI due to IHEA's long and proud history as a reputable organization.

Before becoming a member, Algas-SDI already had many working relationships with a lot of current members of the association. The knowledge and reputation of these IHEA members transferred to the association itself. Another positive for the membership was the knowledge and reputation of the IHEA members as well as the association itself. That stems from IHEA being a trend spotter as well as a trend setter for the combustion industry.

To that end and with IHEA's assistance, Algas-SDI strives to be a preferred supplier of equipment that enables the transition to a clean and efficient use of non-carbon-based fuels.

But the need for being an IHEA member goes both ways.

As a new IHEA member, Algas-SDI is bringing a new team of aspiring and curious combustion enthusiasts to the table – a team driven by the company's desire to provide simple-to-use, quality products. Algas-SDI's focus is to deliver its products with reasonable lead times and personable, top-notch customer service.

To put it simply, Algas-SDI is fueled by curiosity, and the company is ready to serve its customers with a high-energy team. Some members of that team are still early in their careers and are eager to make their mark on the industry.

With all that Algas-SDI brings to the table, the company's IHEA membership will be an important step for Algas-SDI to learn more about the current trends in the combustion industry, to know what the industry is discussing, and network with like-minded individuals.

It will also provide a path to getting the company name on the lips of a constantly evolving industry and let OEMs and solution providers know that Algas-SDI is at the ready to support them while growing its technical knowledge and returning that knowledge whenever possible.

SUSTAINABILITY & DECARBONIZATION SERIES

With the popularity and success of this summer's Sustainability & Decarbonization webinar series, the Industrial Heating Equipment

Phoenix Simple Heat Packaged Burner is a nozzle-mixing burner with an integral air blower designed to operate with fixed combustion air over a wide turndown range.

Association (IHEA) announces an expansion of the series with 11 new sustainability webinars through 2024.

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The series will continue to be offered on the third Thursday of every month with an occasional exception for holidays.

IHEA's Sustainability & Decarbonization webinar series focuses on carbon producing heating processes and provides methods to optimize their efficiency and thereby reduce their carbon emission intensity. The webinars cover the various scopes of carbon emissions and the methods to determine your site, or specific equipment, carbon footprint. IHEA is pleased to add critical subject matter to its educational calendar.

The IHEA board of directors determined the webinar topics that are critical, and IHEA members have volunteered to develop the content and deliver the webinars. IHEA will be adding details for each webinar so be sure to check back often for additional information. To register for the webinars, go to www.ihea.org/sustainabilitywebinars.

Webinar schedule

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›› **March 21, 2024:** Hydrogen Basics, Honeywell Thermal Solutions.

›› **April 18, 2024:** Making Decisions - Gas vs. Electric, Surface Combustion.

›› **May 16, 2024:** Today's Existing Technology for Carbon Reduction, Bloom Engineering.

›› **June 20, 2024:** Understanding Carbon Credits & Net Zero, Surface Combustion.

›› **July 18, 2024:** Industry Adoption: US Codes & Standards, Karl Dungs Inc.

›› **August 15, 2024:** Renewable Fuels, Karl Dungs Inc./Advanced Energy.

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D. SCOTT MACKENZIE, PH.D., FASM
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Causes of intergranular corrosion in austenitic steels, and some of the steps taken to reduce 3XX stainless steels' susceptibility to intergranular corrosion.

Intergranular corrosion of austenitic stainless steels

In this column, I will discuss the intergranular corrosion of austenitic stainless steels (3XX) and discuss the thermal processing causes.

INTRODUCTION

Austenitic stainless steels, such as 304, are used in practically every industry, for chemical plants to kitchen appliances. They are widely used because of their attractive appearance and resistance to corrosion, especially in wet environments.

Austenitic stainless steels are a group of alloys that contain approximately 18 percent chromium and 8 percent nickel. Other alloying elements such as molybdenum and titanium are added to enhance corrosion resistance. Typical compositions of austenitic stainless steels are shown in Table 1. Molybdenum is added to increase overall corrosion resistance, while titanium is added to the melt to trap carbon and form titanium carbides. Typically, titanium is added at five times the amount of carbon and nitrogen present in the melt. Titanium is a strong carbide former, and is a stronger carbide former than chromium, and minimizes the formation of chromium carbides. Sulfur is added to AISI 303 stainless steel to improve the machinability and chip formation.

The "L" designations after the alloy number means that the carbon content is controlled to a much lower level (< 0.030 C). This is to improve weldability and to minimize chromium carbide formation during welding.

AISI grade	C	Cr	Ni	Mo	Others
301	0.1	17.5	8.0	-	-
304	< 0.07	18.5	9.0	-	-
304L	< 0.030	18.5	9.0	-	-
303	< 0.10	18	9.0	-	0.3 S
321	< 0.08	18	10.5	-	0.70 Ti Max
316	< 0.07	17.5	11.5	2.20	-
316L	< 0.030	17.5	11.5	2.25	-
316Ti	< 0.08	17.5	12.0	2.25	0.70 Ti Max

Table 1: Typical compositions for selected austenitic steel grades.

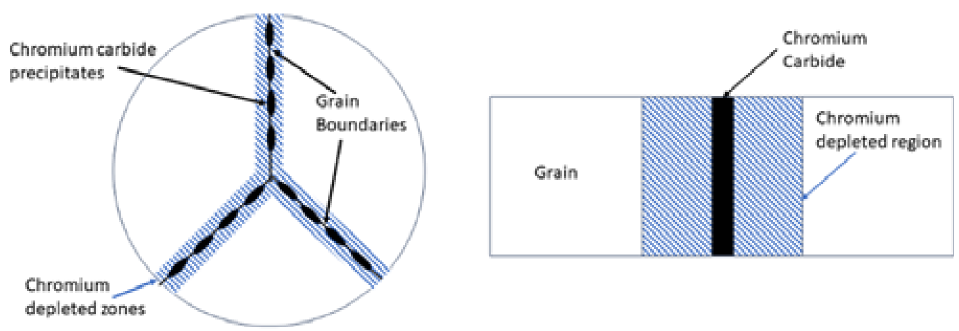

Figure 1: Schematic representation of grain boundaries in a sensitized austenitic stainless steel. The left image shows how this would appear in a microscope, while the right image shows a cross-section of the grain boundary (after Fontanna [2]).

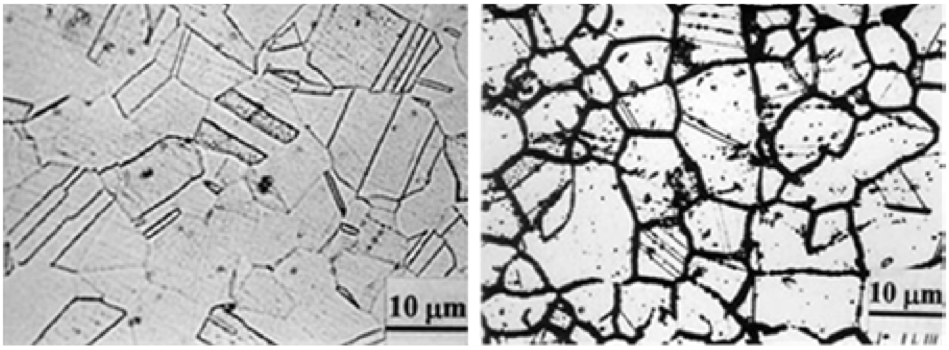

Figure 2: Sensitized 304 stainless steel. (Courtesy: Rolled Alloys, Temperance, Michigan).

SENSITIZATION OF AUSTENITIC STAINLESS STEELS

When austenitic stainless steels are heated in the temperature range of 450 - 900°C, they become sensitized to intergranular corrosion. In many test methods, deliberate sensitization of austenitic stainless steels is accomplished by deliberately holding it at 650°C for one to two hours [1]. Sensitization can occur by holding the alloy at this temperature, or slow cooling the alloy through this temperature range (annealing or slow cooling after welding).

In the temperature range of 450-900°C, carbon, and chromium carbide, $Cr_{23}C_6$, is insoluble in the matrix and precipitates out of solid solution. This occurs when the carbon content is greater than approximately 0.02 percent. The chromium carbide precipitates at low energy sites such as grain boundaries. This removes chromium from the matrix and creates a depleted chromium region adjacent to the grain boundary. This is schematically shown in Figure 1. This effect is striking when viewed metallographically (Figure 2).

In a wet chloride environment, or other acids with low pH, the chromium-depleted regions do not have adequate chromium present to provide sufficient corrosion protection. This chromium-depleted region is preferentially attacked, while the interior of the grain

and the carbide is unaffected [3]. The interior of the grain and the chromium-depleted zone are in intimate contact, with the grains having a much larger area than the grain boundaries, resulting in dissimilar metal compositions. The chromium-depleted regions protect the interior of the grains. A rapid attack of the chromium-depleted region occurs.

This slow cooling of a part through the sensitization zone can often occur in welding of austenitic stainless steels, especially in the HAZ, or Heat Affected Zone. This occurs when the weld slow cools through the critical temperature range of 450-900°C, with precipitation of chromium carbide at the grain boundaries. The HAZ spends greater time in this critical range, and preferential corrosion of the HAZ can occur. This phenomenon is called "weld decay."

Austenitic stainless steels are not hardened by heat treatment. Only by cold work do these steels increase hardness. After processing, usually at the mill, austenitic stainless steels are solution process annealed around 1,050°C to dissolve carbides and any sigma phase present. These carbides may form during heating to the solution annealing temperature. A rapid quench, usually in water, follows solution annealing. This process prevents the formation of carbides at grain boundaries and minimizes the possibility of the chromium-depleted zone surrounding the carbides.

Carbide formers, such as titanium, niobium, and tantalum are used to prevent the formation of chromium carbides. These elements are much stronger carbide formers than chromium, so scavenge residual carbon.

TESTING FOR SENSITIZATION

The predominant test methods for determining if an austenitic stainless steel is sensitized is ASTM A262 [1]. The test specification describes several testing methods to understand if the alloy is susceptible to intergranular corrosion, or if any thermal processing has created a sensitized structure. Often, this is done as part of an initial qualification testing of the part or process [4].

ASTM A262 Practice A – "Oxalic Acid Test"

In Practice A, a test panel is metallographically prepared and examined for the presence of steps or "ditches." The sample is electrolytically etched with 10 prcent at a current density of $1A/cm^2$ for 90 seconds. This is a quick test and is often used for screening materials.

The microstructure revealed is compared to a series of photomicrographs in the standard, and the degree of sensitization.

ASTM A262 Practice B – "Streicher Test"

In this test, a sample panel is immersed in boiling solution of ferric sulfate and 50 percent sulfuric acid for 120 hours. The weight loss of the sample is measured and then converted to a corrosion rate. This is compared to a reference corrosion rate that is not expected to be prone to intergranular corrosion.

ASTM A262 Practice C – "Huey Test"

This method involves subjecting the sample to a series of five periods of boiling nitric acid of 48 hours each period, with a new solution after each period. This test is not performed often because of the time involved, and potential attack of other phases.

ASTM A262 Practice E – "Strauss Test"

The Strauss test was the first test used for detecting sensitized steels, and susceptibility to intergranular corrosion. It is a pass-fail test.

In this method, the sample is exposed to a boiling solution of copper shot, copper sulfate, and 16 percent sulfuric acid for 15 hours. After the exposure, the sample is bent at 180 degrees. The fracture surface is then examined under optical microscopy at low magnification. If fissures or cracks appear, the presence of intergranular attack is confirmed.

ASTM A262 Practice F

This method is very similar to Practice E, but metallic copper is not used. Higher concentrations of copper sulfate and sulfuric acid is used. Weight loss, after 120 hours, converted to corrosion rate, is used to determine resistance to intergranular corrosion.

CONCLUSIONS

In this article, I have described the cause of intergranular corrosion in austenitic steels, and some of the steps taken to reduce 3XX stainless steels' susceptibility to intergranular corrosion. Reducing the carbon content and adding strong carbide formers to the melt to prevent chromium carbide, are the primary mill-controlled methods.

In fabrication (or service), care should be taken to avoid exposure in the 500-800°C temperature range. This can result in the formation of chromium carbides at the grain boundaries, and the material becoming prone to intergranular attack due to sensitization.

Should you have any comments on this article, or suggestions for additional articles, please contact the writer or the editor.

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TONY TENAGLIER
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Sometimes, the secret to success in business is knowing what you don't know — and figuring out what you need to know to get the right results.

Overcoming the knowledge 'blind spot'

No one knows everything. Nor will anyone ever obtain all the knowledge in the world. Sometimes what happens, though, is we learn something and then decide we are now experts in that area. This blind spot can mislead us, a phenomenon known as the Dunning-Kruger effect. This effect is when a person knows very little about something yet has great confidence in their expertise.

This has happened to me in solving complex heat-treat problems over the years, and has humbled me in my learning journey. Simplifying alloy systems to binary eutectic phase diagrams makes the thought process relatively simple when considering solidus and solvus lines for solution and age temperatures. But it can't solve every heat-treat problem. To overcome this situation, one needs to continually ask questions, be honest with themselves about their knowledge base, and get genuine feedback (not flattery for how awesome they always are).

