Thermal processing

FURNACES NORTH AMERICA SHOW ISSUE

COMPANY PROFILE:
AFC-Holcroft

Technologies and Processes for the Advancement of Materials

SEPTEMBER/OCTOBER 2016
thermalprocessing.com

THERMAL PROCESSING MAGAZINE

TRIBOLOGICAL COATING WEAR AND DURABILITY PERFORMANCE GUIDELINE FOR GEAR APPLICATIONS

SEPTEMBER/OCTOBER 2016


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FEATURES

SEPTEMBER/OCTOBER 2016

22 **COMPANY PROFILE: AFC-HOLCROFT**
By Molly J. Rogers
AFC-Holcroft celebrates 100 years as the U.S. market leader in the production of industrial furnace equipment for ferrous and nonferrous metals.

26 **HEAT TREATING EDUCATION**
By D. Scott MacKenzie
For an industry that is key to the performance of many everyday products, creating more higher education programs in heat treating and metallurgy is essential.

28 **HYBRID FORGING: ADVANCES IN OPEN DIE AND CLOSED DIE FORGING**
By Ashley Lukowicz and Margaret Dort
Using the advantages of open die forging combined with the near-net shape capability of closed die forging, the forging process can be tailored to optimize time and cost savings.

32 **SINGLE-PIECE, HIGH-VOLUME, AND LOW-DISTORTION CASE HARDENING OF GEARS**
By Maciej Korecki, Emilia Wolowiec-Korecka, and Doug Glenn
A new concept has been developed for a single-piece flow case hardening system that adjusts to the size and shape of a particular gear in order to minimize distortion and ensure ideal repeatability of results.

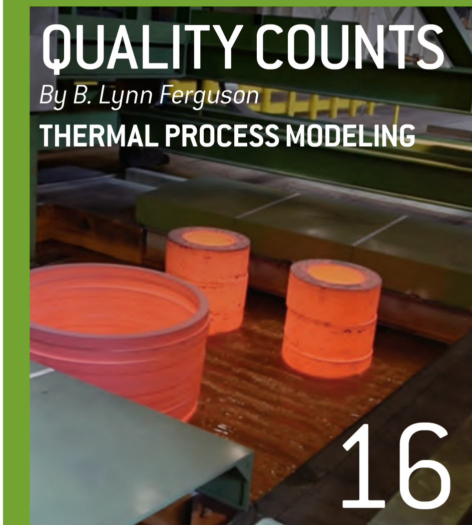
40 **DETRIMENTAL EFFECTS OF SULFUR ON TRANSVERSE IMPACT PROPERTIES IN STEEL FORGINGS**
By Chuck Hartwig
Supplying heat-treated forgings with Charpy impact specifications requires special attention to sulfur content in each heat of steel, even if the levels are within material specification limits.

44 **CARBURIZING AND NITRIDING TREATMENT MODELING**
By Nicolas Poulain
The finite element method can provide insights needed by engineers to calibrate thermal processes, whether it's carburizing or nitriding, and maximize the benefits of the heat treatment.

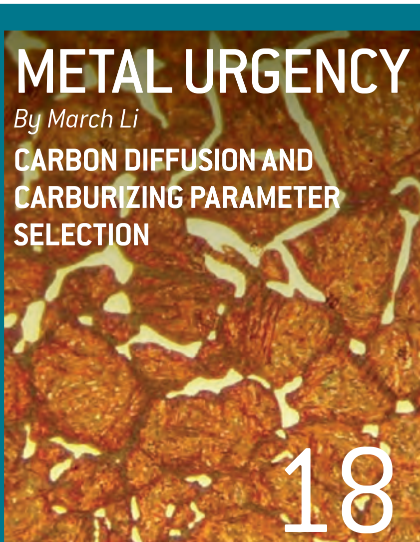
DEPARTMENTS

SEPTEMBER/OCTOBER 2016
Volume 5 / Number 2

UPDATE
NEW PRODUCTS, TRENDS, SERVICES, AND DEVELOPMENTS
08

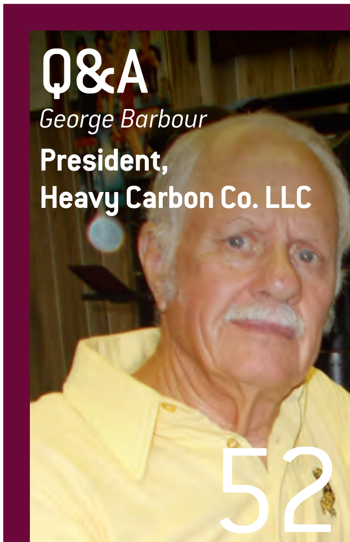


QUALITY COUNTS
By B. Lynn Ferguson
THERMAL PROCESS MODELING
16



METAL URGENCY
By March Li
CARBON DIFFUSION AND CARBURIZING PARAMETER SELECTION
18

HOT SEAT
By Jack Titus
FURNACE DOORS
20



Q&A
George Barbour
President, Heavy Carbon Co. LLC
52

RESOURCES

Cover photo: iSTOCK

EQUIPMENT **48** MARKETPLACE **50** AD INDEX **51**

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LETTER FROM THE EDITOR

We have big news for *Thermal Processing* magazine!

Welcome to the September/October issue of *Thermal Processing* magazine. We are pleased to announce that *Thermal Processing* has reached a celebratory milestone. We will now offer additional issues of *Thermal Processing* per year — an increase from twice a year to six times a year. What's more, we are expanding our editorial focus to cover industrial manufacturing of all heat-treated parts to further serve our readers in the heat treating industry. In 2017, each issue of *Thermal Processing* magazine will have a carefully selected in-focus topic relevant to the industry so that we can zoom in on these areas to keep you informed of the latest developments, products, and applications.

The big news doesn't end there. We are also bringing you a special 2016 Buyer's Guide for *Thermal Processing* in November, so please be on the lookout for it. Starting with the Buyer's Guide, *Thermal Processing* magazine will be mailed to our current subscribers but as a standalone separately from Gear Solutions magazine. Since 2012, the birth of *Thermal Processing* magazine, it has been a bonus supplemental issue to *Gear Solutions*, but we are now giving *Thermal Processing* its wings to fly solo. And we can't wait to see how it will soar. Most importantly, we look forward to strengthening our partnerships with you along the way. While *Gear Solutions* has become the number-one publication in the gear industry, we expect *Thermal Processing* to continue to grow as a leading technical resource for technologies and processes for the advancement of heat-treated materials.

In this issue, we've featured a handful of those advancements from expert contributing writers. You'll read about a new concept from authors at Seco/Warwick for a single-piece flow case hardening system using low-pressure carburizing and high-pressure gas quenching that, this year, has successfully completed technical tests and trials on real parts. The system has the ability to process each part the exact same way with the exact same process parameters — guaranteeing precision and repeatability.

Another development discussed in this issue is hybrid forging, which makes it possible to manufacture larger, more complex parts on an open die press. We also cover higher-education challenges in the heat treating industry, as well as simulation software used for carburizing and nitriding, plus the effects of sulfur in steel forgings.

For this issue's company profile, AFC-Holcroft announces some exciting news of their own. In July, AFC-Holcroft was acquired by Aichelin Group based in Austria. Both companies express their anticipation for building relationships and better serving its customers for a brighter, healthier future.

Jack Titus — with AFC-Holcroft — shares his expertise on the proper seals of furnace doors in the Hot Seat column. In Quality Counts, Dr. B. Lynn Ferguson discusses thermal process modeling. And March Li continues his series on carburizing in Metal Urgency. We wrap up with a conversation with George Barbour of Heavy Carbon Co., who talks about his development of an Endocarb system and how it could benefit manufacturers.

If you would like to be the subject of a Q&A or a company profile, I would love to hear from you. Or feel free to reach out to me for topics you would like to see more of. We know the growth of *Thermal Processing* certainly would not have been possible without you — so thank you for your support in giving us the wings to fly. From here, the sky's the limit.

Lastly, I hope you have a successful show in Nashville if you're headed to Furnaces North America (FNA) in October.

Molly J. Rogers

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Aerospace Testing & Pyrometry Receives Accreditation for New Lab

Aerospace Testing & Pyrometry Inc. recently announced that the company has successfully completed the additional scope accreditation to the requirements of ISO/IEC 17025:2005, "General Requirements for the Competence of Testing and Calibration Laboratories," for the new laboratory in Bedford, Ohio. The additional scope of accreditation includes DC current, RTD, DC volts, and thermocouples type K, J, T, R, S, B, N, E, and C for measure and source. The laboratory will be able to calibrate secondary standards and field test instruments to meet the requirements of AMS2750E and other stringent prime pyrometry specifications.

"We want to offer more services to our clients by providing laboratory grade calibration thereby broadening the current scope of work for pyrometry requirements," said Andrew Bassett, president of Aerospace Testing & Pyrometry, Inc. "Our clients can be assured the level of calibration from our laboratory will match the level of service that we provide in the field."

Laboratory Accreditation Bureau, a division of A-S-B, conducted a one-day site addition audit on July 12, 2016, with no non-conformances.

Also, Dale Praznik has joined Aerospace Testing & Pyrometry as quality manager and laboratory manager. Praznik brings over 35 years' experience related to in-house calibration of secondary standard and field test instruments to the company's new pyrometric metrology calibration laboratory.

FOR MORE INFORMATION: atp-cal.com

GKN Sinter Metals Wins Award at Powdermet 2016

Auburn Hills, Michigan-based GKN Sinter Metals recently won the grand prize in the automotive and transmission category at the Powdermet 2016 International Conference on Powder Metallurgy & Particulate Materials. The award was given for five components — a side gear, two pinion gears, a locking side gear, and a locking plate — comprising a forged powder metallurgy (PM) electronic locking differential gear set made for Ford Motor Company. The parts go into the rear axle differential of the Ford F-150 light truck, marking the first time that forged powder metal differential gears have been used in such an application. The higher performance delivered by the forged PM differential gears, compared to that of competing metal-forming processes, will help usher in downsized gear systems, satisfying a critical need in future automotive design.

Winners of the 2016 Powder Metallurgy Design Excellence Awards Competition, sponsored by the Metal Powder Industries Federation — an international trade association for the metal powder producing and consuming industries — were announced at Powdermet 2016. Receiving grand prizes and awards of distinction, the winning parts are outstanding examples of powder metallurgy's precision, performance, complexity, economy, innovation, and sustainability. They also show how customers from around the world are taking advantage of PM's remarkable design advantages.

Shad Williams, quality engineer at GKN Sinter Metals; Dave Lenhart, RPPC manager; and Jacob Povrik, engineering supervisor for differential assemblies at Ford Motor Company accepted the award.