It is more challenging to read the literature on how other alloying elements can create other phases, change the solidification temperatures, or even impact diffusion mechanisms than it is to rely on what we already know. However, to keep that limited perspective and not look beyond our current knowledge will not result in proper heat treat. It's easy to stick with what we know and the knowledge familiar to us.

Sometimes, working to expand our knowledge base is a daunting prospect. That fear in the employee to look inward to reflect on their current state of knowledge is similar to being on top of the mountain; they don't want to come down. But by keeping their head always pointing up, they can't see where they are going as they don't look down at what they are stepping on. That can translate to overlooking a failed metallographic test here or missed cycle there. Without continually studying the proper literature, being honest in our assessment of our true knowledge base, and receiving appropriate feedback, the proper heat-treat cycle does not get performed.

Running a slow ramp rate past a solvus temperature based upon the binary phase diagram can get you in the ballpark of the correct heat treat. Metallographic results can demonstrate effective ramp rates, solution temperatures, and times. This is genuine feedback. If the results are not passing, then consideration of performing calorimetry testing and studying the effects of alloying elements and their interactions on the system is needed.

However, it takes a certain sort of bravery to embark down a path of knowledge we don't know. Through the "valley of despair," confidence becomes low when we begin to realize how little we know about something — electron vacancy calculations for potential phase formation, slip planes of metallic structures, diffusion mechanisms, or thermodynamic considerations of phonons, for example. These are all potential phenomena to consider at elevated temperatures and times and manufacturing of metal alloys. All are worthy of their own lifetime of exploration in understanding.

This isn't to discourage someone to keep learning. This is the blind

It takes a certain sort of bravery to embark down a path of knowledge we don't know. Through the "valley of despair," confidence becomes low when we begin to realize how little we know about something.

spot we have, the area we cannot see because we are too afraid to look. Instead of being blind to it, the more we keep an open mind, and keep learning fun and exploratory with constructive feedback, we will begin to acquire the toolbox of questions to ask. It isn't necessarily about what we know; it often comes down to what types of questions we can ask to figure out what we don't know so we can solve a given problem.

This phenomenon can also apply beyond just material science calculations for heat-treat cycles. It can extend to other facets of the employee role — employees who are managers, supervisors, or heat-treat operators all have avenues of responsibility that benefit from continuing to widen their knowledge base. The fact that no one is perfect nor can ever truly know everything leaves us at the mercy of the Dunning-Kruger effect if left unchecked.

Peter's Principle is the condition when an employee "rises to the level of their incompetence." That is, an individual can begin as a heat-treat operator and be very skilled. However, over the years this employee gets a promotion and now is the heat-treat supervisor. The skills of being the heat-treat operator are not always transferable to that of being the supervisor (thus reaching the level where the employee is not competent). The lack of developing the skills to be an effective supervisor or manager results from the Dunning-Kruger effect. Because the success of this employee was based upon their heat-treat experience as an operator, there is potential belief that what they were doing then will now work as they supervise. But just as in the example of investigating beyond the simple binary phase diagram for defining heat-treat cycles, more work is needed to develop the social skills necessary for managing other employees in order to be a successful supervisor.

An operator can probably talk to the furnace to make it work, but talking to other employees as a supervisor or manager or even as a leader takes a different type of communication skill. To overcome this blind spot, the same need to ask questions, assess one's personal knowledge, and obtain feedback is required.

Asking questions in the heat-treat department is critical to a successful process. But beyond asking the questions of whether a cycle properly solutions or hardens or tempers, questions around personnel motivation, work ethic, and even emotional intelligence are needed with the step up from operator to manager. Thinking that heat treating is purely technical is a critical mistake for any employee dealing with human relations.

Therefore, it is critical to assess one's knowledge of their own psychological image. What motivates a particular employee? This may not be the same for them as it is for you. Some people work for a paycheck to support a family. Others don't have families and simply love to work. Others have a particular enthusiasm for certain occupations. Knowing what motivates employees is critical to steering the heat-treat facility in the right direction for overall success beyond a successful physical technique.

Feedback with individuals can be measured by overall enjoyment of the job or willingness to perform a particular function. This feedback is like metallographic reports based upon time and temperature in a furnace. If threats are required to motivate employees, that manager is lacking the bravery to understand what motivates themselves. Turning up the temperature of the furnace doesn't always solve the problems in heat treat.

Instead, we must turn inward; we need to put the microscope on ourselves. Again, it is not a matter of what we know. The measure is really the way we approach something and can ask questions, get appropriate feedback, and properly assess how we quantify our knowledge so we can gain the information required to get the results we seek.

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INVESTIGATIONS ON THE TOOTH ROOT BENDING STRENGTH OF LARGER-SIZED, INDUCTION-HARDENED GEARS

In order to achieve a high tooth root load-carrying capacity, a surface hardness exceeding the standard specifications for induction-hardened gears as well as a hardness pattern close to the contour and as uniform as possible over the gear circumference must be reliably set.

By HOLGER CERMAK, DR. THOMAS TOBIE, and PROF. KARSTEN STAHL

Surface hardening is an economical and technological alternative to case hardening. This is especially true for larger-sized gears. Due to the necessary high case-hardening depths required for larger case-hardened gears and due to technological boundaries (e.g., heat-treatment furnace size and heat-treatment duration) typical surface-hardening processes such as flame or induction hardening can exhibit their benefits for these parts. While flame hardening usually results in mostly through-hardened gear teeth, contour-hardened teeth can be achieved by induction hardening. As a result, the properties of surface-hardened gears significantly differ in the surface and in the core region. However, the achievable tooth root bending strength strongly depends on the gear properties, such as the surface hardening depth and the microstructure.

In the framework of this article, the influence of induction hardening on the tooth root bending strength of larger-sized gears is investigated. Therefore, different variants of larger gears that were induction hardened gap-by-gap are compared. In order to gain a deep understanding, a systematical variation of the surface hardening depth, gear size (m_n = 14 mm and 20 mm), and surface condition was carried out. For example, as for the surface condition, one variant is additionally shot blasted after the hardening process. In addition, the experimental results for the induction-hardened variants are compared to a flame-hardened variant. The experimental investigations were done using a pulsator test rig and all variants are characterized by metallographic analysis and the determination of hardness depth profiles. The results are compared to the state-of-the-art for induction-hardened gears according to ISO 6336, part 5 and are additionally contrasted to experimental results for case-hardened gears with an equivalent size found in the literature.

1 INTRODUCTION

To increase the load carrying capacity of gears, they are usually heat treated. The most common process in industrial practice is case hardening. The development of wind turbines and ships shows they have become larger in recent years, and thus the gears used have also increased in size. However, case hardening may reach some limits for large gear sizes. Firstly, for case hardening, the components have to fit completely in furnaces. Secondly, the required case-hardening depth (CHD) for larger gears is in the order of several millimeters. Long process times, sometimes several days, are necessary to reach such high CHDs. Furthermore, the entire gear is heated during case hardening and has to be cooled again. The need for large furnaces and the long process times reduce the economic efficiency of the process.

Induction hardening is an alternative to case hardening with shorter process times, less energy consumption, and relatively small heat-treatment systems. With induction hardening, surface-hardening depths of several millimeters up to centimeters are feasible within short process times per tooth gap. With induction hardening, only the region of the gear hardened has to be heated. The problem is that, for induction-hardened gears, there are no recent publications available regarding the load carrying capacity of larger gears. The documented load carrying capacities (small and larger gear sizes), for example in ISO 6336-5 [1], are based on studies from the 1980s and are about 20 percent lower than for case-hardened gears. Since then, many technological advancements have been made that significantly improved the induction-hardening process. The improvements have led to a significant increase in load-carrying capacity, as shown for smaller gear sizes in [2]

2 STATE OF THE ART

In designing gears, a number of gear damage types, e.g., tooth flank fracture, macropitting and tooth root breakage, must be considered. Each damage type has different damage mechanisms. What all types of damage have in common is that a shortened or prolonged overload of the gear can result in a total failure of the gearbox, either directly or through consequential damage. With ISO 6336 [3], there is a standardized procedure for calculating the load carrying capacity with regard to different types of damage. In order to calculate the load-carrying capacity of gearings, the authoritative stress number is essentially compared with an allowable stress number. The allowable stress numbers for macropitting and bending strength are given in ISO 6336-5 [1] and are based on experimental test results. If the applied stress exceeds the allowable stress, gear damage occurs. To prevent failure, there are two possibilities: Reduce the applied stress, or increase the strength of the gears. To increase the load-carrying capacity, gears are usually heat treated [4-6]. Case hardening is the de facto standard heat treatment for gears. Accordingly, numerous current studies are available on the load-carrying capacity of case-hardened gears [7-11]. Although there are some publications on induction hardened gears [12-19], there are only a few available that show experimentally secured strength numbers, especially more recent ones [20-22].

The maximum allowable stress number for surface hardened gears is about 20 percent lower than that for case-hardened gears according to ISO 6336-5 [1]. But it must be remembered that the standard regarding surface-hardened gears is based mainly on studies from the 1980s [22]. Since then, many technological advancements have been made that significantly improved the induction hardening process.

Recent experimental results with modern induction hardening processes [20, 21] show that, under appropriate conditions, induction-hardened gears can reach load carrying capacities similar to those of case-hardened gears. In FVA 660 I [2] numerous influences on the tooth root bending strength of induction-hardened gears were investigated [23] for gear sizes of m_n = 2 and 4 mm. Figure 1 shows the experimental test results from FVA 660 I [2] for gears of size m_n = 4 mm classified in the strength diagram according to ISO 6336-5 [1] for surface hardened and case hardened gears.

The majority of the variants show a tooth root bending strength in the range of the material quality ML and MQ for case-hardened gears. One variant of FVA 660 I [2] even has a load-carrying capacity in the range of the medium-quality MQ for case-hardened gears. Also, the surface hardness of the gears could be raised above the specifications of ISO 6336-5 [1] without the occurrence of hardening cracks. However, it can also be seen that, if the induction heat-treatment process is not adjusted properly, the resulting load carrying capacity might drop dramatically. Small induction-hardened gears are usually spin hardened, while larger sized gears are usually hardened gap-by-gap. The resulting hardening patterns and therefore the resulting microstructural properties (e.g., residual stresses) differ between spin hardened and gap-by-gap hardened gears. Figure 2 shows the achievable hardening contours. While the hardening contour can range from through hardened (left) to contour hardened (middle), gap-by-gap hardened gears are mainly near contour hardened (right). Therefore, it is not clear whether the results on small gears apply without restriction to larger gears.

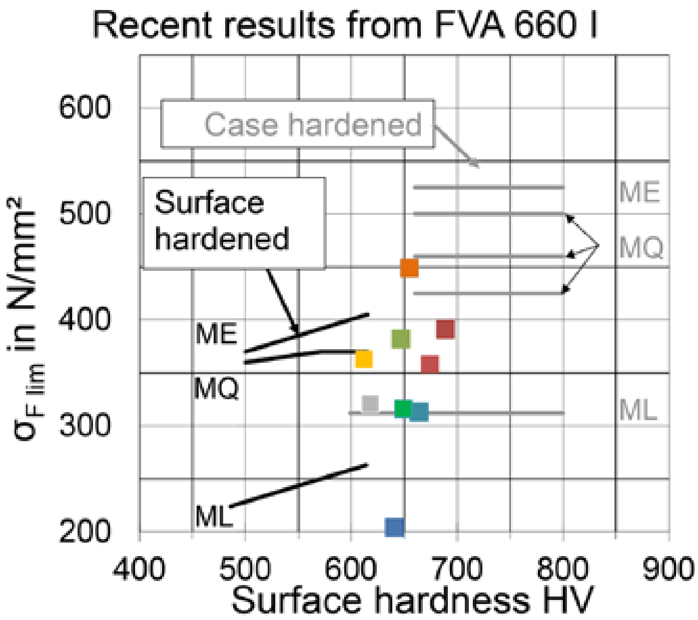

Figure 1: Recent results for tooth root load carrying capacity from FVA 660 I [2] classified in the strength diagram according to ISO 6336-5 [1]

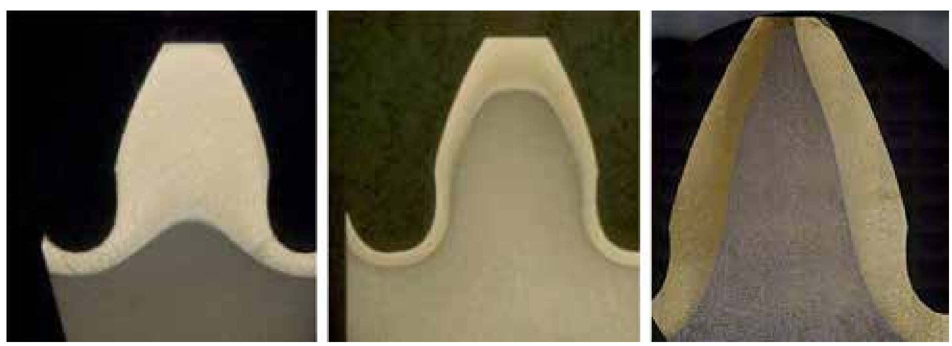

Figure 2: Hardening contour of spin hardened (left and middle) [2] and gap-by-gap (right) [24] induction hardened gears.

3 RESEARCH OBJECTIVES

The documented strength values for surface hardened gears in the standard ISO 6336-5 [1] are mainly based on research from the 1980s [22] on gears of size $m_n \leq 8$ mm. The surface hardened gears had load carrying capacities about 20 percent below the load-carrying capacity of case-hardened gears. Recent research on induction-hardened gears of smaller size m_n = 2 and 4 mm [2, 21, 23] show that, with the latest induction-hardening processes, load carrying capacities similar to case-hardened gears can be achieved. In contrast, no comprehensively documented strength numbers are yet available for induction-hardened gears of larger sizes (module m_n > 8 mm). Thus, in the research project AiF Nr. 19630 N/1 / FVA 660 II [24], the tooth root load carrying capacity for gears of larger size ($m_n \geq 8$ mm) was investigated. Various influences on the tooth root load capacity such as the surface hardening depth (SHD), the gear size, and blasting treatment — among others — were investigated. In a previous article [20], it was shown induction-hardened gears of a larger gear size can also reach load-carrying capacities similar to case-hardened gears.

The main objective of the investigations within the scope of this publication is to examine the influence of the hardening depth, the gear size, and blasting treatment on the load carrying capacity of induction-hardened gears of larger size. In addition, the experimental results of the induction-hardened variants are compared to a flame-hardened variant. For this purpose, seven selected variants from the research project are presented and analyzed. Lastly, the experimentally determined load carrying capacities of the surface-hardened variants are compared to a case-hardened reference. This is done on the basis of the following points:

» Characterization of base material.

» Characterization of gears after heat treatment.

» Comparison of the achieved load carrying capacities in pulsator tests.

» Classification of the results in the strength field according to ISO 6336-5 [1].

4 TEST PROGRAM AND METHODS

The test program includes a selection of different induction hardened variants from the research project FVA 660 II [24], as well as one flame-hardened variant. The variants are listed in Table 1. The variants differ in gear size and surface hardening depth (SHD). The variant M14/S is mechanically cleaned (by shot blasting); apart from that, it is identical to the reference variant M14/25. The main gear dimensions are in Table 2.

The induction hardened gears were gap-by-gap hardened on a single tooth hardening system of the company EFD Induction. In the hardening process, the inductor was moved through the tooth gap along the tooth width. No pre-heating took place. For optimal hardening results, the inductor was fitted with ferrotron concentrators. During the entire hardening process, the mating flank was cooled with a quenchant to prevent unwanted tempering. After heating, the just-hardened gap was instantly quenched as well. The quenchant was a polymer-water solution. After hardening, the induction-hardened gear was tempered for 2 hours at 150°C. The tooth root is in milled condition. After the hardening process, variant 7 was

Variant	Gear size m_n in mm	SHD in tooth root normalized with m_n	Special feature
M14/25	14	0.25	Reference
M14/15	14	0.15	
M14/35	14	0.35	
M20/15	20	0.15	
M20/25	20	0.25	
M14/FH	14	0.25	Flame hardened
M14/S	14	0.25	Mechanically cleaned by shot blasting
CHR	12	0.25	Case hardened reference from [25], mechanically cleaned by shot blasting

Table 1: Considered variants.

Parameter	Symbol	Unit	Module 14 mm	Module 20 mm
Module	m_n	mm	14	20
Number of teeth	z	–	27	18
Normal pressure angle	α_n	°	20	20
Helix angle	β	°	0	0
Face width	b	mm	30	30
Tip diameter	d_a	mm	417	416

Table 2: Gear data of the test variants.

Main area of blasting treatment	Tooth root
Blasting material	Steel ball 1.0 – 1.6 mm, 45 HRC hardness
Throwing speed	54 m/s
Blasting duration	10 min per side

Table 3: Parameters of the shot blasting treatment.

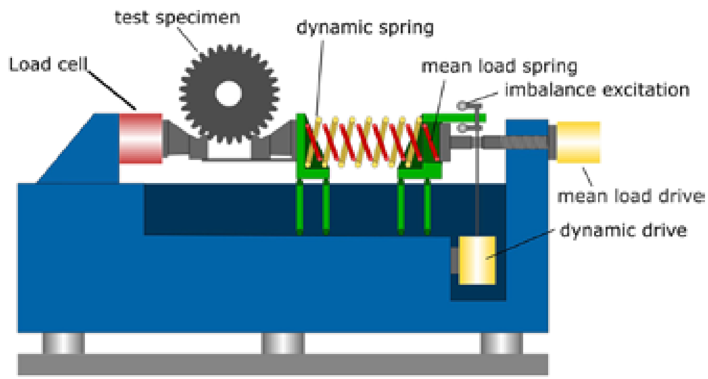

Figure 3: Schematic representation of a mechanically excited resonance pulsator according to [24]

mechanically cleaned by shot blasting.

The flame-hardened variant M14/FH was flame-spin hardened with a hardening temperature of 900°C. After hardening, the flame-hardened gears were tempered for 5 hours at 150°C.

The variant M14/S was mechanically cleaned by shot blasting. The parameters used are in Table 3.

All variants are from one batch of the material 42CrMo4, which is typical for surface hardening. The diameter of the raw material was 430 mm with a reduction ratio of 4:1. The following description is taken from [20]: The material 42CrMo4 was quenched and tempered before heat treatment. For the pre-hardening process, the disk blanks (thickness of the disks: 40 mm) were kept in the furnace for 6 hours at 870°C and then quenched in an oil bath. Subsequently, the disc blanks were tempered at 560°C. For this purpose, the disk blanks were heated to the target temperature for 2.5 hours, kept at the desired temperature for 7 hours and then cooled to 300°C in a controlled manner within 5 hours. The tensile strength of the individual disks after pre-tempering was between approximately 890 and 950 N/mm^2. The material composition was determined by optical emission spectroscopy (S-OES). Table 4 shows the material composition of the material used. All values lie within the target range defined in [26].

The tests to determine the tooth root load carrying capacity of the investigated variants were carried out on a mechanically excited resonance pulsator. The schematic setup is shown in Figure 3.

The test methods are described in [20, 24]. The following paragraphs are based on the descriptions given there:

The resulting tooth root stress depends on the pulsator force, gear geometry, and clamping points.

ISO 6336-3 [27] describes how to convert the pulsator force into the resulting tooth root stress using geometrical values. The geometrical values for the calculation of the tooth root stress of the investigated gears are in Table 5. According to ISO 6336-5 [1], the fatigue strength parameters given in the same standard for the tooth root bending strength $\sigma_{F\,lim}$ and σ_{FE} apply to standard reference test gears under standard test conditions in the running test and 1 percent failure probability. With the aid of the influencing factors defined in ISO 6336-3 [27], strength values can be determined for different gears for the conditions at hand. It is also possible to classify experimental test results in the strength field of the standard. As $\sigma_{F\,lim}$ and σ_{FE} are given for running gears, the test results from the pulsator tests need to be converted to the conditions in gear-running tests. This is done using the established conversion factor of 0.9 [28]. The other required factors for the calculation according to ISO 6336-3 [27] were determined following the standard. The factors influencing the tooth root fatigue strength for the investigated variants are in Table 6. The conversion factor $f_{1\%F}$, for converting 50 percent to 1 percent failure probability depends on the material, the heat treatment, and the blasting treatment. The conversion factor can be determined in two ways [20, 24]: In the first method, the conversion factor is determined based on the standard deviation of

Material		C	Cr	Mn	Mo	S	P	Si	Ni
42CrMo4	ISO 683-2	0.38 – 0.45	09 – 1.20	0.60 – 0.90	0.15 – 0.30	≤ 0.035	≤ 0.025	0.10 – 0.40	–
	Measurement	0.39	1.06	0.73	0.16	0.002	0.007	0.27	0.20

Table 4: Chemical composition in mass fraction in % and comparison with the nominal values for 42CrMo4 according to ISO 683-2 [26].

the tests performed for finding the fatigue strength. The second, more-common approach uses a conversion factor based on literature sources and an underlying statistical analysis of a larger test database. For the induction hardened variants, the conversion factor was determined in the FVA 660 II project [24] according to Method 1. The FH variant showed significantly larger scatter compared to the induction-hardened test series investigated in FVA 660 II [24], therefore the conversion factor from FVA 660 I [2] was applied for induction-spin-hardened gears. The applicability was checked on the basis of the test scatter. In comparison with literature for the conversion factor of case-hardened gears [28], it can be stated that the test scatter of the induction-hardened variants is comparable to the empirical values of case-hardened and mechanically-cleaned gears.

Parameter	Symbol	Unit	Gears size mn = 14 mm	Gears size mn = 20 mm
Clamping over number of teeth	zE	–	5	4
Load direction angle	α_{Fn}	°	26.67	30
Bending moment arm for tooth root stress	h_{Fn}	mm	23.13	31.25
Tooth root chord at the critical section	s_{Fn}	mm	30.11	42.48
Tooth root radius at the critical section	ρ_F	mm	6.16	7.23
Tooth form factor	Y_F	–	2.04	1.92
Stress correction factor	Y_S	–	1.85	2.00

Table 5: Geometric quantities for calculating the tooth root stress (actual geometry) in Pulsator.

Parameter	Symbol	Induction hardened	Flame hardened
Conversion factor from 50% → 1% failure probability	f1%F	0.93	0.845
Stress correction factor for reference test gear	YST	2.0	
Relative notch sensitivity factor	YδrelT	1.000	1.000
Relative surface factor	YRrelT	0.90…0.95	0.95
Size factor	YX	0.91 / 0.85	0.91

Table 6: Factors influencing the toot root fatigue strength according to ISO 6336-3 [27].

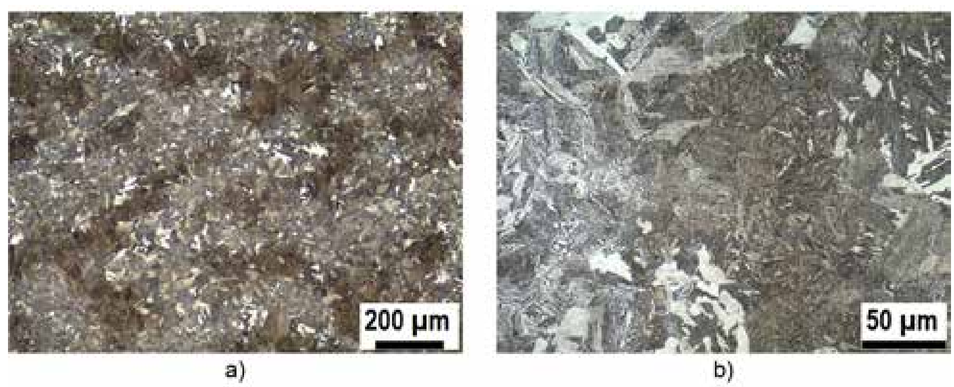

Figure 4: Etched metallographic microsection in the core area of a representative gear.

5 MATERIAL AND GEAR CHARACTERIZATION

Figure 4 shows the microstructure of the core area of a representative gear. As all variants are from the same batch of gear material with the same pre-hardening treatment, the core microstructure of all variants is the same. The microsection shows a hardened and tempered microstructure with clear segregations.

The segregations are within the expected range for 42CrMo4 and the used diameter of raw material.

Figure 5a shows a metallographic cross section of a whole tooth of variant M14/25. The microsection shows the hardening contour along the tooth surface. The hardening contour is typical for gap-by-gap induction-hardened gears. The brightly colored martensitic surface layer is in contrast to the dark-core microstructure. The surface layer shows the same segregations as the core microstructure. Because of the short heating times and fast quenching, the transition layer between the martensitic surface and the quenched and tempered core microstructure is very small. The hardening contour is similar for all investigated induction-hardened variants and only differs in the hardening depth and/or the gear size. For all induction-hardened gears, the hardening contour is thickest at the tooth flanks and lowest in the area of the 30° tangent to the tooth root fillet. The tooth rounding is in between. Figure 5b shows the cross section of the flame hardened variant M14/FH in contrast to the induction hardened variants. The whole tooth is hardened, and the transition from martensitic to the core microstructure is below the 30° tangent to the tooth root fillet. The transition layer is much larger than that of the induction-hardened variants and shows a smooth transition from the hardened tooth to the core microstructure.

Figure 6 shows the hardened surface layer in detail. All variants show a similar microstructure in the surface layer. The surface layer is almost completely martensitic with only little retained austenite.

Variant M14/35 shows a certain decarburization at the surface over the first few micrometers (Figure 6b) and therefore proeutectoid ferrite. The detailed metallographic microsections of the surface layer show a few non-metallic inclusions as highlighted in Figure 6a.