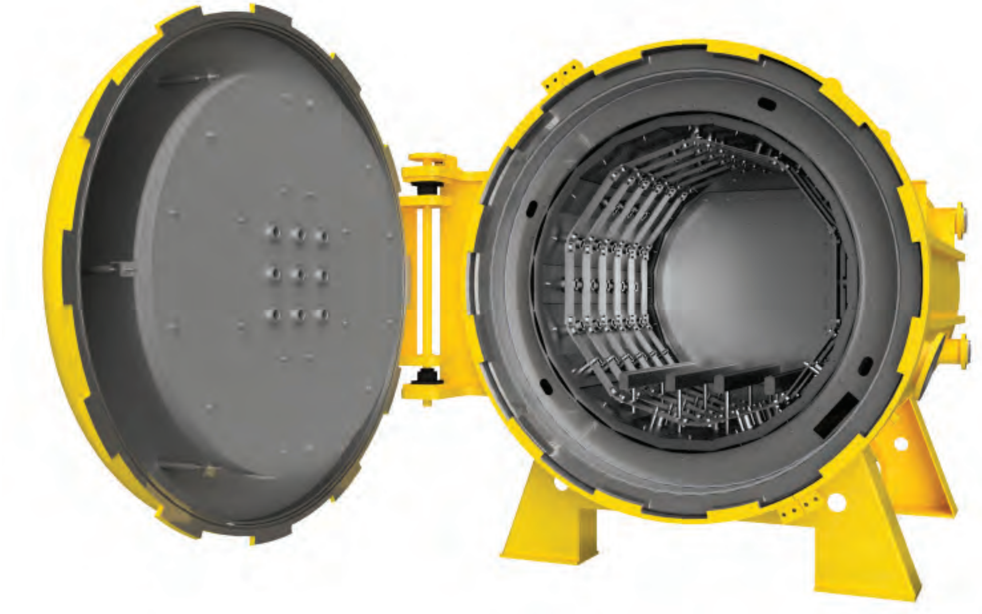
FOR MORE INFORMATION: mpif.org gkn.com

Solar Manufacturing and Graphite Machining Develop a New Material

Graphite Machining, Inc. (GMI) in Topton, Pennsylvania, and Solar Manufacturing in Souderton, Pennsylvania, have been cooperating for the past year on the development and testing of a new graphite board material and its application for vacuum furnace hot zones. This new graphite board material has undergone extensive thermal and vacuum testing to prove its improved thermal efficiency and excellent vacuum performance compared to prior or present graphite board designs.

GMI intends to market this new graphite board under the name Heatguard insulation, while Solar Manufacturing will incorporate this new material into its vacuum furnace hot zones under the trade name Hefvac™ (high-efficiency vacuum).

"After extensive testing against our existing and competitive insulating materials, Solar Manufacturing and Graphite Machining combined our respective experience and created this new thermally efficient graphite board insulation material," said Frank C. Schoch, president of GMI.



Incorporating this new Hefvac™ board insulation, Solar Manufacturing has now developed a proven, more thermally efficient vacuum furnace hot zone design that is capable of achieving faster and better vacuum levels because of the Hefvac™ sealed and low moisture absorption structure.

"I will be giving a presentation at the 2016 FNA (Furnaces North America) show in Nashville, Tennessee, to highlight the testing and comparisons of prior designs to this new board material and to illustrate not only the more thermally efficient aspect of the new material but also the ease and advantage of its use," said William R. Jones, CEO of the Solar Atmospheres family of companies. "Hefvac™ will be on display at Solar Manufacturing's Booth #301-303 with a full size hot zone."

FOR MORE INFORMATION: solarmfg.com graphitemachininginc.com

Ipsen Ships a Custom-Built Global Vertical Heat-Treating System to the West Coast

Ipsen recently shipped a Global Vertical (GV) vacuum furnace with 6-bar gas quenching to a commercial heat treater on the West Coast. The GV heat-treating system is from Ipsen's TurboTreater® line, which allows customers to order vacuum furnaces specific to their needs.

This custom-built furnace features a 60" D x 60" H (1,524 mm x 1,524 mm) graphite work zone and an 8,000-pound (3,629 kg) load capacity. It operates at temperatures of 1,000°F to 2,200°F (538°C to 1,204°C) with ± 15°F (± 8°C) temperature uniformity. The furnace is also equipped with a 35-inch diffusion pump and Ipsen's CompuVac® controls system. In addition, this GV furnace is equipped with an argon and nitrogen gas cooling system with gas injection nozzles located 360 degrees around the perimeter of the hot zone, as well as a variable frequency drive on the gas cooling motor for controlled cooling. A spare parts starter kit was also included in this shipment to help users prevent unplanned downtime by supplying them with essential parts and consumables.

Overall, Ipsen's GV heat-treating system provides users with the best of both worlds: improved uniformity of large production parts during heat-up and cool-down segments and the space-saving benefits of a vertical configuration.

FOR MORE INFORMATION: ipsenusa.com

Ajax Tocco Announces New General Manager of Aftermarket Sales

Ajax Tocco Magnethermic introduces Joe Hawkins as general manager of aftermarket sales. Hawkins brings over 20 years of induction melting and heating expertise to the company. His entire career evolved within the metals industry, beginning with Lectrotherm Inc. in 1991. Hawkins most recently served as director of sales for ReMelt Scientific. A graduate of Kent State University, Hawkins later earned his MBA from Malone University.

Ajax Tocco maintains a team of skilled technicians strategically located throughout the world to repair and maintain Ajax Tocco equipment as well as competitors' equipment. In addition, the company houses a large inventory of parts for all of its equipment including older units and some competitor equipment. A convenient, 24-hour service hotline is provided to answer urgent requests and for emergency assistance.

FOR MORE INFORMATION: ajaxtocco.com

Houghton International Launches Advanced Fluid Monitor and Control Systems

Houghton International, a global leader in metalworking fluids and services, has launched two new fluid equipment solutions that provide manufacturers with significantly greater control of fluid quality and concentration. The Houghton Greenlight™ Continuous Concentration Monitor and the Houghton® ACTS™ Fluid Monitor and Control System provide significant advances in the control of vital water-based metal-cutting fluids, cleaners, aqueous quenchants, water glycol hydraulic fluids, and offshore fluids. Many variables affect the performance of metalworking fluids; however, concentration is usually the most critical in assuring long tool life, achieving tight tolerances, reducing corrosion, improving surface finish, and pushing the envelope on productivity.

The Greenlight Fluid Monitor is a completely self-contained measurement system that sets a new industry standard for continuous concentration monitoring of metalworking fluids. Its small, modular design enables easy, reliable, and low-cost continuous monitoring of fluid concentration using state-of-the art refractive index sensor technology with a user-friendly interface.

The Houghton ACTS Fluid Monitor and Control System is a fully integrated system, which also measures pH, temperature, conductivity, or other fluid properties in addition to concentration via refractive index. It provides automatic concentration control capability by independently controlling six separate programmable relay outputs for additions of water, fluid concentrates, or additives.

"We are very pleased to offer these exciting new systems to our customers," said Dianne Carmody, Houghton Americas' marketing director. "Houghton is resetting the industry standard in metalworking fluid property measurement and control. These innovative, robust, and flexible systems not only deliver control, but more importantly, yield the operational and financial benefits of a well-managed system, including longer tool life, reduced use of additives, and lower maintenance, metalworking fluid, and waste treatment costs. Excellent control yields excellent productivity."

FOR MORE INFORMATION:
houghtonintl.com

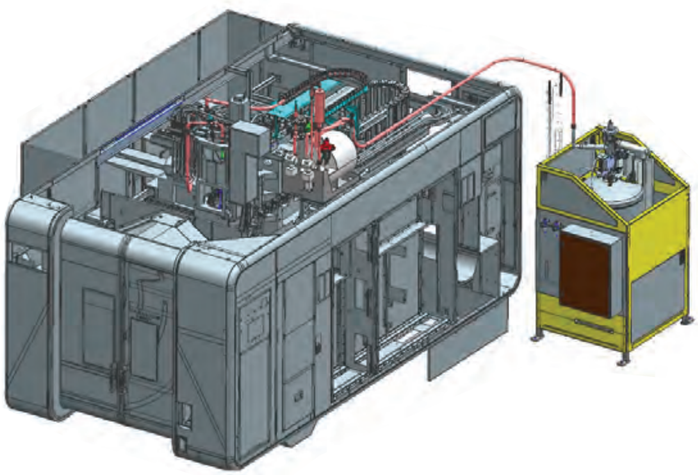
5ME Demonstrates Cryogenic Machining Technology at IMTS

5ME® will showcase its cryogenic technology and production management software with high-profile partners at IMTS on September 12-17, joining forces with Mazak, Okuma, FFG MAG, Star SU, Fullerton Tool, Hydromat, Sunnen, Bosch Rexroth, and NUM to demonstrate the cost-saving and production benefits of cutting with cryo and digital management of the shop floor.

5ME's multi-patented cryogenic machining process is a breakthrough technology that enables higher cutting speeds for increased material removal and longer tool life by transmitting liquid nitrogen at minus 321°F through the spindle/turret and tool body, directly to the cutting edge. This environmentally friendly machining technology increases throughput, part quality, tool life, and profitability while reducing energy consumption. It also provides a healthier, safer work environment through the elimination of traditional water-based or oil-based coolants.

The revolutionary Variaxis i-800T with cryogenic machining technology will be unveiled at Mazak's Booth #S-8300. The machine, a 5-axis VMC with a trunnion table and turning capability, manufactures high-value titanium aero engine components. 5ME and Mazak aim to launch cryogenic machining technology across numerous Mazak platforms and create a "designed for Cryo" machine tool by 2019 to coincide with Mazak's 100-year anniversary.

At Booth #S-8500, 5ME and Okuma will offer 5ME's cryo technology across numerous Okuma platforms, showcasing it on the MU-8000VL 5-axis VMC with trunnion table and turning capability. The machine is particularly suited for processing tough materials commonly used in aerospace part production, such as blisks and aero engine components. 5ME and Okuma look to tackle difficult-to-machine alloys for the aerospace industry as they collaboratively expand the application of this technology.



In 2017, FFG and its U.S. distributor, Star SU (Booth #N-2964), will offer 5ME cryogenics on the Boehringer VDF lathe platform. BlueZone™ cryogenic tool technology licensed by 5ME will be at the Star SU/Star Cutter Booth #N-2964 and #W-2258 as well as the Fullerton Booth #W-1693.

Also at IMTS 2016, Hydromat (Booth #S-8348) and Sunnen (Booth #N-7400) will demonstrate 5ME's new Freedom 4.0 smart manufacturing IoT platform, running on their equipment with the new Freedom Gateway™ hardware appliance with Edge Analytics software. Okuma, Mazak, FFG MAG (Booth #S-8129), Bosch Rexroth (Booth #E-4854), and NUM (Booth #E-4837) will all show Freedom 4.0 with the new SmartBoard (smart dashboards) feature from 5ME. Highly configurable, SmartBoard allows users to create their own dashboards with the data they select, as well as the ability to embed images, websites, work instructions, and spec sheets.

The Freedom software suite leverages the MTConnect standard and automatically extracts critical manufacturing data to produce web-based reports and analytics on asset utilization, availability, performance, quality, and OEE. It is brand, asset, and process agnostic. The software integrates seamlessly with ERP, MES, maintenance, and quality business systems and can be accessed anytime via smartphone or tablet device.

FOR MORE INFORMATION: 5me.com

FabTech 2016 Offers Education Programming with Industry-Leading Speakers

FabTech 2016, North America's largest collaboration of technology, equipment, and knowledge in the metal forming, fabricating, welding, and finishing industries, has scheduled a comprehensive education program of notable speakers to present on a variety of topics at the forefront of the industry. The lineup is comprised of more than 100 sessions, addressing the needs of attendees with basic, intermediate, and advanced skill levels. The event takes place November 16-18 in Las Vegas at the Las Vegas Convention Center.