For all variants, the hardness-depth profiles were measured in the left and right tooth root at 30° tangents to the tooth root fillet. Figure 7 shows the hardness depth profiles of the representative induction-hardened variant (M14/25) and of the flame-hardened variant (M14/FH) for the left 30° tangent. The hardness-depth profile of the induction-hardened variant M14/25 is typical for gap-by-gap hardened gears. The surface hardness is about 675 HV1. The hardness stays more or less the same up to the depth where the SHD is reached. For this investigation, the hardness limit to determine the SHD was chosen to be 400 HV1 to have a better comparability within the variants and with earlier research. Close to the SHD, a steep transition of the hardness from about 650 HV1 to the core hardness of about 300 HV1 occurs. The SHD differs from the left to the right sides. The hardness-depth profile of the flame-hardened variant (M14/FH) shows a surface hardness similar to that of the induction-hardened variant but has some fluctuations. The transition from surface-to-core hardness is gradual. In the area of the SHD, the hardness fluctuates again until it drops to the core hardness. The core hardness for the induction and flame-hardened variants is more or less the same, as they are from the same batch of base material with the same pre-heat treatment. The main parameters that describe the hardness depth profiles of all variants are in Table 7. The SHD in Table 7 is the mean value for the left and right sides. The surface hardness is the mean value of the first three measurements (0.1, 0.2, and 0.3 mm below the surface) of the left and right sides.

For the investigated variants, the residual stress-depth profiles were determined by X-ray measurements in the relevant tooth root area. The residual stresses were measured with an X-ray diffractometer, type Seifert (XRD 3003 PTS). Figure 8 shows the resulting residual stress-depth profiles. Overall, the residual stresses are relatively low below the surface. Some variants have practically no residual stresses at the measured depth. Case-hardened gears usually have higher compressive residual stresses in the hardened-surface layer. However, one must bear in mind that case-hardened gears are usually mechanically cleaned by shot blasting. The variant M14/S has the highest compressive residual stress of all variants close to the surface due to the blasting treatment.

In summary: The microstructure and hardness depth profile of the investigated variants are typical for an induction respectively flame hardened specimen. The microstructure and the hardness depth profile show no anomalies. Further information regarding the detailed microstructure, hardness depth profiles, and residual stress profiles of the other variants can be seen in the final report of FVA 660 II [24]

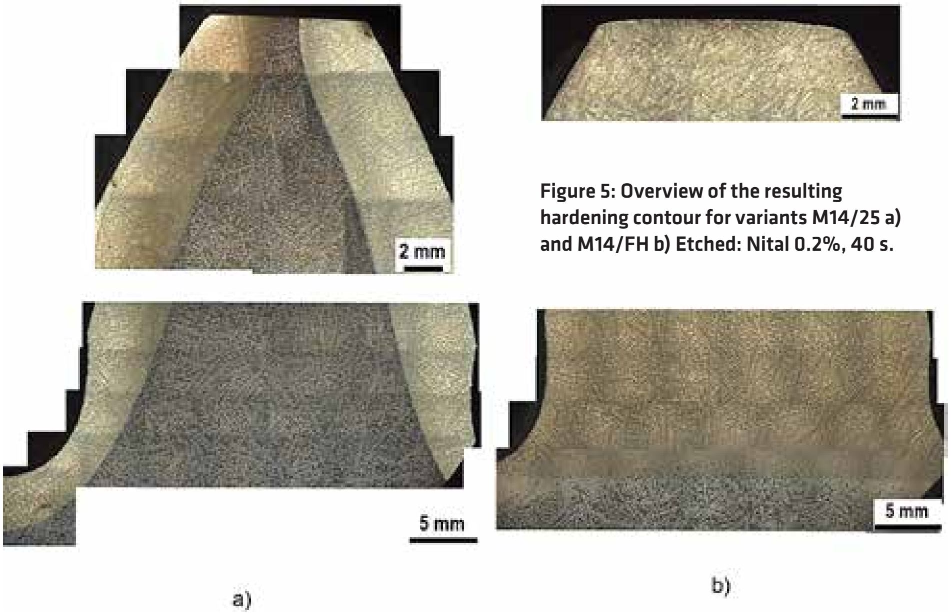

Figure 5: Overview of the resulting hardening contour for variants M14/25 a) and M14/FH b) Etched: Nital 0.2%, 40 s.

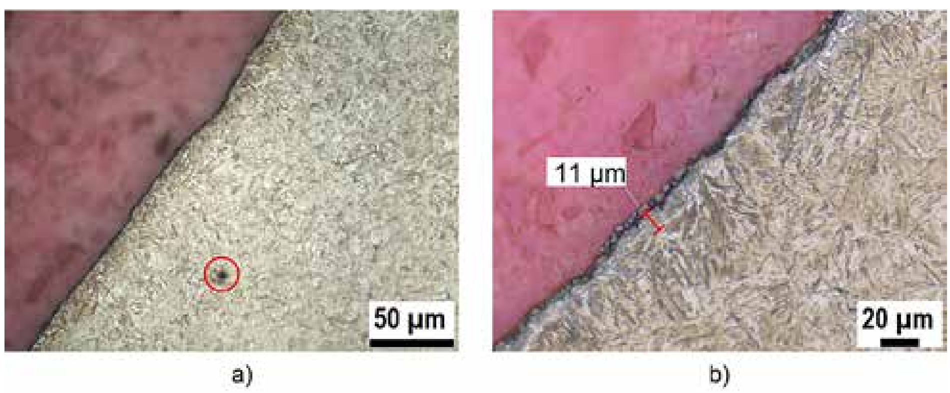

Figure 6: Microstructure of surface layer at 30° tangent to the tooth root fillet for variants M14/25 a) and M14/35 b) Etched: Nital 0.2%, 40 s.

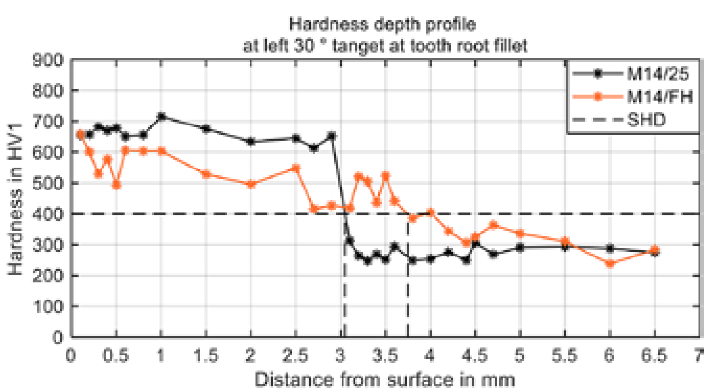

Figure 7: Hardness depth profile at left 30° tangent to the tooth root fillet for variants M14/25 and M14/FH.

6 EXPERIMENTAL RESULTS

To obtain the S-N curves for tooth root bending strength, experimental tests were carried out at different load levels. The endurance limit was determined with the staircase method according to [29]. To determine the high-cycle fatigue strength, tests at two load levels with 3-5 test points each were performed, if possible (load limit of pulsator test rig). Figure 9 shows by way of example the test results and the resulting S-N curve of the variant M14/25. Similar S-N curves for the other variants were determined and are in the final report

	M14/25	M14/15	M14/35	M20/15	M20/25	M14/FH	M14/S
Mean surface hardness in HV1	675 ± 32	669 ± 55	642 ± 42	687 ± 46	654 ± 49	576 ± 85	663 ± 33
Mean SHD_{400} in mm	3.2	2.0	4.9	2.8	4.3	4.4	2.9
Mean SHD_{400} / mn	0.23	0.15	0.35	0.16	0.21	0.31	0.21
Core hardness in HV1	291 ± 30	283 ± 36	266 ± 16	289 ± 30	270 ± 13	248 ± 28	279 ± 33

Table 7: Main parameters of the hardness-depth curves at 30° tangent to tooth root fillet.

of FVA 660 II [24]. The resulting endurable nominal tooth root bending strength for 50 percent failure probability was then converted to the experimental nominal stress number for bending $\sigma_{F\,lim}$, as described in Section 4. The resulting stress numbers for the variants at hand are shown in Figure 10 and compared to the experimental stress number of the case-hardened variant. The variants of gear size m_n = 14 mm have an experimental stress number for bending about 370 to 490 N/mm^2. The gears of size m_n = 20 mm are overall a little bit lower, with stress numbers about 360 N/mm^2. The flame-hardened variant M14/FH has the lowest stress number with 280 N/mm^2. The mechanically-cleaned (by shot blasting) variant has the highest tooth root bending strength with nearly 600 N/mm^2, which is about 30 percent higher than the reference variant M14/25. The tooth root bending strength of the induction-hardened "standard" variants is only a little below the case-hardened and mechanically-cleaned (by shot blasting) reference CHR. The mechanically-cleaned, induction-hardened variant M14/S has a higher tooth root bending strength than the case-hardened reference. This shows induction-hardened, larger-sized gears can reach similar tooth root bending strength numbers as case-hardened gears of similar size.

7 DISCUSSION

The experimental test results show a clear influence of different parameters. The first parameter to be discussed is the surface-hardening depth. As shown earlier in this article, some variants of gear size m_n = 14 and 20 mm have different SHDs by intention. Figure 11 shows the relative tooth root bending strength of the gears taken from Figure 10 normalized with the tooth root bending strength of the variant M14/25 for the variants of gears size m_n = 14 mm and M20/25 for the variants of gear size m_n = 20 mm. The resulting diagram shows a clear influence of the SHD on the tooth root bending strength: With decreasing SHD, the tooth root bending strength rises. The tooth root bending strength of the variant with an SHD of 0.35 • m_n reaches only 80 percent of the tooth root bending strength of the variants with lower SHD.

The variant with an SHD of 0.15 • m_n has a slightly higher tooth root bending strength than the variants with 0.25 • m_n, These results are in correlation with the measured residual stresses, which show higher compressive residual stresses in the hardened layer with smaller SHD respectively, even tensile residual stresses for variant M14/35 with the largest SHD. Presumably, there is a limit for the minimum SHD where the tooth root bending strength will drop significantly. In conclusion and based on the herein determined results for induction hardened gears from gear size m_n = 14 to 20 mm, there seems to be an optimal SHD_{400} in the range of 0.15 to 0.25 • m_n. This is in accordance with earlier research on induction-hardened gears in [22], whereas in [22], a SHD of about 0.15 • m_n was not investigated.

The drop in the tooth root bending strength of variant M14/35 might be due to the decarburization of the surface layer and the resulting proeutectoid ferrite on the one hand and tensile residual stresses in the surface area on the other. This suggests there is a maximum (absolute) SHD that should not be exceeded for induction-hardened gears of larger size. Further research is needed to prove this hypothesis.

The gear size has another influence on the load carrying capacity of induction-hardened gears of larger size. Figure 12 shows the maximum tooth root bending strength for induction hardened gears according to ISO 6336-5 [1] for the material quality grades ME and MQ multiplied by the size factor YX over the gear size in comparison to the experimental test results of variants M14/25, M14/15, M20/15 and M20/25. The experimental tooth root bending strength numbers of

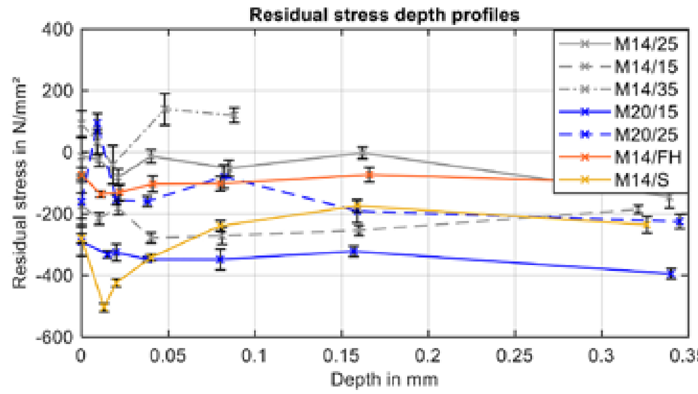

Figure 8: Residual stress depth profiles at 30° tangent to the tooth root fillet.

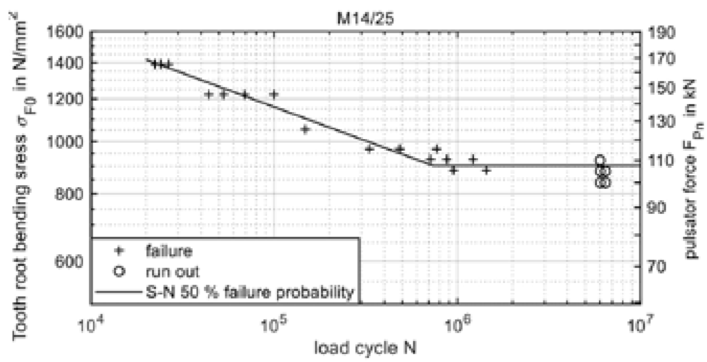

Figure 9: S-N curve for variant M14/25.