The education component is one of the show's most valuable features and a critical component of FabTech. Led by manufacturing experts from a variety of backgrounds, the in-depth sessions are designed to provide valuable and insightful programming to participants from all manufacturing disciplines. Each session will offer an inclusive setting, giving attendees the opportunity to sharpen their skills and network with colleagues, executives, and thought leaders.

"FabTech represents a wide range of manufacturing technologies and processes, so it's important to us that our educational programming reflects that diversity," said Mark Hoper, FMA show co-manager, FabTech. "The most effective way to advance these highly specialized fields is through collaboration and exchanging ideas. If you work in the metal fabricating industry, and you want to learn how to improve, there is something at FabTech for you."

The technical, operational, and managerial sessions are divided into 12 tracks including cutting, lasers, finishing, forming and fabricating, lean, welding, management strategies, job shop solutions, stamping, automation, additive manufacturing, and workforce development. This year's dynamic agenda features 65 new sessions and a number of sessions that cover new developments in additive and smart manufacturing.

All sessions are organized by FabTech 2016's five co-sponsors – SME; the Fabricators & Manufacturers Association International (FMA); Precision Metalforming Association (PMA); Chemical Coaters Association International (CCAI); and the American Welding Society (AWS). This ensures that the content covers manufacturing's expansive landscape, while also delivering the highest quality, most relevant information to attendees. To better serve the varying levels of expertise among attendees, each session is categorized by experience level — basic, intermediate, and advanced.

FOR MORE INFORMATION: fabtechexpo.com

CAN-ENG Furnaces Contracted to Manufacture a Rotary Furnace for Weber Metals

CAN-ENG Furnaces International Limited has been contracted to design, manufacture, and commission a rotary furnace system for the heating and hot working of titanium and alloy billets and pre-formed shapes for Weber Metals Inc. of Paramount, California, Long Beach facility. Weber Metals is a subsidiary of Otto Fuchs KG of Meinerzhagen, Germany, and an operating unit of the Otto Fuchs Aerospace Group.

This large diameter rotary furnace is part of Weber Metals' 60,000-ton press expansion project. The 60,000-ton press will allow Weber Metals to manufacture larger and lighter forgings utilizing more advanced materials and will incorporate the latest in green technology to reduce waste and energy consumption and increase efficiency. The new facility will house the largest aerospace forging press in the Americas, making some of the world's largest monolithic forging components. CAN-ENG Furnaces International Limited is proud to be a part of this groundbteaking project.

FOR MORE INFORMATION: can-eng.com

Roger Jones Nominated to ASM Board of Trustees

Roger Jones, corporate president of Solar Atmospheres, was nominated as a trustee on the ASM International Board of Trustees effective October 2016. The board of ASM, the Materials Information Society, is comprised of four officers and nine trustees. Three new trustees are elected by the membership every year, and each serves a three-year term.

Jones attended Hocking Technical College in Nelsonville, Ohio, where he studied heat processing technology. He has also taken selective metallurgical (MEI) courses from ASM and other technical organizations. He joined ABAR Corporation in 1975 and worked in the heat treating division until 1978. He then started work at Vacuum Furnace Systems Corporation at its inception in 1978, along with his father, William R. Jones FASM, who founded the company. His primary duties included manufacturing vacuum heat treating and brazing furnaces, as well as hot zone installation and field service work.

In 1983, Jones assisted the founding of Solar Atmospheres, Inc. where he held the position of vice president. He was promoted to president of Solar Atmospheres, Inc. in 1993. With the addition of Solar's Hermitage, Pennsylvania, facility in early 2001, Jones was then promoted to the position of corporate president. In 1995, he established a strategic management team within Solar Atmospheres. Today, Solar is the largest privately owned vacuum heat treating company in North America with four facilities: Souderton and Hermitage in Pennsylvania and Fontana in California. The newest facility is in Greenville, South Carolina, operational in May 2015.

Jones has been a member of the Metal Treating Institute since 1983, a member of the Board of Trustees since 1998, and was president of the Institute from 2004 to 2005. He was called back onto the board in 2009 for a third term and completed that role in 2012.

Jones has also been a member of ASM Philadelphia "Liberty Bell" chapter since 1983 and has chaired nine committees within that time. He became his company's sustaining member representative in 1986. He was Philadelphia chapter chairman for the 1993-1994 chapter years. Also, he was an instructor for the chapter-sponsored MEI courses and he continues to support the local chapter in numerous ways.

Jones was a founding member of HTS in August 1994. In 2005, he was appointed to the HTS Board and served as vice president from 2011 to 2013 and served as the president of HTS from 2013 to 2015.

Jones was the recipient of the Philadelphia chapter William Hunt Eisenman Award in 2001 and the Distinguished Service Award in 2004. In 2009, he received the President's Award. Most recently, he received the Adolph Schaefer Special Achievement Award in May 2015. In 2009, he received the Distinguished Service Award. Other awards from MTI also included the Award of Merit in 2011 and the Exemplary Service Award in 2012. Jones has given talks and published various technical papers in industry publications.

FOR MORE INFORMATION: solaratm.com

Bodycote Opens New Heat Treatment Facility in South Carolina

Ron Adams (center), sales director, Aerospace, Defense & Energy (HT) – East Region, meets with the South Carolina Department of Commerce delegation, including Deputy Secretary of Commerce Jennifer Noel and Director of the South Carolina Europe office Andre' LeBlanc, at the 2016 Farnborough International Airshow.

Bodycote, a leading thermal processing services provider, announced that its new plant in Greenville, South Carolina, is open for business. The facility is now ready to process metal and alloy parts that require brazing or vacuum heat treating services.

The new Greenville facility primarily serves the Southeast region's manufacturers and their supply chains in the aerospace, defense, energy, and medical industries. The plant is expected to receive Nadcap accreditation by the end of 2016, offering quality assurance based on stringent auditing standards for the aerospace and defense industries. Bodycote intends to offer additional services from the facility in the future in response to customer demand.

This investment is part of Bodycote's further expansion in the Southeast. Bodycote is committed to offering world-class heat treating and specialist technology services and is investing in improvements as part of an ongoing strategy to provide the best possible capabilities, mix, and geographical network to better serve customers.

FOR MORE INFORMATION: bodycote.com

Grieve 2000°F Gas-Fired, Heavy-Duty Furnace

No. 1042 is a 2000°F (1093°C) gas-fired heavy-duty furnace from Grieve, currently being used for heat treating at its customer's facility. Workspace dimensions of this furnace measure 30" W x 60" D x 30" H. Also, 750,000 BTU/HR are installed in four modulating natural gas burners with a floor-mounted combustion air blower. Burners fire below hearth, with 9-inch-thick insulated walls comprising 5-inch-thick 2300°F ceramic fiber, 4-inch 1900°F block insulation, and 8 1/2-inch floor insulation made from 4½ inches of 2300°F firebrick and 4 inches of 1900°F block insulation.

This Grieve furnace has two lanes of roller rails supported by firebrick piers and an air-operated platform with roller rails to bridge from loading table to workspace. Features include a ¼-inch plate steel exterior reinforced with structural steel, ½-inch steel faceplate at doorway and an air-operated vertical lift door.

Other features include safety equipment required by IRI, FM, and National Fire Protection Association Standard 86 for gas-heated equipment plus a free-standing 390 CFM high-pressure combustion blower.

Controls on the No. 1042 include a digital indicating temperature controller and manual reset excess temperature controller with separate contactors.

FOR MORE INFORMATION: grievecorp.com

The selected examples show how thermal process modeling is being used in commercial applications for analyzing and improving heat treatment processes.

By B. Lynn Ferguson

THERMAL PROCESS MODELING HAS been a hot topic in the heat treating community over the past few years. The project conducted by ASM International under sponsorship by the federal government highlighted the diverse role that thermal process technology has in every industrial sector — with heat treatment of metallic components being a primary partaker of this technology. From the many meetings and discussions that have taken place, several key items have arisen. First, the use of process modeling as a practical tool for analyzing and improving heat treatment processes was documented. Second, the importance of both material data and process data was continually cited as being even more important than the models themselves, because, without the availability of accurate data, modeling is removed from commercial use and relegated back to theoretical use. Coupled with another federal initiative, Integrated Computational Materials Engineering (ICME), thermal process modeling offers the heat treater an economical, effective way to improve processes, troubleshoot production problems, evaluate new processes, and develop a broader understanding of the metallurgical phenomena that occur during heat treating processes. The following are some examples of commercial applications of thermal process modeling that are currently being used.

DESIGNING LOW-PRESSURE CARBURIZING PROCESS SCHEDULES

Low-pressure carburization schedules are far different than conventional gas carburization schedules because the surface carbon level can be much higher due to dissociation of the gaseous carbon source directly on the hot part surface. Too much surface carbon leads to surface carbide formation, which blocks carbon absorption and case development. This is the reason for the multiple boost-diffuse steps instead of the more familiar long boost/long diffuse step used in conventional gas carburizing. Modeling instead of trial-and-error is being used to determine the appropriate boost-diffuse schedule for vacuum carburizing. An accurate vacuum carburization model can give the instantaneous carbon profile and the final carbon profile for the process, and, if coupled with proper phase transformation models, can predict the final hardness profile and distribution of metallurgical phases.

UNDERSTANDING MATERIAL AND HARDENING PROCESS EFFECTS ON PART PERFORMANCE

During product design, the part geometry that is necessary for carrying service stresses is determined. The mechanical properties for carrying the service stresses are developed by heat treatment of the part. Modeling provides a method to predict the stress response of the part to in-service loading while including the residual stress state resulting from heat treatment. With such capability, the designer, in conjunction with the heat treater, can select the best option for the component alloy and the proper heat treatment method for producing the part. This represents ICME at its finest.

Source: McInnes Rolled Rings

SELECTING THE OPTIMAL QUENCH METHOD

An unavoidable fact is that part dimensions change during heat treatment. Modeling has provided a tool to analyze the sequence of dimensional change and the reasons behind it. With modeling, different quenching processes can be compared so that the final properties can be achieved while maintaining dimensional control. This may involve adjusting the green dimensions prior to heat treatment, changing the quench media or agitation level to modify the cooling rate or adjust the quench uniformity, or using a fixture or external load to control dimensions during the quench.

DETERMINING THE CAUSES OF INTERNAL CRACKING IN INDUCTION-HARDENED PARTS

Induction hardening involves locally heating a surface layer of a component followed by spray quenching to harden the heated surface. The electrode and part may be stationary, known as a single shot process, or they may move relative to one another, known as a scanning process. In either case, induction hardening is well-known for generating compressive surface stresses in the hardened layer, and consequently, the part interior must have balancing residual tensile stresses for equilibrium. Typically, these tensile stresses are maximum at or near the case/core interface. Again, using an ICME approach, a modeling tool with electromagnetic capability can be used in combination with a software tool that has thermal, stress, and metallurgical phase transformation capabilities to simulate the induction hardening process to determine the level and location of stresses generated throughout the process. This is something that can only be done by modeling, as the transient process conditions inside of the part cannot be measured during the process. In components such as axle shafts, high levels of subsurface residual tension have led to premature failure, or in severe cases, immediate failure of the shaft. The presence of high levels of subsurface tensile stress is difficult to detect even with nondestructive methods, and in worst cases, ultrasonic or X-ray methods are required to detect the presence of subsurface cracks. The consequence is additional cost. Modeling is being used to modify the induction hardening process to reduce the magnitude and location of the subsurface tensile stress so that the expected part life is realized.