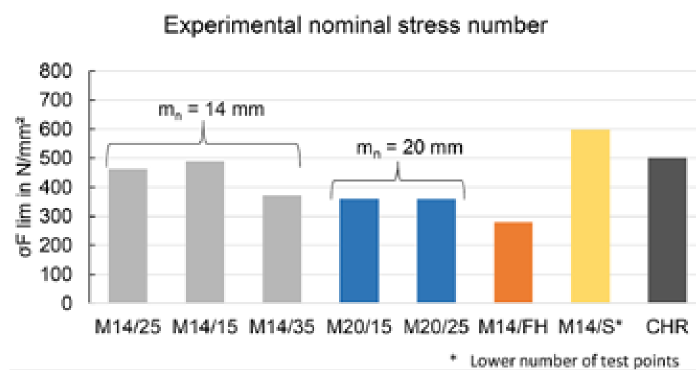

Figure 10: Experimental nominal stress number for bending (tooth root).

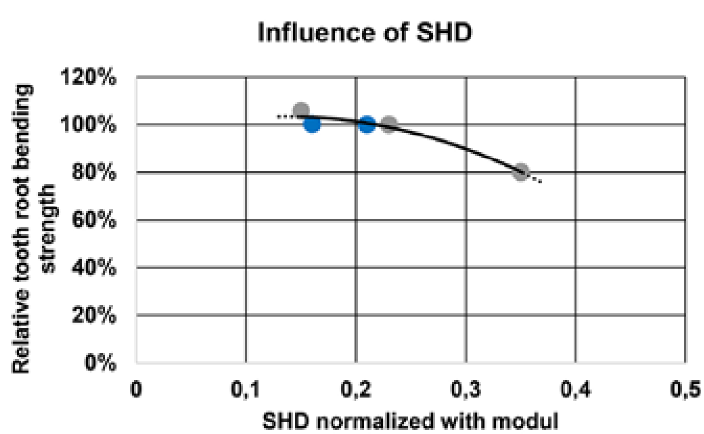

Figure 11: Influence of the SHD on the tooth root bending strength of induction hardened gears of size m_n = 14 and 20 mm.

Surface hardening has certain advantages over case hardening in terms of process economy, but older research and the standard suggest that the load carrying capacity is about 20 percent lower than that of case-hardened gears. Recent studies show, for smaller gears sizes, that is no longer the case. To apply these findings to larger gears, the load-carrying capacity of induction-hardened gears of larger size was studied.

the gears of size m_n = 14 mm are higher than the standard specification for that gear size and material quality, while the gears of size m_n = 20 mm align with the standard specification. To evaluate the influence of the gear size, the experimental test results are shown once with size factor Y_X taken into account and once without. The experimental test results without size factor Y_X suggest the influence of the gear size is underestimated in ISO 6336-3 [27] for induction-hardened gears. The red dotted line shows the influence factor according to the experimental test results for the investigated variants. It must be remembered that the standard is mainly based on case-hardened gears. In order to reliably determine the influence of the gear size, further investigations should be considered.

8 CLASSIFICATION OF THE TEST RESULTS

The test results are classified according to the standard ISO 6336-5 [1]. Figure 13 shows the experimental nominal stress number of the surface hardened variants and the case-hardened reference within the allowable stress numbers diagram for bending from ISO 6336-5. The induction-hardened variants exceed the hardness specifications for induction-hardened gears. The surface hardness of the induction-hardened variants is about 650 to 700 HV, while the maximum surface hardness for surface-hardened gears according to the standard is 615 HV. The induction-hardened variants with gear size m_n = 20 mm and variant M14/35 have a tooth root bending strength in the range of the extrapolated line for the material quality MQ. Variants M14/25 and M14/15 are significantly above the extrapolated line for material quality ME and reach a tooth root bending strength similar to that of the case-hardened reference. This is the case despite the fact that the case-hardened reference is mechanically cleaned by shot blasting while the induction-hardened variants are not. The characteristic numbers of these variants are in the region for the material quality MQ of case-hardened gears with respect to both the surface hardness and the bending strength. The mechanically cleaned (by shot blasting) variant M14/S reaches the highest tooth root bending strength of all variants and lies well above the material quality ME for case-hardened gears with a tooth root bending strength of nearly 600 N/mm^2. The flame-hardened variant M14/FH lies just above the line for the material quality ML for surface hardened gears.

The classification shows that induction-hardened, larger-sized gears can endure much higher bending stresses than indicated in ISO 6336-5 [1]. It must be remembered that the standard regarding induction-hardened gears is based mainly on studies from the 1980s. This study shows that, with the technological progress in the induction-hardening process, higher tooth root bending strength numbers similar to case-hardened gears can be achieved. Therefore, induction hardening can be an alternative to case hardening for larger gears. As mentioned before, induction hardening has shorter heat-treatment times and lower energy consumption than does case hardening. To reach such high load carrying capacities, some preconditions must be fulfilled:

- For gear sizes from m_n = 14 to 20 mm, the SHD_{400} should be in the range of 0.15 to 0.25 • m_n.
- The SHD on the left and right sides of the tooth should be more or less equal.
- The surface hardness should be in the range of 650 to 750 HV, but hardening cracks must be avoided.

9 SUMMARY

Surface hardening has certain advantages over case hardening in terms of process economy, but older research and the standard suggest that the load carrying capacity is about 20 percent lower than that of case-hardened gears. Recent studies show, for smaller gear sizes, that is no longer the case. To apply these findings to larger gears, the load-carrying capacity of induction-hardened gears of larger size was studied.

The aim of the investigations in this article was to show some crucial parameters influencing the load carrying capacity of induction-hardened gears of larger size. To achieve that, seven selected variants from the research project AiF Nr. 19630 N/1 / FVA 660 II [24] were presented. As a basis for further discussion, the base material and the gear properties of the selected variants were analyzed in detail. For this characterization, the microstructural condition, the hardness depth curves, and residual stress depth profiles were considered. The experimental results of the pulsator tests were then presented. The experimental test results show a clear influence of the SHD, gear size, and optional blasting treatment.

Furthermore, the experimental load carrying capacity for induction-hardened gears of larger size was compared to that of case-hardened gears and proves the beneficial applicability for an appropriate induction-hardening process.

In conclusion, the research shows some crucial parameters to achieve high bending-strength numbers for induction-hardened gears. In order to achieve a high tooth root load-carrying capacity, a surface hardness exceeding the standard specifications for induction-hardened gears as well as a hardness pattern close to the contour and as uniform as possible over the gear circumference must be reliably set. The occurrence of hardening cracks must be reliably avoided. Furthermore, care must be taken to ensure sufficient hardening depth in the area of the 30° tangent, which is important for tooth root load carrying capacity.

If these requirements are met, induction hardening can be a time-saving and cost-effective alternative to case-hardened gears for certain applications.

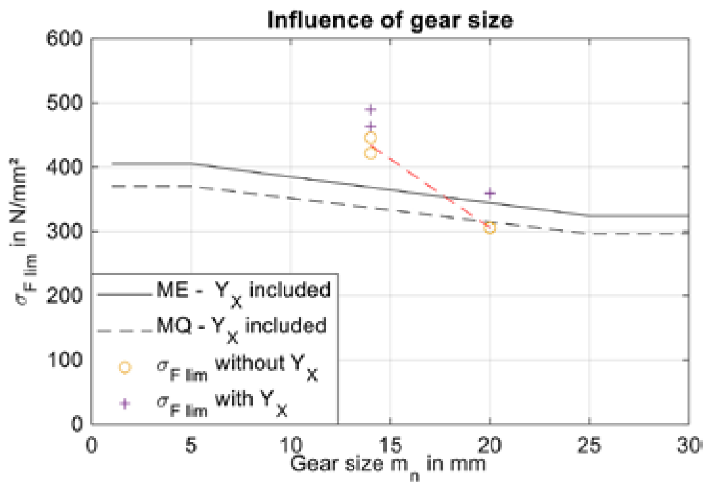

Figure 12: Influence of gear size on the tooth root bending strength of induction hardened gears of size m_n = 14 and 20 mm.

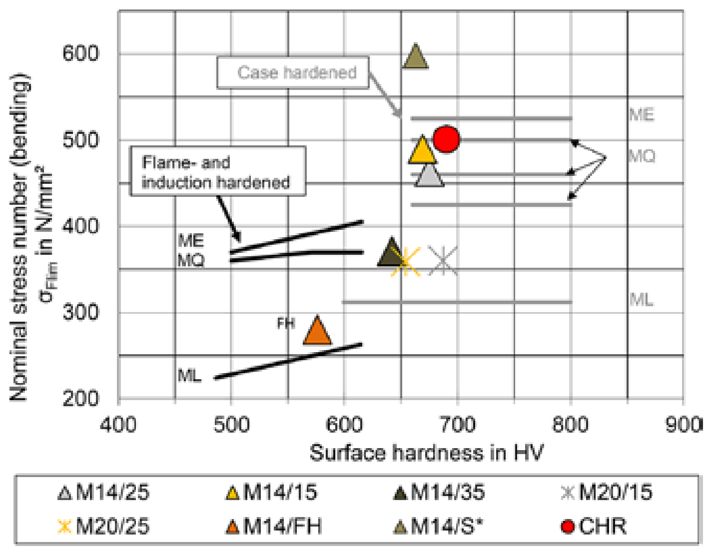

Figure 13: Classification of the test results in the allowable stress numbers diagram for bending according to ISO 6336-5 [1].
*** fewer number of test points**

ACKNOWLEDGEMENTS

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ABOUT THE AUTHORS

Holger Cermak, Dr. Thomas Tobie, and Prof. Karsten Stahl are with the Gear Research Center (FZG) – Technical University of Munich (TUM).

10 STEPS FOR ACCELERATING THERMAL PROCESSING DECARBONIZATION

In order to achieve net-zero emissions objectives, a wide array of measures is available to assist in making sure heat-treating companies' goals are successful.

By DALE SMITH

Companies throughout the thermal-processing sector are under increased pressure to meet CO_2 emission reduction goals, particularly net-zero emissions, by 2050 or sooner. At the same time, they must meet increasingly uncertain energy source demands. All of this must be done cost-effectively.

Honeywell Thermal Solutions recommends 10 steps to help organizations accelerate their progress in achieving their overall energy-transition objectives. Many are supported by Honeywell products and services, and any or all of them can be undertaken to best meet a company's specific needs.

The first five steps entail the monitoring and measurement of combustion systems to help organizations understand where they stand in terms of their CO_2 emissions, energy costs, and other performance criteria. The remaining five steps offer implementation solutions to help optimize operations for better performance and lower emissions today with flexibility for future energy-transition opportunities.

1. CARBON REDUCTION AUDIT AND ROADMAP

The process ideally begins with a team of experts conducting an onsite, equipment-specific audit to determine current energy use and emissions. This helps establish a baseline from which to measure progress against net-zero goals as well as industry protocols, fiscal targets, and sustainability KPIs.

From there, a decarbonization transformation roadmap is created. The multi-year plan outlines strategies and technologies for reducing energy costs, as well as CO_2 and NOx emissions. It features four stackable outcome-based services:

» **Measure/monitor:** Entails digitizing systems for continual, enhanced visibility and real-time monitoring and reporting of current and future changes.

» **Reduce:** Includes hands-on services, upgraded control technologies, the use of higher efficiency burners, and heat recovery and low-emissions solutions.

» **Replace:** Replaces CO_2 fuels with alternative hydrogen-blended fuels created using renewable energy sources.

» **Recapture:** Captures CO_2 before it leaves a facility using CO_2 capture sequestration units (CCSU).

2. PERFORMANCE AND PROCESS MONITORING

One of the most effective ways to reduce emissions is to track the real-time performance of combustion systems, make adjustments as needed, and fix potential issues before they become problems. Unfortunately, critical performance data is often trapped at the equipment level. A solution like Honeywell's Thermal IQ™ platform unleashes that information.

Connecting Thermal IQ to a company's combustion systems or a digital performance "twin" of those systems enables entire systems to be remotely monitored. Real-time thermal process data can be accessed anytime, anywhere, and on any smart device or desktop.

Users can also receive immediate alerts when key parameters are outside normal limits and track historical data over time to identify when and why issues occurred. Dashboards provide performance KPIs and comparative analytics for best-in-class outcomes, along with actionable recommendations that can drive energy savings and CO_2 reduction.