In regard to the metal being heat-treated, certainly steel alloys apply to all of the mentioned examples. But aluminum, copper, nickel-base, and titanium alloys also are applicable to some of the selected cases cited. Solid-state phase transformations, whether they involve change of the crystal structure of grains or precipitation of new phases within grains or at grain boundaries, cause dimensional changes and internal stresses in addition to mechanical behavior changes, and thermal process modeling is being used to understand the phenomena, optimize the product shape to maximize economics and part performance, and to determine the proper thermal process for producing the component.

ABOUT THE AUTHOR: B. Lynn Ferguson, founder and president of DANTE Solutions Inc., received his Ph.D. in materials engineering from Drexel University. He has over 40 years of industrial experience in thermal and mechanical processing of steel parts and has been a leader in the application of mathematical modeling of heat treatment processes.

In the carburizing process, the carbon diffusion determines the carbon concentration gradient and hardness profile in the case of the workpiece.

By March Li

ALTHOUGH CARBURIZING IS A complicated process, it can be broken down into two main steps: carbon generation in the furnace and carbon diffusion into the workpiece. The first step provides the source (carbon atoms) while the second determines the purpose (carbon concentration gradient and hardness profile) of the whole thermal process. Carbon generation was discussed in the Spring/Summer 2016 Metal Urgency column, so this paper focuses on the diffusion part of carburizing. Processing parameters including temperature and carbon potential based on diffusion theory are also discussed.

Generally, the goal of carburizing is to reach a designated case through which improved mechanical properties — such as surface hardness, tensile strength, and fatigue and wear resistance — as well as the preferred stress condition (compressive residual stress) on the surface can be reached after quenching and tempering. Historically, this case is called total case depth, which refers to the maximum depth of diffused carbon. Nowadays, effective case depth (ECD) is used to replace total case depth, as it can be practically defined and more consistently measured. Per the American Gear Manufacturers Association (AGMA), ECD is defined as the distance between the carburized surface to a location where the hardness number is 50 HRC (542 HK_{500} or 515 HV_{500}) by conversion from a microhardness test result [1]. For plain carbon steels, this ECD corresponds to a depth where about 0.4 wt.% carbon content is contained and 50 HRC is measured.

Before discussing carburizing parameters, carbon diffusion in the steel should be analyzed.

CARBON DIFFUSION

Disregarding interactions between carbon and other elements such as iron and alloying components (manganese, chromium, nickel, molybdenum, etc.), carbon diffusion within the workpiece can be described by Fick's laws of diffusion. Because the diffusion flux and the concentration gradient near the surface vary with time due to accumulation of carbon, it is considered a nonsteady-state diffusion and can be expressed by Fick's second law:

$$\frac{\partial C}{\partial t} = \frac{\partial}{x}\left(D\frac{\partial C}{\partial x}\right)$$

Equation 1

In the equation, C is the concentration of carbon, t is time, x is the position or depth below the surface of the part, and D is the diffusion coefficient.

For simplicity, if we ignore the dependence of D on carbon content, Equation 1 can be revised as:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

Equation 2

When some boundary conditions are specified and assuming surface carbon concentration to be constant (i.e., equal to carbon potential), and the carburized part is thick enough compared with the case depth (typically, thickness of the part is larger than $5\sqrt{Dt}$), Equation 2 can be solved and expressed as:

$$\frac{C - C_0}{C_S - C_0} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

Equation 3

Here, C is the concentration at depth x after time t. C_S is the constant surface concentration at x = 0. Usually, this is equal to carbon potential. Expression $erf\left(x/2\sqrt{Dt}\right)$ is the Gaussian error function.

It can be seen from Equation 3, for specific carbon concentration C such as 0.40 wt.%, the left-hand side of Equation 3 is a constant. This implies the right-hand side is also a constant, therefore:

$$\frac{x}{2\sqrt{Dt}} = \text{constant, or } x = k\sqrt{t}$$

Equation 4

K is the carburizing factor, and x (more commonly, effective case depth) is a parabolic function of carburizing time.

From Equation 3, it is concluded that carburized depth x or effective case depth (ECD) is a function of several parameters including carbon content of the steel, carbon potential, specified carbon content at 50 HRC, carbon diffusion coefficient, and time:

$$x \ or \ ECD = f(c_0, c_s, c, D, t)$$ Equation 5

Clearly, for a given steel and specified carbon content at 50 HRC, ECD is mainly determined by carbon potential, diffusion coefficient, and carburizing time.

CARBURIZING PARAMETER SELECTION

Diffusion theory indicates that the diffusion coefficient is determined by activation energy for diffusion and temperature:

$$D = D_0 \exp\left(-\frac{Q}{RT}\right)$$ Equation 6

Where D_0 is a temperature-independent pre-exponential (m^2/s), Q is the activation energy for diffusion (J/mol), R is the gas constant, 8.314 J/mol·K, and T is the absolute temperature (K).

Specifically, for the diffusion coefficient of carbon in austenitic iron from 800°C to 1000°C, Reference [2] revealed:

$$D(C, \gamma - Fe) = 16.2 \cdot 10^{-6} \cdot \exp\left(\frac{-137800}{RT}\right) \ m^2/s$$ Equation 7

Temperature

Equation 6 shows that temperature has a most profound influence on the diffusion coefficient — the higher the temperature, the faster the carbon diffuses. This is one of the reasons that carburizing is processed in an austenitic region. For plain carbon steels, this is above the A_{c3} line on the iron-carbon phase diagram. As a rule of thumb, at normal carburizing temperatures, when temperature increases 100°F, the diffusion coefficient of carbon will roughly be doubled; when temperature increases 100°C, the diffusion coefficient of carbon will roughly be tripled. This is displayed in Figure 1.

Therefore, from a processing point of view, we should always try to set a high carburizing temperature as it will shorten the cycle time. On the other hand, this is restricted by manufacturing capability (the highest temperature the furnace can reach), cost, and maintenance. Furthermore, when temperature is too high, the grain growth will give rise to unexpected mechanical properties. Taking into all these considerations, the carburizing temperature is usually no higher than 1800°F (982°C).

Carbon Potential

Equation 3 shows that carbon potential facilitates carburizing. This is similar to temperature, although the effect of the former is not as remarkable as the latter. Correspondingly, we should set carbon potential as high as possible at a given carburizing temperature. However, this setting is limited by the maximum dissolved carbon content in austenite, i.e., the A_{cm} line on the iron-carbon phase diagram at the carburizing temperature. When the limit is reached, a carbide network will be formed on the grain boundaries. Whenever this happens, the workpiece should be reworked, otherwise it will likely get cracked during the following manufacturing operation, such as grinding, or will fail prematurely during service. An example of a carbide network with an SAE 9310 steel is shown in Figure 2.

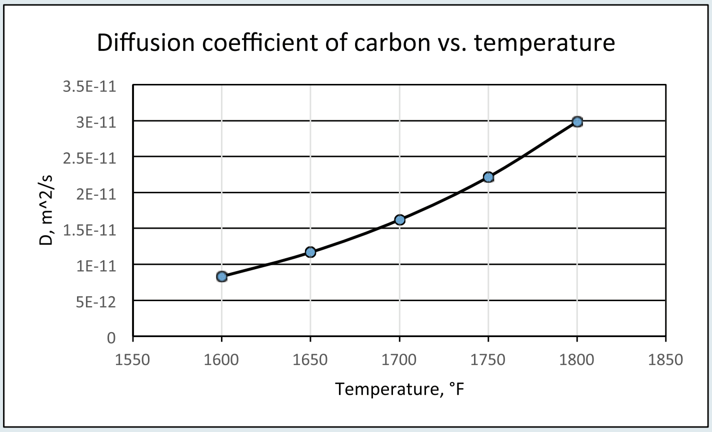


Figure 1: Diffusion coefficient of carbon in austenite vs. temperature. Within the indicated temperature range (1600°F to 1800°F or 871°C to 982°C), *D* will roughly be doubled when *T* increases 100°F or tripled when *T* increases 100°C

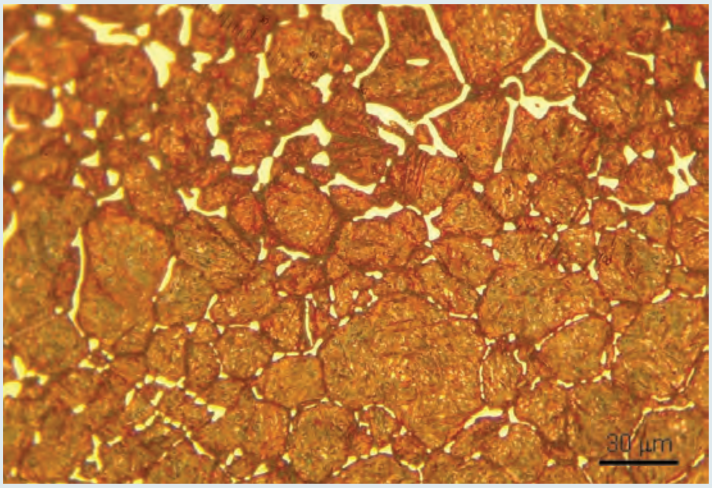


Figure 2: A carbide network in SAE 9310 steel due to high carbon potential during carburizing

For most carburizing steels, the appropriate carbon potential is roughly 0.90 wt.% to 1.40 wt.% at 1600°F to 1800°F.

Based on Equation 3 or 5, once carburizing temperature and carbon potential are set for a specific steel, carburizing time can be determined to reach a designated effective case depth.

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1. AGMA 923-B05, p. 6.
2. R.P. Smith, Acta Met., Vol 1, 1953, p. 578.

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For proper seal and functionality, doors are the furnace's most critical component.

By Jack Titus

NO MATTER THE CONFIGURATION, single or multi-chamber vacuum, batch integral quench, continuous, or even pits — an item that all furnaces have in common regardless of their size, design, and material handling and, if defective, can have catastrophic consequences, is doors.

Doors are the weak link in any furnace system because while reducing heat loss and withstanding pressure, they must also seal tightly enough to eliminate the minutest leak and in some cases, all leaks. The problem with doors is they must open and close repeatedly without fault and therefore they often, or should, demand the most maintenance.

The following describes the characteristics of a few door concepts starting with the vacuum furnace.

Elastomer seals such as o-rings are not absolutely leak tight. O-rings seal probably 99 percent of vacuum furnace doors and will leak perhaps only 7×10^{-7} cc/second (1.8 ft^3/ month) at atmospheric pressure. Figures 1 and 2 show a 10-foot-diameter 2-bar nitrogen or argon quench high-vacuum vessel that employs a suspended sliding charge door. This technique, instead of a swinging door, is used primarily to allow a track-mounted transfer car to pass in front of the vessel with the door open. A single o-ring provides the door seal with a rotating ring to hold the door closed. In addition, a carrier-mounted rollaway door closes the rear of the vessel for easier maintenance.