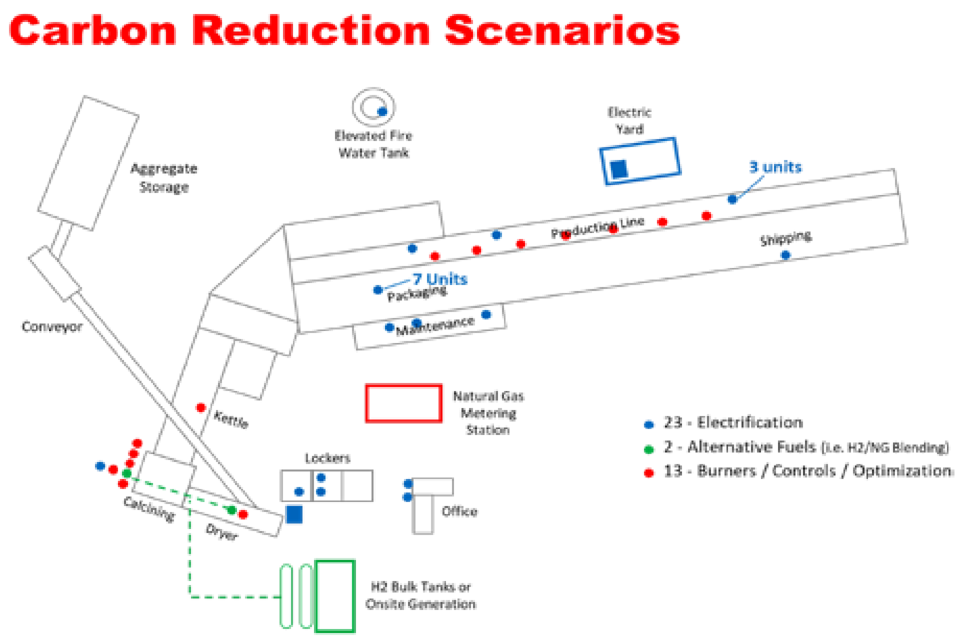


Figure 1: Carbon reduction scenarios.

3. BASELINE EMISSIONS

Using a system such as Honeywell's Thermal IQ platform to "digitize" thermal systems also helps companies establish baseline emissions (BLE). The platform's built-in analytics and machine learning then calculate real-time energy usage and CO_2 emissions trending over hours, weeks, and months.

These insights enable companies to calculate carbon footprint reduction potential, as well as identify equipment-specific and process inefficiencies and determine the need for more efficient system components. More than 100 performance analytics, including safety, reliability, efficiency, and production capacity, can also be tracked.

Figure 2: Connecting Thermal IQ to a company's combustion systems – or a digital performance "twin" of those systems – enables entire systems to be remotely monitored.

Figure 3: Using a system such as Honeywell's Thermal IQ platform to "digitize" thermal systems also helps companies establish baseline emissions (BLE).

4. SENSOR INTEGRATION

Increased visibility into the performance and accuracy of thermal processes is essential for reducing CO_2 emissions. It is also critical for assessing how well various solutions work toward that goal. A wide range of sensors and connected hardware devices that can help include burners, burner controls, flame scanners, oxygen and methane sensors, blowers, actuators, and more.

Kitted sensor packs are also a way to provide insights into specific areas, including process, flow, and emissions. In some cases, the cost of adding these devices may be covered by incentives or rebates from a local utility. (See No. 8 for more information.)

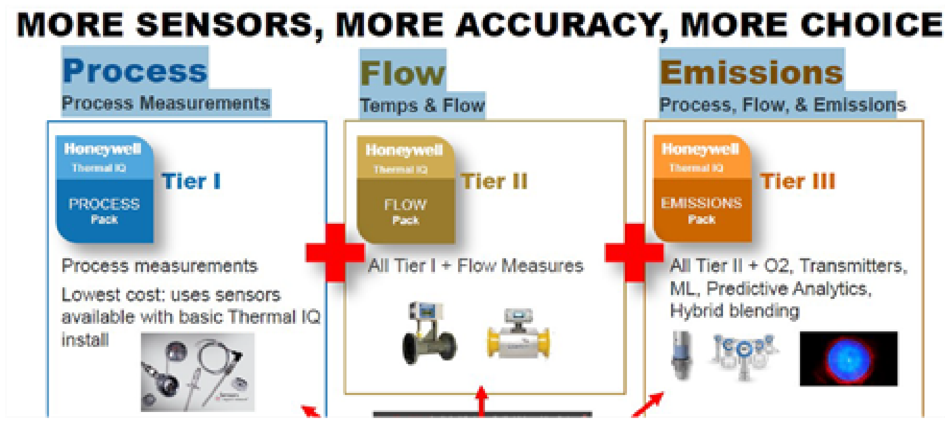


Figure 4: Kitted sensor packs are also a way to provide insights into specific areas, including process, flow, and emissions.

5. DATA SCIENCE AND MACHINE LEARNING

While CO_2 reduction tactics can be implemented based on current equipment performance, numerous factors can change how that equipment will work going forward. That makes future performance and the resulting CO_2 emissions harder to predict. A way to overcome this challenge is through the combination of machine learning and data science.

Data scientists can build sophisticated machine-learning models and train them on current and historical data extracted at both the equipment and system levels. This enables patterns of energy consumption and CO_2 emissions to be identified and future performance to be more accurately predicted. Honeywell further supplements these insights with prescriptive recommendations. This allows companies to proactively take actions to optimize their systems and accelerate their progress toward their CO_2 goals.

6. REMOTE MONITORING AND SERVICE TUNING

Many companies lack the time and expertise to thoroughly monitor their combustion systems, much less plan and implement corrective actions. Thermal systems experts who can take on those responsibilities are available, freeing up internal resources and providing exceptional domain knowledge through the provision of professional remote monitoring and reporting services.

Honeywell's global network of thermal systems service professionals can balance NO_X and CO_2 emissions reduction, system efficiencies, and production capacities. In addition to remote monitoring, they can also provide burner tuning to optimize burners and fuel-air ratios; commissioning, engineering, training, and safety inspections; and other services with the goal of reducing emissions and optimizing system performance.

These services should be backed by service level agreements (SLAs) to ensure regular and timely thermal system optimization, maintenance, and spare parts management.

7. BETTER CONTROLS

As thermal systems age, their performance and efficiencies decline. Simply implementing better, smarter controls can make a difference. Actuators and sensors can help optimize processes and contribute to lower emissions.

Still, some companies must deal with individual components from multiple vendors, separate platforms and protocols, and complicated wiring schematics that can prevent optimal efficiencies and emissions control from happening. For these companies, all-in-one solutions can generate an even broader array of benefits as well as efficiencies. Honeywell's SLATE™ integrated combustion equipment management platform is an example.

Solutions like SLATE can enable companies to improve process efficiency and safety through optimal burner control, reduce fuel costs, reduce CO_2 emissions, and more.

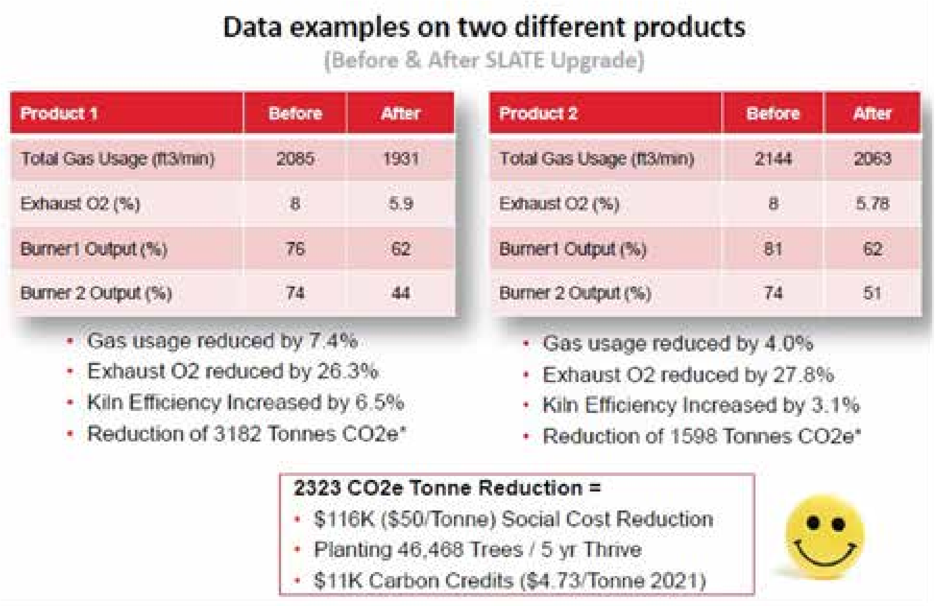
8. RENEWABLE ENERGY/EFFICIENCY INCENTIVES

Upgrading or replacing equipment is not cheap, so it is not surprising that costs remain one of the biggest obstacles companies face in their efforts to reduce CO2 emissions. Fortunately, numerous local and state governments, as well as utilities, offer a variety of rebates, low-cost loans, tax credits and other incentives to help offset the costs of programs that help reduce energy waste, energy demand, and emissions.

Assistance is available to help customers access federal, state, and local energy and emissions reduction funding sources to help drive down project costs. Depending on a project's energy and/or emissions reductions, funding may be available for up to 50 percent of the costs.

9. FUEL EFFICIENCY SOLUTIONS

Boosting fuel efficiency is yet another way to reduce emissions. A com-


Data examples on two different products
(Before & After SLATE Upgrade)

Product 1	Before	After
Total Gas Usage (ft3/min)	2085	1931
Exhaust O2 (%)	8	5.9
Burner1 Output (%)	76	62
Burner 2 Output (%)	74	44

- Gas usage reduced by 7.4%
- Exhaust O2 reduced by 26.3%
- Kiln Efficiency Increased by 6.5%
- Reduction of 3182 Tonnes CO2e*

Product 2	Before	After
Total Gas Usage (ft3/min)	2144	2063
Exhaust O2 (%)	8	5.78
Burner1 Output (%)	81	62
Burner 2 Output (%)	74	51

- Gas usage reduced by 4.0%
- Exhaust O2 reduced by 27.8%
- Kiln Efficiency Increased by 3.1%
- Reduction of 1598 Tonnes CO2e*

2323 CO2e Tonne Reduction =
- $116K ($50/Tonne) Social Cost Reduction
- Planting 46,468 Trees / 5 yr Thrive
- $11K Carbon Credits ($4.73/Tonne 2021)

Figure 5: Solutions like SLATE can enable companies to improve process efficiency and safety.

prehensive range of solutions is available that can facilitate greater process efficiency and, consequently, more efficient fuel usage and less emissions. Those include:

» Based on Honeywell Thermal Solutions and Department of Energy calculations, self-recuperative burners that recover heat from exhaust cases with integrated heat exchangers can reduce natural gas consumption by about a third vs. cold air burners while also reducing NOx emissions.

» Heat exchangers that recover heat from the exhaust stream of processes and reuse it to enhance fuel efficiency. Preheated air needs burners coupled with recuperators to boost efficiency.

» Controls for precise air/fuel ration control to boost burner efficiency.

» Software that continuously monitors thermal processes to diagnose issues and optimize performance, while service technicians keep combustion systems tuned for better operations.

» Separate heat-recovery systems to increase energy efficiency and reduce fuel usage by recovering heat from industrial processes.

» Variable frequency drives that control the speed and torque of single-phase and three-phase induction motors by varying their input frequency and voltage, driving the performance, management, and energy efficiency of the system.

10. HYDROGEN SYSTEMS AND FUELS BLENDING

The use of hydrogen and biofuels are proving to be an effective way of reducing CO_2 emissions. When produced using 100 percent hydrogen, no greenhouse gases are emitted; there are no carbon atoms in 100 percent hydrogen, and, therefore, zero carbon is used or created during combustion. Its ubiquity in industrial processes and its suitability as fuel for a wide range of applications make it ideal for widespread adoption.

A wide array of flexible fuel burners and complete fuel blending skids is available that is ready to provide clean heat in many thermal applications today and can meet future demands. Burner management and control systems, pressure, and safety shut-off valves have also been evaluated and assessed on hydrogen and are ready to safely start, stop, and control hydrogen-fired appliances.

As an example, Honeywell continues to lead the digitalization of the thermal industry with the Thermal IQ platform, which connects thermal assets with analytics to create an enterprise-wide digital thermal ecosystem. Users can measure thermal system performance in real time and estimate cost savings as well as emission levels when blending fuels such as hydrogen.

ABOUT THE AUTHOR

Dale Smith is the HTS growth leader for digitalization/energy transition solutions. He has more than 25 years of experience in driving global safety, reliability, energy optimization, sustainability, and engineering service solutions. His teams have deployed enterprise-wide optimization solutions that drive better business outcomes across all types of industries and clients. He originally joined Combustion Safety, now part of Honeywell Thermal Solutions, in 1991. Dale is a certified maintenance and reliability professional (CMRP). Honeywell remains committed to helping companies accelerate and succeed in their energy transition journeys. It recognizes the numerous challenges and competing priorities companies face and continues to develop solutions that reduce emissions while helping companies meet a wide range of business needs.

Figure 6: A comprehensive range of solutions are available that can facilitate greater process efficiency.

BALANCING A PLANT SECURITY PROFILE

Even in a cyber-focused world, it is still important for thermal processing plant operators and owners to focus on physical security.

By NELSON DURAN

In today's technology-driven world, where cyber threats dominate headlines and organizations invest significant resources in safeguarding their OT and IT infrastructure from digital threat vectors, the importance of physical security of a process facility can sometimes be overlooked. However, it remains an essential component of enterprise risk mitigation.

Process industries are no place for uncertainty and risk. With the increasing concerns related to energy shortage and carbon emission issues worldwide, sustainable and safe operations of thermal processes are consistently attracting extensive attention. A comprehensive security strategy should prioritize and address both cyber and physical vulnerabilities. After all, a malicious actor in either area can cause significant undesirable outcomes (e.g., compromised employee health and safety, damage to equipment, lost production, etc.). Supply chain disruptions can lead to huge complications such as shortages of key goods, significant delays, and negative economic impacts.

Over the past 50 years, U.S. infrastructure has been consistently subject to attack, though at a relatively low number of incidents per year. According to the Global Terrorism Database, between 1970 and 2020 there have been 102 attacks on U.S. infrastructure. Since 2009, there has been a period of increased attacks on all targets in the United States — infrastructure, specifically. Infrastructure attacks rose 70 percent in 2022 compared to 2021, according to Politico.

OLD THREATS, NEW TECHNOLOGY

Despite advancements in technology, some hazards will continue to exist. Insider threats, for example, always pose a significant risk to organizations. Typically, these types of attacks are orchestrated by individuals (e.g., employees, contractors, trusted partners, etc.) who have authorized access to systems, data, or facilities but misuse that access for malicious purposes. The threat they present can range from accidental breaches due to negligence or lack of awareness to deliberate acts of sabotage, espionage, or data theft.

Insider threats can be particularly challenging to detect and mitigate because the individuals often have legitimate access and can exploit their privileges without raising suspicion. Some of the best prevention methods for this type of risk are implementing robust access controls, regular monitoring, and employee awareness programs. Promoting a culture of security and vigilance can minimize the potential impact of insider threats, and valuable assets such as sensitive information can be better safeguarded.

Vandalism, theft, and release of toxic or flammable substances are also an ever-present risk to thermal-process facilities. In recent years, many organizations have upgraded their assets to include the latest digital monitoring equipment, promoting the rapid uptake of industrial cybersecurity measures. However, this doesn't eliminate the risk of physical attempts at vandalism, theft, or purposeful releases, nor does it negate the need to defend against such attempts. Organizations should remain vigilant of these threats, even in a cyber-focused world.

EVOLVING PHYSICAL THREATS

Cyberattacks are typically the first things that come to mind when discussing the impact of increased digitalization on thermal industrial plant security. However, physical attack vectors have also evolved with technology.

One prominent physical attack vector example involves the use of unmanned aerial vehicles (UAVs) or drones. Several high-profile drone attacks on critical infrastructure outside the U.S. have raised questions about how process facilities can protect against aerial attacks. While most of these incidents originate from nation-states or designated terrorist groups with military-grade UAVs, access to recreational drones is now ubiquitous.

Whether operating within the bounds of the process plant incidentally or with malicious intent, even the most unsophisticated of UAVs can easily penetrate traditional physical security measures (e.g., fences, gates, perimeter cameras, etc.). Most enterprises did not have to consider this when their plant was originally built, thus potentially leaving them exposed to such modern-day threats.

Even on projects today, the implications of a drone attack are not always incorporated into a facility's risk assessment. Part of this is attributable to the perception that nothing can proactively be done to prevent such an occurrence. However, this is only true in some cases, as certain critical areas of the plant and facility can be hardened.

By incorporating the threat into a facility risk assessment, personnel will be forced to think about reactive measures if an event does occur, which is important to help minimize its impact and better preserve safety after the fact.

Embracing the concept of "Security-By-Design," which prioritizes integrating security features into the plant during its development, is also important. By addressing physical threats as early as possible with the same rigor and focus as those in the digital space, organizations can enhance their overall security posture, mitigate threats, and help ensure business continuity.

Countries such as Singapore are leading physical security regulations in up-front building design through their Infrastructure Protection Act (IPA). In the future, as threats to mission-critical facilities continue to evolve, it is expected that other countries will implement similar regulations.

THREAT, VULNERABILITY, AND RISK ASSESSMENTS

To help better ensure all physical security risks are addressed, it is beneficial for enterprises to perform either Security Vulnerability Assessments (SVAs), Threat and Vulnerability Risk Assessments (TVRAs), or both. Each constitutes a comprehensive approach to risk mitigation and can help facilities develop an effective physical security strategy by:

» **Better understanding the unique threats they face:** When conducting a threat assessment, process facilities can start by identifying potential adversaries, their intent and capability, then review tactics from past attacks at similar locations to estimate the threat to the organization.

With the increasing concerns related to energy shortage and carbon emission issues worldwide, sustainable and safe operations of thermal processes are consistently attracting extensive attention. (Courtesy: Shutterstock)

» **Assessing vulnerability:** Understanding the threat is essential, but the ability to deter attack is amplified by understanding vulnerability. Vulnerability can be considered as the psychological, sociological, or physical characteristics that leave an asset unprotected or exploitable for attack. Typically, the emphasis is on physical security vulnerabilities, but the human factor can make or break security efforts. Thinking, "It will never happen here," or "It will never happen to me," can add to vulnerability.

» **Quantifying risk:** Risk is defined in the basic form as "R = L x C," where R is risk, L is the likelihood of the event occurring, and C is its consequence. When it comes to performing risk calculations, most organizations focus heavily on the consequence term of the equation without measuring it against its associated likelihood. This makes it difficult to accurately prioritize risks and efficiently allocate resources toward mitigation measures. It also shifts the focus away from identifying critical vulnerabilities in infrastructure and can leave plant operations unprotected from "low probability" events. To develop a complete risk profile, both the consequence and likelihood terms of the risk equation should be thoroughly evaluated.

After quantifying the risk, organizations can begin to take preventative action by physically hardening infrastructure, such as using perimeter protection, blast analysis and design, facade strengthening, disproportionate collapse mitigation, local hardening of security command centers, and more. Another important step is security systems evaluation and design (i.e., intrusion detection, monitoring and surveillance, access control systems, security policies and procedures, redundancy evaluations, etc.), along with the implementation of dependency mitigation measures related to emergency backup power, spare parts, supply chains, emergency response, and so on.

CONCLUSION: AN INVESTMENT, NOT A COST

Adversaries will continually seek the weakest link in their target's security. Therefore, a balanced and well-thought-out security profile that includes both cybersecurity and physical security can be vital for effective facility protection and safety.

In the ever-evolving landscape of cybersecurity threats, physical security continues to play an indispensable role in protecting organizations. While cybersecurity measures are vital and growing in importance, they should be accompanied by robust physical security measures to provide comprehensive protection. In the process and manufacturing sectors, organizations of all types and sizes should be able to adapt themselves to the latest technologies and international best practices.

In both the physical and cyber worlds, security should never be viewed as a cost but as an investment to improve the overall safety of a facility. Organizations should remember that one of the primary goals of any security measure is to preserve the safe, reliable operation of physical infrastructure.

ABOUT THE AUTHOR

As the Director of Operations for the Protected Design Group within ABS Group, Nelson Duran heads up a highly talented team that spans the world, helping customers mitigate the threat potential of both man made and natural disasters.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A LEADING MANUFACTURER OF INDUSTRIAL OVENS AND STERILIZERS

Gruenberg industrial ovens and dry heat sterilizers — such as this batch oven — are designed with high quality materials. (Courtesy: Gruenberg)

For more than 90 years, Gruenberg has offered standard and custom industrial drying ovens, pharmaceutical dryers, and sterilizers to a wide range of industries, including the automotive, aerospace, metallurgic, semiconductor, pharmaceutical, and medical sectors.

By KENNETH CARTER, Thermal Processing editor

Heat-treat drying processes are often a critically necessary step in many industries, including the automotive, aerospace, metallurgic, semiconductor, pharmaceutical, and medical sectors.

The products offered by Gruenberg ensure that important step in the manufacturing process is not only done efficiently, but economically.

Gruenberg is a leading industrial oven and sterilizer manufacturer. The company's standard and custom industrial drying ovens, pharmaceutical dryers, and sterilizers are used for a variety of applications including curing, drying, annealing, dry-heat sterilization, depyrogenation, and other heat-processing applications.

Gruenberg industrial ovens and dry heat sterilizers are designed with high quality materials and available in both batch and conveyor configurations with maximum temperature ratings up to 1,200°F. Batch oven configurations include reach-in or cabinet style, truck-in, batch, benchtop, and top-loading models. Many batch ovens can be configured in a stackable manner to save shop floor space. Conveyor ovens can be designed modularly with multiple zones of heat for maximum temperature control and uniformity during continuous process. Conveyor oven styles include belt, drag, spindle, overhead, and many other styles appropriate for the application and the products being processed.

A Gruenberg dual lane conveyor oven. (Courtesy: Gruenberg)

'COMPREHENSIVE OFFERINGS'

"As a whole, Gruenberg's a big player in the medical, pharmaceutical, and lab animal science industry, and we have a comprehensive line of industrial heat treat ovens," said Mike Schneck, director of engineering and product manager at Gruenberg. "We offer cabinet, truck-in, top load and continuous ovens of all variations, as well as modifications that can be custom to any of those. That's just a few examples of what Gruenberg has provided to various industries that can perform a wide range of heat-treat drying processes. We have a very broad base and a comprehensive offering that we can usually fit a client into."

That includes working with composites, according to Schneck.

"We provide composite curing solutions for aerospace and automotive," he said. "We do heat treating. We work with the oil-and-gas industry with regards to designing and manufacturing ovens for their equipment that they send into the earth."

MEETING CUSTOMERS' NEEDS

With a history that goes back more than 90 years, Gruenberg has established itself to be able to immediately meet the needs of any customer from almost any industry, according to Schneck. That includes any custom work that may be needed.

"We have a lot of historical data," he said. "We're usually able to grab a data point and use it as a starting point for our customer base. We do have standard designs and base models, but as we've evolved to where we are right now, we have the tools and have put together enough engineering expertise that allows us to take what a customer wants and adapt it pretty seamlessly and quickly."

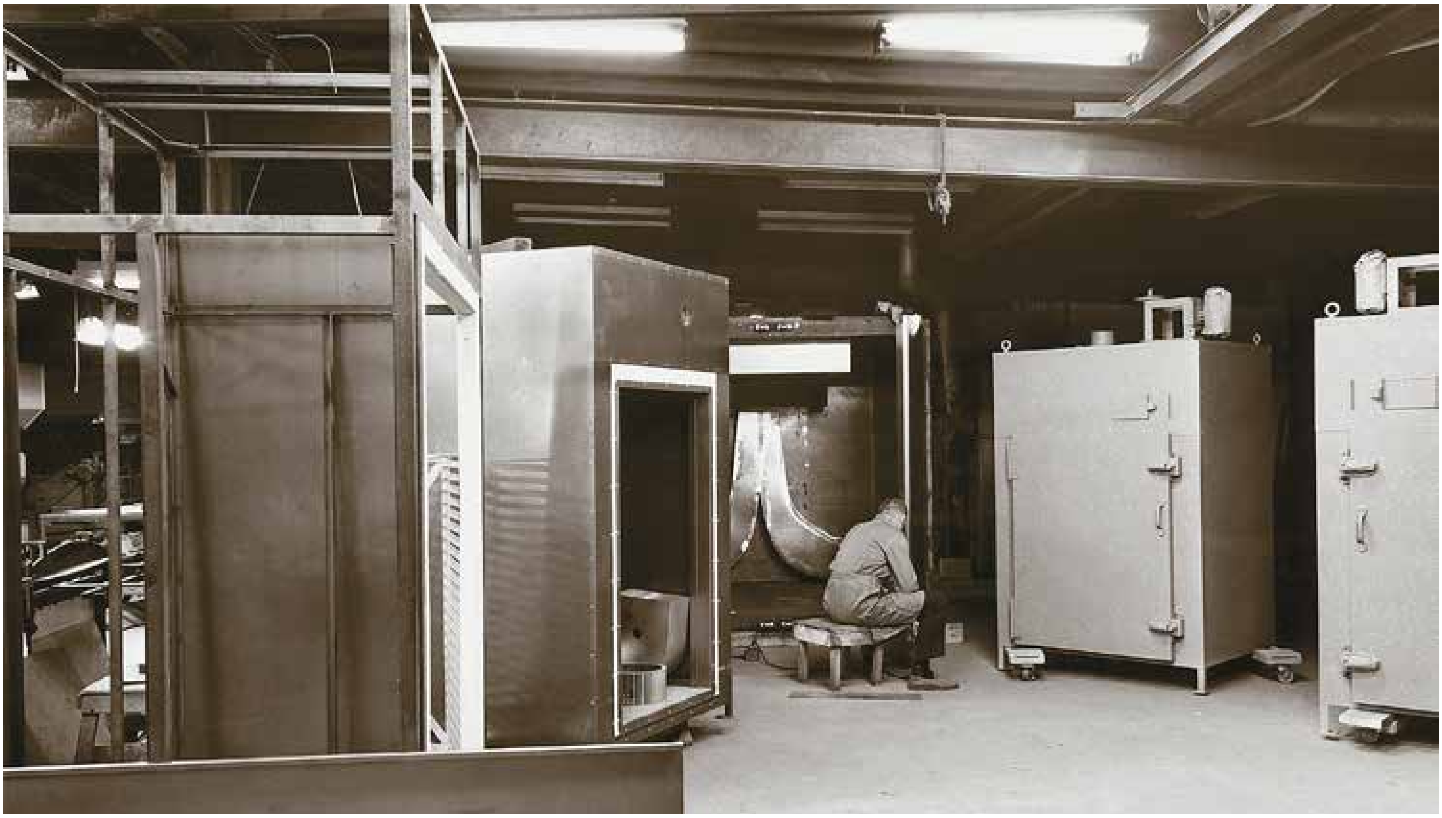
To that end, Gruenberg has positioned itself over the decades to partner and innovate with its customers to provide the highest quality of thermal-processing solutions in the world, according to Schneck.