Batch integral quench (BIQ) carburizing furnaces use endothermic gas containing 40-percent hydrogen, 20-percent CO, and 40-percent nitrogen, so the integrity of its doors are just as or even more critical than vacuum furnaces. Carburizing takes place primarily between 1550°F and 1750°F (843°C and 954°C). BIQ furnaces usually have one position in the hot zone, vestibule, and quench tank with two doors — an inner door separating the quench vestibule from the hot zone and an outer vestibule door through which the tray is loaded onto an elevator above the quench oil. The inner door typically seals only around the perimeter with a designed leak at the bottom where the rear handler chain guide is located or centered in the door, continuously purging the vestibule with process gas. Although it's obviously not gas-tight, the door is designed to provide a heat seal plus provide a defined gas flow path at a low point in the hot zone. Carburizing gas that is leaking over the top or sides of the inner door can make atmosphere control difficult. For the carburizing atmosphere to completely interact with the load, the hot zone must be constantly filled with gas and allow the recirculating fan to distribute the atmosphere through the parts. If the process gas is allowed to short-circuit around the door, it cannot dwell long enough in the hot zone to transport adequate carbon to the parts being carburized.

Figure 1

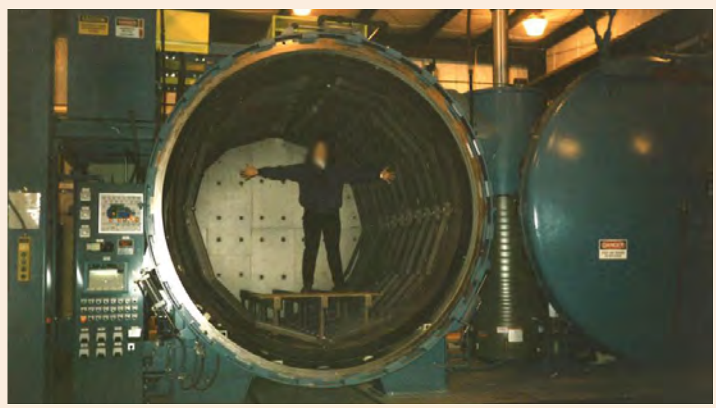

Figure 2

The Universal Batch Quench (UBQ) furnace's outer or vestibule soft-sealed door not only plays a critical role by keeping air out, but also provides pressure relief (see Figures 3 and 4). Many BIQ outer doors consist of a machined plate that slides open and closed via metal-to-metal contact against the vestibule frame.

No matter the furnace type — vacuum or atmosphere — carburizing has risks due to the hazardous nature of mixing atmospheres: acetylene/air for vacuum and hydrogen/air for endo gas. In BIQ furnaces, especially those with top-cool chambers, a premix of fuel and air could develop in the vestibule when the inner door is not timed properly. For example, if the inner door closes too quickly after transferring a tray to the vestibule for quenching, the vestibule atmosphere will cool and collapse rapidly, creating a partial vacuum and possibly pulling air into the confined space. As the carburizing atmosphere continues to purge the vestibule, the premix could ignite thus causing a significant gas expansion and increased pressure. This can be avoided by slowing the door's descent thereby allowing the heated vestibule gas to cool more gradually and reducing the pressure deferential.

The force of the ignition is a direct function of how the vestibule door is sealed. The door shown in Figures 3 and 4 allows the pressure from gas ignition to easily escape by overcoming the wedged weight that's holding the door closed. An atmosphere seal is provided by the knife edge attached to the door, compressing a ceramic rope. After the internal pressure is released, the door again seals without damage.

Pusher furnaces have been and still are the high-production mainstay all over the world and may seem to define the mundane of heat treating equipment, but this is where the function of their doors is most critical to atmosphere control. Multi-zone and multi-row pusher furnaces have several doors of which only two — the charge and discharge doors — isolate the atmosphere from the plant environment. Inboard to both doors are at least two more doors that provide the heat seal and, like the BIQ inner door, have a leak point below the doors to allow atmosphere to escape through the push-across channel and purge the charge and discharge vestibules. Also like the BIQ furnace's vestibule, the pusher charge and discharge vestibules have effluent pipes that provide the atmosphere exit point. Door sequencing occurs as such:

1. One tray in the programmed selected row is pushed to the discharge push-across tunnel.
2. The tray is pushed or pulled through the discharge tunnel through the discharge inner door into the quench vestibule.
3. The tray is lowered into the oil and quenched.
4. The quench vestibule is purged with endo gas.
5. The outer charge door opens to push a new tray into the charge vestibule.
6. The charge vestibule is purged with endo gas.
7. The tray is pushed or pulled through the inner charge door into the charge tunnel.
8. The tray is pushed into the row that discharged the previous tray.
9. After quenching, the discharge door opens to remove the tray.
10. All doors are closed.

Figure 3

This described sequence causes the atmosphere to move to the end of the furnace that has the path of least resistance. Thus, the quantity and composition of the atmosphere entering each zone must be compatible with the overall furnace carburizing potential, meaning that cold trays entering zone one must not cause the atmosphere to be compromised in zone two, three, etc.

For this discussion, it's noteworthy to mention two well-known doors used in heat treating today — one old, the Holcroft Pusher "alligator door" (shown in Figure 5), and one new, the AFC-Holcroft EZ™ Endo generator maintenance door (shown in Figure 6). As previously mentioned, the Achilles heel of any door is the constant opening and closing, causing wear and tear to sliding mechanisms and sealing membranes. But the alligator door has neither. As its name suggests, the door hinges at the bottom, integrating the tray skid rails inside of the door with a pneumatic cylinder, rotating the assembly up to closure, and eliminating any chance of abrasion to the ceramic rope seal membrane.

The second door is the first of its kind for an endothermic generator. All endo generators prior to the EZ™ system required the catalyst containing retort to be vertically lifted out of the heated case for maintenance, thus requiring excess overhead space. A typical 3,000 CFH (85 M^3) retort will be approximately 9 feet (2,743 mm) long, which requires about 10 feet below the crane hook over the generator to remove the retort. A 4,500 CFH (127 M^3) EZ™ generator provides a hinged door allowing the 9-foot-long retort to be removed horizontally via forklift or walk-behind loader. The side swinging door allows the user to locate the EZ™ generator anywhere in their plant where only 14 feet (4,267 mm) is required.

Figure 4

Figure 5

Figure 6

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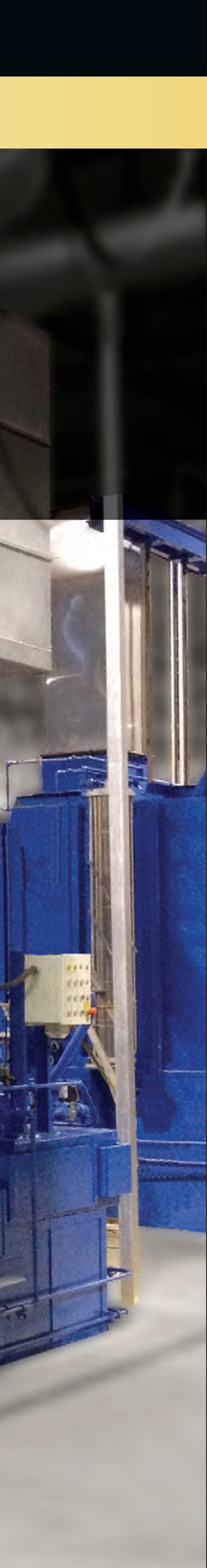
AFC-Holcroft

AFC-Holcroft celebrates 100 years as the U.S. market leader in the production of industrial furnace equipment for ferrous and nonferrous metals.

By Molly J. Rogers



Now part of AICHELIN Group, AFC-Holcroft looks forward to combining its long-standing traditions with an innovative future to continue providing heat treating solutions to its customers worldwide.

AFC-HOLCROFT BEGAN BUILDING FURNACES in 1916 when Holcroft and Company was founded in Detroit, Michigan, by Charles T. Holcroft, supplying equipment to the fledgling automotive industry in its earliest days. Although today it uses modern design software and technology, the company continues to maintain its original drawings, many hand-drawn and some dating as far back as the 1900s, in order to provide parts and service to customers with equipment of any age.

In 1962, Atmosphere Furnace Company (AFC) was formed by Robert Keough. AFC acquired Holcroft in 1999 and then renamed the company AFC-Holcroft. In July 2016, AFC-Holcroft was purchased by Aichelin Group, headquartered in Austria, whose own roots date back to 1868. Aichelin Group — with manufacturing companies Aichelin, EMA Indutec, SAFED, BOSIO, and Noxmat — is a leading provider of industrial furnaces, induction hardening equipment, and industrial gas burner systems. With the recent acquisition, Aichelin Group plans to strengthen its overall market position as one of the leading global heat treatment groups and is now the largest provider of atmosphere furnaces worldwide with 1,100 employees.

Through the combined network of Aichelin Group and AFC-Holcroft, customers will have access to a larger product selection as well as the latest technologies and innovations. The entire group looks forward to the joint growth opportunities and sustainable profitability for their customers, stakeholders, and employees.

AFC-Holcroft has about 100 employees at its facility in Wixom, Michigan, its headquarters for engineering as well as manufacturing heat treatment equipment including universal batch quench (UBQ) and universal batch quench austemper (UBQA) furnaces, pusher furnaces for high-volume processing, rotary and roller hearth furnaces, and single-layer systems for large loads.

One of the company's most celebrated products is the UBQ system, known globally for consistent, repeatable metallurgical results in a compact, modular design. Whether a standalone unit or fully automated cell integrated with companion equipment, the UBQ offers flexible production capability and a wide range of metallurgical processes.

"We are also the recognized technology leader in furnaces with salt quench systems," said Tracy Dougherty, the sales manager at AFC-Holcroft. "UBQA furnaces are used for the processing of larger parts, while mesh belt furnaces are utilized for smaller parts such as stampings and fasteners. With either design, salt quench processes are performed under a protective atmosphere for increased safety and better results."

Serving markets such as automotive, fasteners, commercial heat treat shops, bearings, gears, earthmoving, agricultural, and mining, among others, AFC-Holcroft provides a complete turnkey service to its customers — beginning with standard or custom-designed equipment, fabrication, and installation and continuing through its entire life cycle including upgrades, retrofits, moving/relocations, and spare parts.

With additional offices in Switzerland and China and a network of global partners, AFC-Holcroft's worldwide geographic reach will be further strengthened as a part of Aichelin Group.

"We have an unmatched reputation for quality and reliability, and we are one of the most trusted names in the industry," said Dougherty. "We work with our customers from the initial inception of their project through the implementation and after production begins. We are known to provide the highest level of service to our customers throughout the sales, implementation, and production utilization of our equipment."

According to Dougherty, AFC-Holcroft makes its customers' needs a top priority and listens to their challenges.

"Today's customers understand much more about what their desired outcomes may be and want a company who will propose solutions that meet their needs, not rely upon what they have done in the past," said Dougherty.

While AFC-Holcroft is best known for providing equipment for the processing of steel components, the company recently announced that a Tier 1 automotive supplier located in the Midwest placed two orders with AFC-Holcroft for the supply of heat treating equipment related to the processing of aluminum. The first order consisted of a roller hearth homogenizing furnace for processing aluminum products. The system includes a multi-position loading table, a multi-position furnace, cooling station, and multipurpose unload table. The second order is for a solution heat-treat line that includes charge and discharge transfer cars, a multi-position solution furnace, water quench system, multi-position age furnace, multi-position accumulation charge and discharge tables, accumulation crossover mechanism, and a tray pullout station.