"Gruenberg has uncompromising performance, and it has been that way since the early '30s," he said. "Technology has been at the forefront of evolution for many years. It has taken leaps and bounds by grand magnitudes in recent years. By utilizing component innovations built into our designs and new manufacturing techniques, we are able to lower our costs and pass that along to our customers."

THE CONCEPT STAGE

That one-on-one partnership with its customers begins at the concept stage, according to Schneck.

"We typically ask them to describe their process and, instead of a customer modifying their process, we work with them to design a



Gruenberg, a division of Thermal Product Solutions LLC, first opened its doors as the Gruenberg Electric Company in Brooklyn, New York, in 1932. (Courtesy: Gruenberg)

piece of equipment that perfectly meets their needs," he said. "We come to some conclusions, and we propose that to them, and it's like an 'a-ha' moment. We find the most success talking directly with process experts and the people who are most intimate with the process where they're looking to add a piece of equipment."

That collaboration could be in regards to performance or control capability or something as "simple" as the best way to take advantage of limited space used for that critical piece of equipment, according to Schneck.

"We definitely strive to provide them what they need," he said.

In today's technical age and the ability to search for a company to solve heat-treating or sterilization needs — perhaps someone is looking for a cure oven or sterilizer, for example — Gruenberg's long history of expertise stands out to make it a go-to company for potential customers, according to Schneck.

"Once we're able to get on a call with them, we are able to build a confidence level with the customer," he said. "From there, it is just a conversation. We design a unit and thoroughly articulate within our proposals so they have a full understanding of what they're getting. When we're able to do that and they're able to present that to their management, they can put together an ROI and also explain the advantages of Gruenberg vs. another supplier."

Once the equipment is finalized, Gruenberg has an aftermarket service team that can provide a full line of services for a customer's thermal processing equipment no matter the brand, including start-up and training, installation options, preventative maintenance, temperature uniformity, GAMP documentation, relocation services, and more. All aftermarket services are performed by Gruenberg's factory-trained technicians.

A Gruenberg batch oven. (Courtesy: Gruenberg)

PARTNERING WITH AALAS

Through its long history, Gruenberg has been able to offer its heat-treating expertise to many industries, but Schneck pointed out that it has recently found success in providing products to its partners in the Animal Lab Science Community or AALAS.

"It's truly a niche community," he said. "They have historically used autoclave-type equipment to do this process, and the solution we're

A Gruenberg pharm oven. (Courtesy: Gruenberg)

providing them gives them flexibility, cost savings, and it's energy friendly. It's just a win-win for them. It's becoming a big game changer in that community — it has the same effectiveness as a steam sterilizer with validated cycles."

Gruenberg provides equipment that sterilizes the cages the animals are kept in, according to Schneck.

"That's important just from the standpoint of mouse A could be the one that provides a cure for cancer," he said.

Autoclaves use pressurized steam for sterilization; however, Gruenberg's sterilizers use dry heat, which is more economical overall, according to Schneck.

"There are so many advantages to using dry heat from a facility standpoint; significantly lower infrastructure/construction costs, no water usage, modular designs, sterilization cycle costs at about 50 percent to that of an autoclave, and the fact is that it performs and each and every one is validated with biological spore strips," he said. "It's just a game changer."

90-PLUS YEARS OF EXPERTISE

Gruenberg, a division of Thermal Product Solutions LLC, first opened its doors as the Gruenberg Electric Company and then the Gruenberg Oven Company in Brooklyn, New York, in 1932, according to Schneck.

"It started with manufacturing industrial ovens, cabinet, bench and truck-in and eventually added sterilizers, dryers, and continuous process ovens to name a few," he said.

As the company grew, it became known industry wide for its performance and custom designs, according to Schneck.

"An old timer with the company who has since retired once compared Gruenberg's ovens to the strength and durability of a Sherman tank with the craftsmanship of a Swiss watch," he said with a chuckle. "We pride ourselves with that."

As Gruenberg continues to offer the best heat-treating and sterilization needs to a global network of industries, Schneck said the company is always striving to keep ahead of evolving technology.

"We are looking at newer, lighter materials," he said. "I think you're going to see processes migrate to cleaner requirements, maybe into an ISO-type environment requiring minimal particulate exposure just due to miniaturizing everything and micro-sizing things, and you're going to have Gruenberg still here providing solutions to that customer base. It's all bread-and-butter for Gruenberg. It's all an area where we want to serve our customer base."

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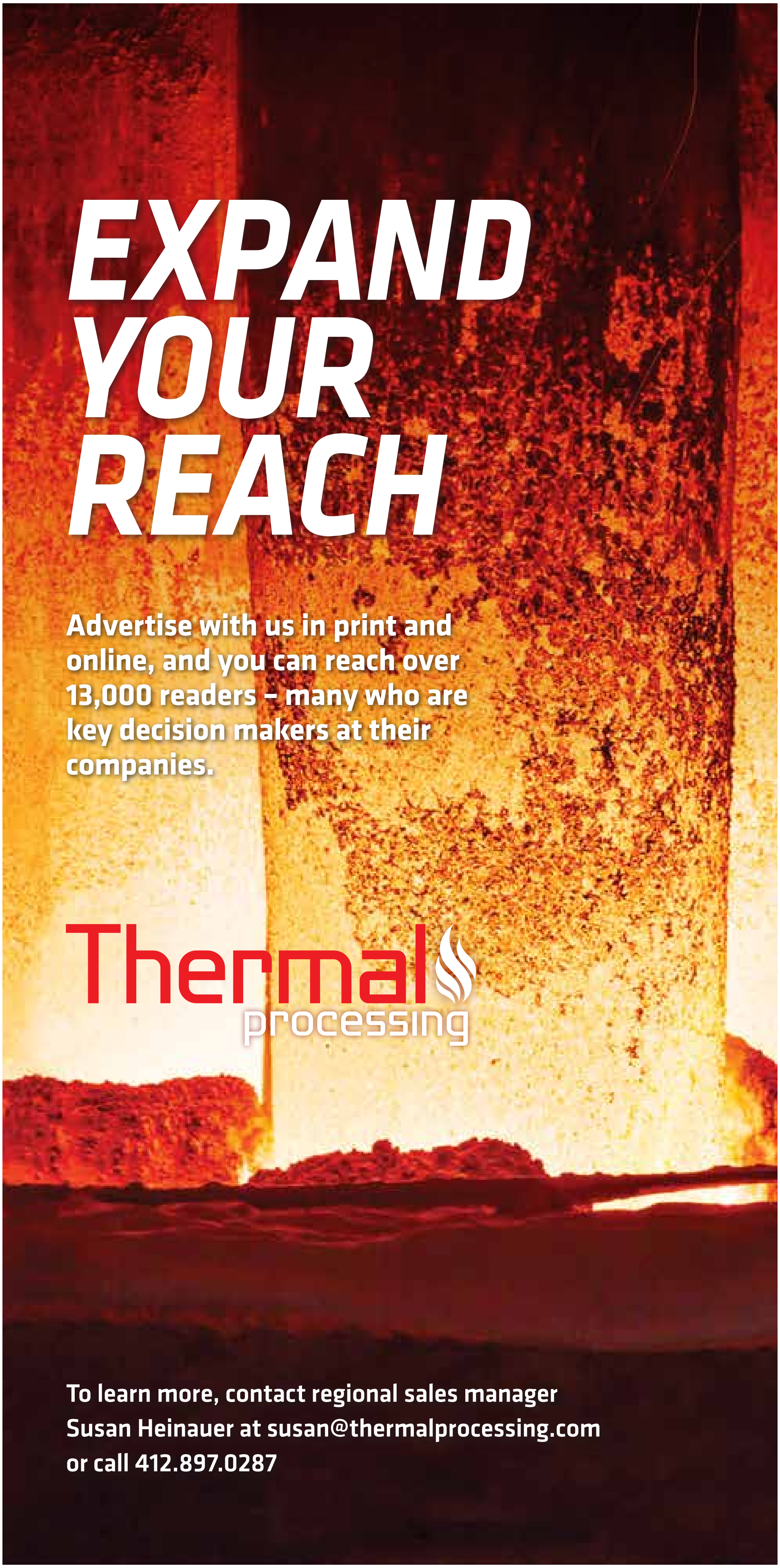
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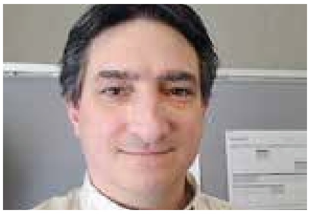

MIKE GRANDE /// VICE PRESIDENT OF SALES /// WISCONSIN OVEN

"For companies that want a cost-effective, more compact arrangement, the horizontal quench is a good solution."

Wisconsin Oven recently shipped a horizontal spray quench furnace to C/A Design in Dover, New Hampshire. What makes quenching important to this company?

Any time aluminum is produced for an important stress-related application — where it has to have strength and the parts have to meet performance requirements — it has to go through a solution treatment process. It involves bringing the parts up to a temperature of between 800- and 1,000-degrees Fahrenheit, and then it's held there for a few minutes. That allows it to go into solution, where the alloys become homogenized throughout the matrix, and then the load is pulled out and quickly quenched. You end up with a very uniform piece of aluminum as far as metallurgy and strength goes. Then it goes through a later process called aging.

The solution treatment process for C/A Design was especially important because they make very precision components, and this is true for anyone that produces aluminum parts that play a critical role. They're all solution-treated, which is done with an aluminum-solution furnace and quench system.

How can this quench furnace be advantageous to other companies looking for quenching solutions?

In the last 10 years, horizontal quench for aluminum has been evolving. It's a fairly new technology that, due to automation and intense R&D, we've been able to use to reduce the quench time down to as low as seven seconds. After aluminum parts in the furnace have been heated up, they have to be extracted and quenched within a specific time (typically seven to 30 seconds), from when the furnace door starts to open, until the load is fully quenched in the water. This time depends on the alloy and the thickness of the aluminum. One of the things that we've developed with the horizontal quench system is to decrease the cost and the footprint over the traditional drop-bottom furnace technology. We still build drop-bottoms, but horizontal quench is something that has become an alternative, and it's turning out to be a really good solution because of the footprint and the price. For companies that want a cost-effective, more compact arrangement, the horizontal quench is a good solution.

What went into the process that concluded with C/A Design deciding on this particular quench system?

What they wanted was something a little different and a little out of the ordinary. Instead of dunking the parts in a tank — which is the most common way — some companies want it spray-quenched. The quench system C/A Design purchased has over 40 individually controlled spray nozzles that are in a spray enclosure with doors on it. The parts get pulled quickly out of the furnace and into the spray quench, and then the doors close on the spray quench, and the nozzles turn on and absolutely drench the parts with water, rather than submerging them in a tank. Some customers prefer the spray quench, as opposed to submersion quench, because it gives them less part distortion. It's a slightly more controllable quench, and it enables them to slow the quench rate by turning particular spray nozzles on and off. If they're getting distortion in a certain area because they're quenching too fast, they can reduce the spray volume by turning nozzles off. For C/A Design, that was really critical, so this particular quench system was an ideal solution, selected for that reason.

What makes your horizontal spray quench furnace more advantageous to other quenching methods?

The big thing: Years ago, when companies like us did horizontal quenches, we only did it for very long quench times — when customers didn't need it any faster than 15 or 20 seconds. Within the industry, they really liked the horizontal quenches, but if they had to get a fast quench, that meant getting it out of the furnace, transferring onto the quench system, and then either spraying or dunking. It was hard to reliably do this in less than 15 seconds. These loads weigh hundreds or thousands of pounds, and they can be fairly large, too.

About 15 years ago, we started to experiment with faster quench times. This means the door has to open faster; the transfer has to happen faster, and the dunk has to happen faster. Through R&D and engineering improvements, we can get each of those down to two seconds or so, and then, with some cushion in there, we can reliably get the total quench time under 10 seconds. So now we are able to quench faster with this compact, less expensive technology.

What advice would you give potential customers looking for a quenching system like this one?

There are some key parameters that you want to make sure you specify. Whether you buy it from Wisconsin Oven or someone else, you want to make sure they have a history of reliable systems in the field. You want to look at the technical requirements and the temperature uniformity. A lot of customers these days require the furnace meet AMS 2750 or CQI-9 specifications, which are aerospace and automotive specifications. Make sure your supplier understands those well. That's something that we see is a little lacking in the industry, and so we focus on it at Wisconsin Oven. We thoroughly understand these requirements, and routinely provide equipment that meets them. We have some experts in-house, and then we've gotten training over the years. We explain and document to our customers what we do to make sure the equipment certifies, and confirm it through testing, prior to shipment. This is important because they will need to pass an AMS2750 or CQI-9 audit in order to operate the equipment after it is installed.

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