AFC-Holcroft's offerings also include its Remote Diagnostics™ Service during the furnace warranty period, which allows the company to use data to help target and resolve operational inefficiencies that a customer may be experiencing and, in many cases, recommend corrective actions. The service eliminates human time and cost associated with manually gathering historical data for the same purpose.

"We also use technology through the use of computational fluid dynamics (CFD) modeling to prove out our designs during the concept phase," said Dougherty. "We continue to evolve and improve our products and services by using data collected by the IIoT (Industrial Internet of Things)."

AFC-Holcroft is a member of the Metal Treating Institute (MTI), Industrial Heat Treating Equipment Association (IHEA), ASM International, ASM Heat Treat Society, and the Association of Water Technologies (AWT). Additionally, the company is ISO 9001:2008 certified and offers ongoing training to its employees.

AFC-Holcroft will be exhibiting at Furnaces North America (FNA) on October 4-5, in Nashville, Tennessee, Booth #208-210.

FOR MORE INFORMATION, go to www.afc-holcroft.com.

Heat Treating Education

By D. Scott MacKenzie

For an industry that is key to the performance of many everyday products, creating more higher education programs in heat treating and metallurgy is essential.

In a recent paper by Janusz Kowalewski of Ipsen at the 3rd International Conference on Heat Treatment and Surface Engineering in Automotive Applications held in Prague, May 11-13, 2016, several global trends in heat treatment were identified. One trend is that the demand for heat treatment, services, and equipment is growing at a faster rate (2-4 percent) than the global economy (0.5-1.5 percent). Another important trend is the "graying" of the heat treating industry. If you attend any of the heat treating conferences in the United States or abroad, you'll notice the lack of younger people in the heat treating industry. These two trends portend both opportunities and challenges for the heat treating industry.

At the present time, there are seven schools in the U.S. that offer a degree in metallurgy or metallurgical engineering (see Table 1). The vast number of academic programs related in some manner to heat treating or metallurgy in the U.S. are materials science or materials engineering programs.

At the Center for Heat Treating Excellence at Worcester Polytechnic Institute, the heat treating program is part of the mechanical engineering or materials science program. This is a rare program that trains young engineers in carburizing, nitriding, and other heat treating facets. The focus of the course curriculum of most materials science programs is on all facets of materials engineering, such as ceramics, plastics, metals, nano-technology, and biomaterials. The understanding of microstructure and the critical field of heat treating is diluted by other materials. As the department head of a Big 10 university said, "Students may be exposed to martensite in one lecture during their entire four years in materials science." Also in discussing this topic, a professor at the University of Missouri – Rolla (now the Missouri University of Science and Technology) said, "A company searching for a candidate for heat treating should hire a mechanical engineer. They have at least been exposed to heat treating."

This change from metallurgy and metallurgical engineering to materials science occurred in the early 1980s, with many universities such as The Ohio State University and other land-grant schools dropping their metallurgy programs and transitioned to materials science.

Institution Name	Total Students	B.S.	M.S.	Ph.D.
The University of Texas - El Paso	23079	Y	Y	
Montana Tech of the University of Montana	2085	Y	Y	
South Dakota School of Mines and Technology	2798	Y		
Missouri University of Science and Technology	8640	Y	Y	Y
University of Idaho	11702		Y	
The University of Alabama	36047	Y	Y	Y
Colorado School of Mines	5962	Y	Y	Y

Table 1: Universities in the U.S. currently offering a metallurgy or metallurgical engineering degree (B.S., M.S., or Ph.D.). Note: Total enrollment reflects the total enrollment in the school, not in the metallurgical engineering or metallurgy programs.

As vital as heat treatment is to the performance of so many things, many of the engineering schools should focus more on metallurgy and heat treating.

For a good example, IWT in Bremen, Germany, focuses on materials manufacturing, with a large program in heat treating and surface engineering. Its laboratory has full-scale industrial integral quench furnaces, vacuum carburizers, and support equipment, as well as fully equipped metallurgical laboratories. It has created a strong distortion engineering curriculum focused on reducing distortion and residual stress in heat-treated and manufactured parts. There is a conference series on distortion engineering, now the IFHTSE (International Federation of Heat Treating and Surface Engineering) Quenching and Distortion Engineering Conference, presented every three to five years. The next conference will be in Japan in 2018.

There are other bright spots. The IFHTSE/Linde Tom Bell Young Author award, sponsored by Linde, is designed to promote young talent and give budding engineers an opportunity to present the young author's contribution to the advancement of heat treatment and surface engineering. This award has been given at the IFHTSE Congress annually since 2001.

One of the main challenges in heat treating and metallurgical education is the dependence of universities on funding of research, and the government is the primary source for research funding. However, there is limited funding for heat treating from the government, so universities focus on what is being funded, such as nano-technology, friction stir welding, or additive manufacturing. While these are all important long-term technologies, they neglect the critical infrastructure of heat treating.

Corporate funding of research is small and focused on short-term goals. However, one excellent example of corporate research applied to universities is with the Center for Heat Treating Excellence, where the predominance of funding is from industry partners.

Another challenge is cost. In the effort to reduce costs, corporate research has been drastically curtailed. In addition, reductions in labor costs have forced many operations with strong heat treatment content to rely on maintenance staff, rather than engineering staff, to make equipment and quenchant decisions. Where there were once several metallurgists at an operation, there is now one, who oversees operation across many facilities or countries.

Lastly, the heat treating industry needs to improve on the effort of selling the business of heat treating. There are materials science camps to explore materials science and engineering principles. And there is an interest in metallurgy and heat treatment that can be witnessed by the popularity of the History Channel's "Forged in Fire" program where blacksmiths compete to produce the perfect blade. Heat treating is a critical part of the blade creation. The industry needs to sell the fascination of taking a part that would fail if not heat-treated, and by applying temperature and time, the component is made stronger to perform its designed task.

> "The industry needs to sell the science … of computational metallurgy, computational fluid dynamics, heat transfer, and microstructure."

Without heat treatment, many of the things we take for granted, such as landing gear, airplane wings, and transmission gear trains would fail catastrophically. Those in the industry need to sell the science — the use of computational metallurgy, computational fluid dynamics, heat transfer, metallurgy, and microstructure — in order to have a vibrant heat treating industry in the future.

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Hybrid Forging: Advances in Open Die and Closed Die Forging

By Ashley Lukowicz and Margaret Dort

Using the advantages of open die forging combined with the near-net shape capability of closed die forging, the forging process can be tailored to optimize time and cost savings.

Today's high-strength material users are increasingly obliged by everyday economic and competitive realities to seek alternatives to their current manufacturing processes. The reality that forgings can be used for more than simple parts — and forged at very large sizes and unique geometries — is slowly being realized. Companies who are looking for a better competitive advantage have started seeking the help of forging facilities with the metallurgical know-how to deliver improved products, processes, and especially costs.

Forgings target a lower total cost when compared to a casting or fabrication. When considering all the costs that are involved in a product's life cycle from procurement to lead time to rework and then factoring in the costs of scrap, downtime, and further quality issues, the long-term benefits of forgings far outweigh the short-term cost savings that castings or fabrications might offer.

Due to computer-aided design, close customer collaboration, and creative forging techniques, advanced forging companies have been able to combine the advantages of open die forging with the near-net shape capability of closed die forging to tailor a forging process that optimizes time and cost savings. These hybrid open die, closed die designs allow for part flexibility and economic advantages for gearing innovation and are ideal for prototypes or low-volume production where the die block cost for impression die does not provide economic justification. The immediate availability of this tooling can also allow for a shortened production lead time, offering flexible order quantities and reduced lead time in situations where needed.

HOW IT WORKS

Instead of pushing 100 percent of the material's surface area, hybrid forgers are able to use far less tonnage in a prescribed manner to move material more efficiently. This is due to the tooling and mechanics of the process. For impression die (or closed die), a forging company must manipulate 100 percent of the workpiece at the same time. So it comes down

to pounds per square inch, which is why this hybrid process makes it possible to make larger, more complex parts on an open die press. It's also a more efficient use of tooling and investment dollars; the tool design can be changed quicker and more effectively than closed die impression blocks or casting molds.

HYBRID GEAR CASE STUDY

For example, a typical bull gear is manufactured in three parts: a rim, a hub, and a plate welded together. Fabricating a gear from multiple parts increases the risk for error and requires continual sourcing management. Added processing for welding of the fabrication proves to be costly and time-consuming. Not only is coordinating the manufacturing and shipment of all three components tedious, but someone also has to manage the requirement flow-down and payment schedule from different vendors. From a product standpoint, cracking in the weld layer is common, causing failures in the field that require extensive weld repair and re-inspection.

Fortunately, this product can be manufactured as a single-piece hybrid forging, improving properties and eliminating non-value-added steps. The strength and structural integrity of the forged material meets demanding application requirements, resulting in less rework, fewer rejections, and increased part life. The elimination of welding shortens part-production process time, and the component is better able to withstand the rigors of field use. The ultimate benefit, however, is that the component can be turned around faster and machine-finished for immediate production response. A single-piece forging is much less prone to error and setback due to the removal of steps, such as managing multiple suppliers and welding.

HYBRID FORGING COMPARED TO CASTINGS AND FABRICATIONS

When compared to alternative metalworking processes, forging delivers significant economic, manufacturing, and quality advantages such as directional strength, structural strength, and impact strength.

Directional Strength

By mechanically deforming the heated metal under tightly controlled conditions, forging produces predictable and uniform grain size and flow characteristics. Forging stock is also typically pre-worked to refine the dendritic structure of the ingot and remove porosity. These qualities translate into superior metallurgical and mechanical qualities and deliver increased directional toughness in the final part.

Structural Strength

Forging also provides a degree of structural integrity that is unmatched by other metalworking processes. Forging eliminates internal voids and gas pockets that can weaken metal parts. By dispersing segregation of alloys or non-metallics, forging provides superior chemical uniformity. (See Figures 1 and 2.)

Impact Strength

Parts can also be forged to meet virtually any stress, load, or impact requirement. Proper orientation of grain flow assures maximum impact strength and fatigue resistance. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising final part integrity.

GRAIN FLOW

Forging also provides means for aligning the grain flow to best obtain desired directional strengths. It is well-known that bridges are prone to cracking and fatigue problems. Therefore, it is helpful to understand how proper orientation of grain flow can ensure maximum fatigue resistance.

Bull gear that was previously welded as a three-component fabrication is now being produced as a single piece forging

Machined forgings ready for shipment; upon customer's receipt, gear teeth will be cut and parts will be ready for use

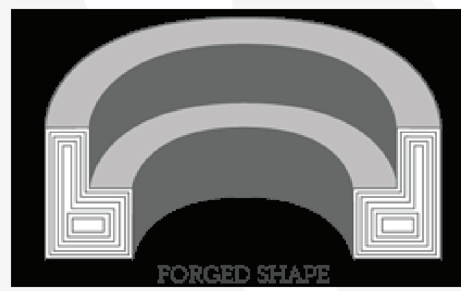

Figure 1: Forged shape

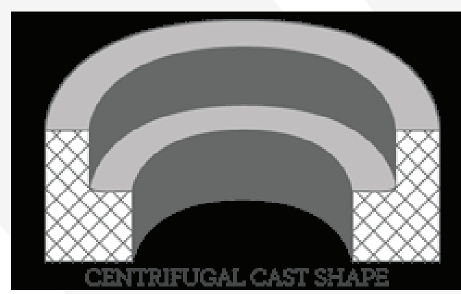

Figure 2: Centrifugal cast shape

In open die forging, the metal — once subjected to the compressive stress — will flow in any unconstrained direction. The expanding metal will stretch the existing grains and, if the temperature is within the forging temperature region, will recrystallize and form new strain-free grains. This results in even better resistance to fatigue and stress corrosion than a forging that does not contour the component.

This predictable structural integrity inherent to the forging process reduces part inspection requirements, simplifies heat treating and machining, and ensures optimum part performance under field-load conditions. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising final part integrity.

Forged Grain Flow

Forgings to near-net shape offer contoured grain flow, yielding greater impact and directional strength. Grain flow is oriented to improve ductility and toughness and increase fatigue resistance. (See Figure 3.)

Cast Grain Flow

Castings typically do not have a grain structure, which is not desirable for critical, load-bearing components. (See Figure 4.)

Machined Grain Flow

Machined parts have a unidirectional grain flow that has been cut when changing contour, exposing grain ends. This renders the material more liable to fatigue and more sensitive to stress corrosion cracking. (See Figure 5.)

ADDITIONAL BENEFITS

Forging can also measurably reduce material costs, as it requires less starting stock to produce many part shapes. Therefore, less machining is needed to finish the part with the added benefits of shorter lead time and reduced wear and tear on equipment.

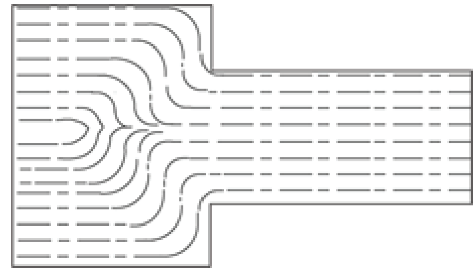

Figure 3: Forging grain flow

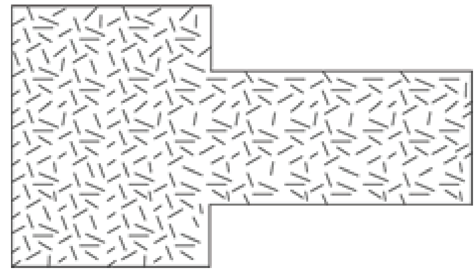

Figure 4: Casting grain flow

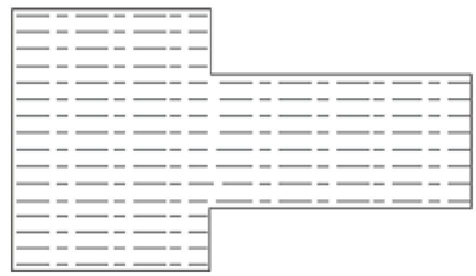

Figure 5: Machined grain flow

Virtually all open die forgings are custom-made one at a time, providing the option to purchase one, a dozen, or hundreds of parts as needed. In addition, the high costs and long lead times associated with casting molds or closed die tooling and setups are eliminated.

Furthermore, by providing weld-free parts produced with cleaner, forging-quality material and yielding improved structural integrity, forging can virtually eliminate rejections (as opposed to fabrications). Using the forging process, the same part can be produced from many different sizes of starting ingots or billets, allowing for a wider variety of inventoried grades. This flexibility means that forged parts of virtually any material or geometry can be manufactured relatively quickly and economically.

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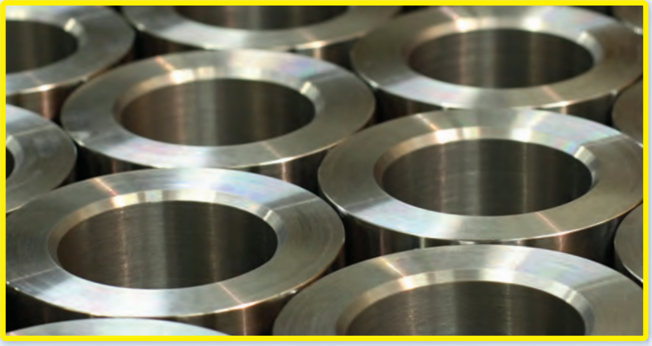

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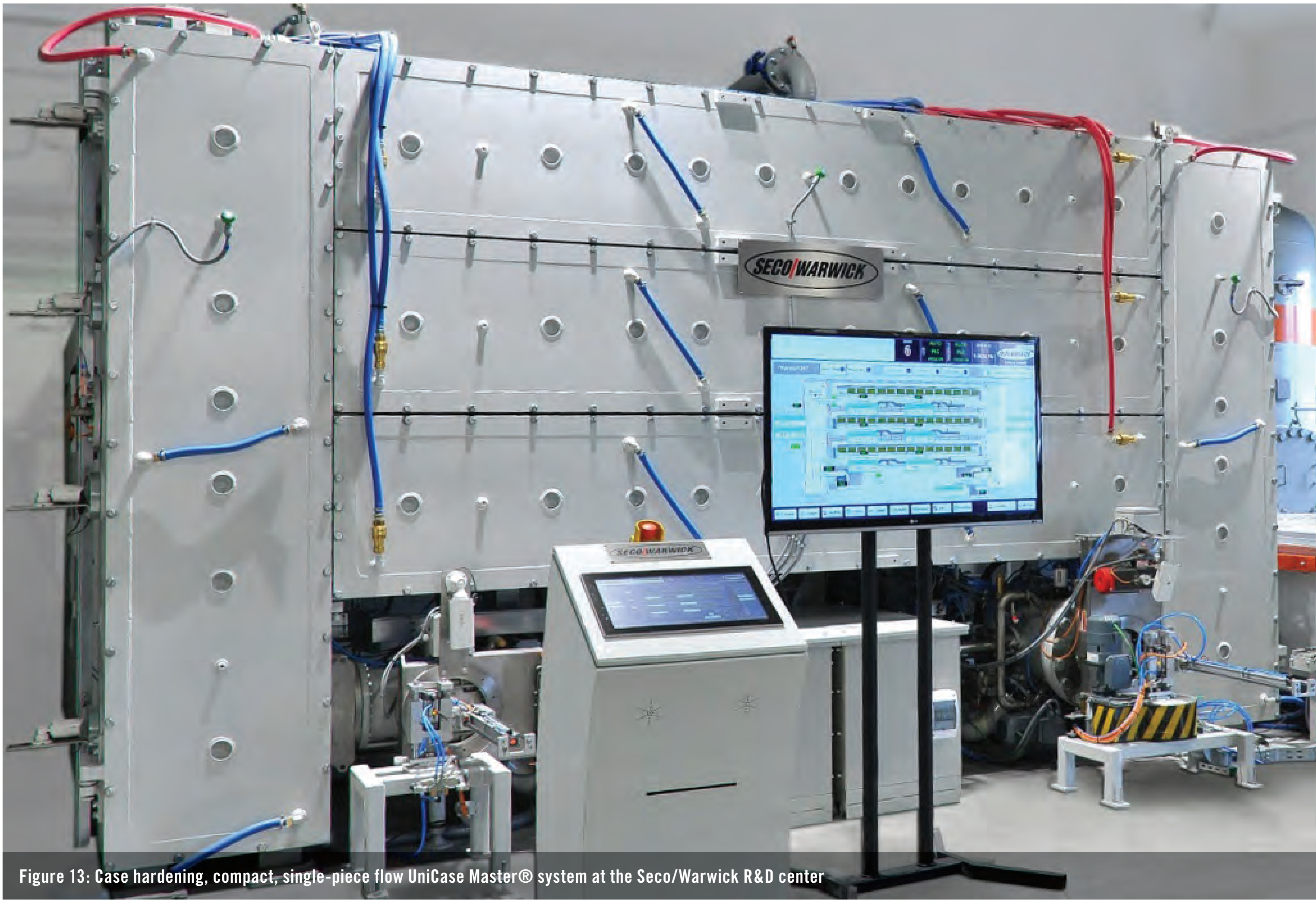

Figure 13: Case hardening, compact, single-piece flow UniCase Master® system at the Seco/Warwick R&D center

Single-Piece, High-Volume, and Low-Distortion Case Hardening of Gears

By Maciej Korecki, Emilia Wolowiec-Korecka, and Doug Glenn

A new concept has been developed for a single-piece flow case hardening system that adjusts to the size and shape of a particular gear in order to minimize distortion and ensure ideal repeatability of results.

Global output of the automotive industry reached 86 million vehicles in 2014. Each vehicle is fitted with a transmission gearbox (see Figure 1). Ninety percent of these gearboxes are traditional automatic or manual, with gears being the main component (see Figure 2). Modern automatic transmissions have eight to ten steps with multiple gears for each step, as well as other parts, such as drive shafts, synchronizing rings, and bearings. Excluding stepless, constant-velocity transmissions (CVT), which comprise approximately 10 percent of the market, and adding the output increases intended for the secondary market in the coming years, global output of gears in the automotive industry is estimated to be approximately 1 billion gears per year.

While the automotive industry is the largest manufacturer of gears, it is not the only one. There are a wide variety of gears produced for other types of machines and vehicles as well. Beyond gears, there are other steel parts that will be produced, such as several hundred million drive shafts, all requiring case hardening [1].

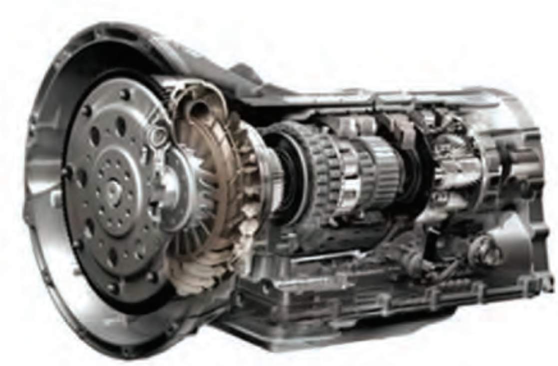

Figure 1: Modern gearbox

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Figure 2: Typical gears in a gearbox of a passenger car

CASE HARDENING OF GEARS

After the appropriate shape is obtained using a variety of CNC machines, each gear is case hardened to impart the right mechanical properties: hard, wear-resistant teeth and a ductile, impact- and load-bearing core. In most cases, the heat treatment used is carburizing, quenching, and tempering [2], [3]. The most common steels for carburizing are the EN 16MnCr5 or 20MnCr5 grades (AISI/SAE 5115, 5120, 8620), their equivalents, or slight modifications. Heat treating produces a typical effective case depth of 0.4–1.5 mm (0.017–0.063 inch), a surface hardness of 58–62 HRC, and a core hardness exceeding 30 HRC [4].

Figure 3: Furnaces for traditional case hardening (clockwise from top left): integral quench furnace, pusher-type furnace, rotary hearth furnace, and roller hearth furnace

DEFORMATIONS RESULTING FROM CASE HARDENING

Typically, case hardening results in the dimensional deformation of the gear caused mainly by a change of the steel structure volume that results from austenite transformation and lack of uniformity of process parameters during the heating process, especially quenching. Distortion can also be exacerbated by non-homogeneous incoming material or by stresses created during initial machining. Distortion also depends on the geometry of the part. Since the dimensional integrity of the gear, and especially the teeth, is essential for its life, efficiency, and vibration and noise reduction, any post–heat treat distortions are corrected by relevant methods, e.g., grinding. These deformation corrections are one of the most costly processes in gear manufacturing, because it requires very high dimensional precision and requires costly working tools with material hardness of approximately 60 HRC, with as much as 0.1 mm (0.004 inch) or more material being removed [5], [6], [7], [8].

An analysis of the cost for removing quenching deformations performed in 1995 by IWT (Institut fur Werkstofftechnic) Bremen for the German industry determined the cost to be approximately 850 million euros per year in the automotive and gearbox industry and 1 billion euros per year in the bearings industry [9]. Extrapolating this data to the global industry and taking into account the 20-year production increase, the current estimated cost to correct post–heat treatment deformation is roughly 20 billion euros per year. It is a great burden for the industry and a great opportunity for savings.

TRADITIONAL MASS PRODUCTION CASE HARDENING

Current Case Hardening Furnaces

The case hardening process is usually conducted in an atmospheric furnace using an endothermic atmosphere, followed by an oil quench. These furnaces can vary in size from as small as a batch integral quench furnace capable of processing approximately 100 kg (220 lbs) gross per hour, up to continuous furnaces capable of processing much larger loads. Examples would include pusher-type furnaces — up to 500 kg/h (1,100 lbs/h), rotary hearth furnaces — up to 1,000 kg/h (2,200 lbs/h), and the largest, roller hearth furnaces with capacity exceeding 2,000 kg/h (4,400 lbs/h) (see Figure 3). These larger capacity continuous furnaces are typically used in the mass production automotive industry [10].

Carburizing in endothermic atmospheres has been known for dozens of years, and the process is properly controlled with oxygen probes and gas analyzers. However, it carries with it an inherent defect: intergranular oxidation (IGO), which is caused by the presence of oxidizing gases (CO_2, H_2O, and O_2) in the atmosphere. Surface grinding is required to remove the dangerous IGO imperfections to the depth of as much as several dozen μm, and this removal comes at a high cost [4].

Moreover, carbon transfer in endothermic atmospheres is not especially effective (several dozen g/m³). In order to compensate for this poor transfer, large amounts of the carbon-carrying atmosphere must be supplied to the furnace — from one to over 100 m³/h, depending on the furnace size and surface to be carburized.

The overall cost of heat treating in an endothermic atmosphere is relatively high. Fuel is consumed not only to create the atmosphere, but additional fuel is consumed to bring and keep the newly introduced atmosphere up to the appropriate temperature within the furnace. Continually introducing and heating the atmosphere consumes additional energy. This, in addition to the fact that much of the atmosphere is exhausted, contributes to the system's overall inefficiency. Endothermic atmosphere carburizing also carries with it the inherent risk of fire and explosion, and numerous costly safety procedures must be followed to mitigate the risk, not to mention the environmental issues associated with emissions [11], [12].

Quenching, which in most cases is done in oil, is an important stage of the case hardening process. Oil is a commonly used quenchant with known disadvantages arising from the three-phase nature and speed of quenching and the uncontrollability of the process. If one takes into account that each phase appears at a different time in different places on the part being quenched, large and unique deformations associated with oil quenching are obvious. Additionally, parts need to be washed after quenching in special washers where chemicals are used; these chemicals are increasingly problematic with respect to environmental regulations.

Continuous furnaces can occupy hundreds of square meters of valuable floor space. Because of the large size of these furnaces, changing the process parameters and stabilizing the working environment takes hours. Switching these furnaces on/off takes weeks. Any interruption of the production process results in huge energy and production losses.

Modern Technologies and Devices

In response to the aforementioned weaknesses of traditional case hardening technologies, low-pressure carburizing (LPC) and high-pressure gas quenching (HPGQ) technologies were developed in the 1970s to 1980s. By the 1990s, the technologies had been perfected enough to find industrial applications, including mass production industries like automotive. Currently, LPC and HPGQ carried out in vacuum furnaces have effectively replaced traditional atmosphere furnaces. These new LPC/HPGQ furnaces include batch, semi-continuous, and modular systems for mass production [10] (see Figure 4).

Figure 4: Vacuum furnaces for case hardening (top: single- and double-chamber HPGQ; bottom: double-chamber oil quench and multi-chamber HPGQ)

Low-pressure carburizing overcame the weaknesses of endothermic carburizing and added a range of new possibilities. IGO was eliminated because of the total absence of oxygen in carburizing gases. Carbon transfer effectiveness increased about 20 times, considerably decreasing atmosphere consumption. Moreover, the atmosphere in the furnace is neither flammable nor explosive due to its low density. LPC is also characterized by the extraordinary capability of the atmosphere to penetrate and uniformly carburize parts with shapes, which make access difficult (blind holes) and densely packed loads. In addition, the processing temperature can be raised considerably, resulting in shortened carburizing time — as much as four to five times shorter when the temperature is raised from 920°C (1688°F) to 1040°C (1904°F) [13].

Furthermore, HPGQ significantly improved the outcome of the quenching process by decreasing the deformation rate. Gas quenching is a single-phase process and is a more uniform process with respect to a single part. Moreover, quenching rates can be regulated freely by a change of gas pressure (density) and velocity (fan rotation), thereby making the process totally controllable. Modern HPGQ systems with nitrogen or helium under 25 bar pressure are equivalent to oil quenching. As an added benefit, gas quenching eliminates the process of washing, making it a much more environmentally friendly process [14].

LPC/HPGQ vacuum furnace systems are compact, energy-efficient, and environmentally friendly devices. They are flexible, can be switched on and off at any time, and take about one hour to make production-ready. Moreover, they do not require atmosphere stabilization, and process parameters can be changed virtually instantaneously. The case hardening technology implemented in modern vacuum furnaces is a precise, efficient, clean, and environmentally friendly process [15], [16], [17], [18], [19].

Characterization of Batch Case Hardening

Although there are many benefits to these new technologies (LPC and HPGQ), there is one feature that remains unchanged. Even in new LPC/HPGQ vacuum furnace systems, parts are configured and processed in batches on special fixtures (see Figure 5) and undergo the whole case hardening process in such a configuration. This means that each part in a batch is affected by the process conditions in a unique manner based on its position within the batch. Each part is affected differently regarding the heating rate, composition of the process atmosphere, and intensity and direction of the cooling medium. There is no doubt that the parts in the outer layers of a batch are heated more quickly and to a different temperature (according to the temperature distribution within the batch), as the atmosphere around them is "richer," and they are quenched more intensely, compared to the parts toward the center of the load.

Figure 5: Typical batch composition

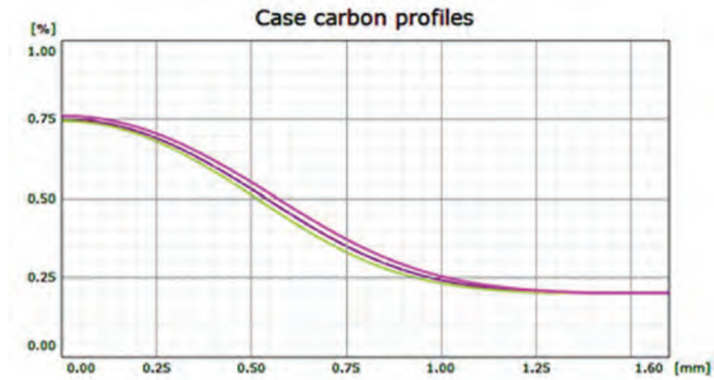

Figure 6: The extreme carbon profiles at temperature 950°C (1742°F) at uniformity of +6°C and -6°C (+/- 10°F)

The result is that parts inside the batch have different physical and metallurgical properties than those on the outside of the batch, e.g., surface and core hardness, microstructure, and especially the effective case depth [20], [21], [22].

In an analysis of the effect of the carburizing temperature on the effective case depth, a typical parameter of the temperature uniformity was adopted: +/- 6°C (+/- 10°F) for a class II furnace, in accordance with AMS 2750E. Figure 6 shows the extreme carbon profiles achieved in the low-pressure carburizing process at the temperature of 950°C (1742°F) for a 0.75 mm (0.03 inch) case (for the 0.35%C criteria). The effective case depth obtained at 944°C (1731°F) was 0.72 mm (0.03 inch), whereas at 956°C (1753°F), it was 0.78 mm (0.033 inch). The difference between the effective case depths is 0.06 mm (0.003 inch), or 8 percent, for the temperature dispersion of +/- 6°C (+/- 10°F).

Similarly, the composition of the carburizing atmosphere is not uniform and changes as the atmosphere moves toward the center of the batch, with the amount of carbon decreasing gradually, resulting in poorer carburization of the parts at the center of the batch. The differences in the atmosphere composition (carbon potential) can be as great as 10 percent, and the case depth can change accordingly. The cooling rate during the quenching process also affects the case depth, with a faster quench increasing the case depth and a slower quench decreasing the case depth. Non-uniformities of the cooling medium flow rate through the batch can be as high as 50 percent and can also significantly impact the case depth by several more percentage points [14].

Due to the compounding effect of these varying parameters inherent in batch processing, it is not surprising that the industry's quality expectations are very liberal. Tolerances can be as high as 50 percent

(0.6–0.9 mm or 0.025–0.038 inch) — a direct consequence of batch processing and the currently accepted tolerances of the batch processing case hardening systems.

The intensity and uniformity of parts quenched in batches is a separate issue. Intensity of quenching determines the hardness of the core and the effective case depth, and the uniformity determines the dispersion of those parameters across parts within the batch, and, more importantly, the size of quenching deformations on individual parts. Batch quenching has one important common feature. Regardless of the device or the cooling agent (liquid or gas), batch quenching is a single-direction cooling (referred to in this paper as "2D"). This means that an individual part is affected by the cooling agent, which flows in one specific direction (e.g., from top to bottom or from left to right, with the flow not necessarily linear). In consequence, the part cooling rate is different in different places on the part. Surfaces on the inflow side are cooled more intensely than those on the outflow (or obscured) side, and the difference can be very significant.

Non-uniform quenching results in temperature gradients within each part resulting in thermal stresses and a non-uniform transformation of the microstructure. This ultimately results in large deformations of the part being quenched. Quenching results are made even worse by the fact that the quenching stream within the batch is dispersed and each part is cooled differently based on its position within the batch. A critical summary of batch 2D quenching (especially oil quenching) shows that it is an uncontrolled and non-uniform process, producing great deformations within each part and little consistency within the batch.

Using gas as the quench media, compared to oil, can reduce deformations within each part due to the single-phase nature of convection cooling with gas, but all the variations within the batch still remain [23].

Batch processing also has other quality, material handling, and cost pitfalls. For example, monitoring and reporting on the case hardening process is for the entire batch and not for individual pieces within the batch. That makes it difficult, or even impossible, to introduce and implement tighter quality standards.

Material handling of batch loads is typically complicated and costly. Gears are produced individually. After being shaped, they are collected, packed, protected, and transported to the case hardening department (captive) or to an external firm (commercial), which can range from hundreds of meters to hundreds of kilometers away. The gears are then unpacked, washed, and racked in order to form batches on fixtures designed specifically for the case hardening process. Following an oil quench, the parts are washed again, dismantled, packed, protected, and transported back to the mechanical processing department. The whole undertaking may be divided into more than 10 operations and may take days. These material handling costs consume considerable resources, including time, materials, and money.

It is critically important to have special fixtures for case hardening, and these fixtures are typically made of heat-resisting Ni-Cr alloys. The price of a medium-sized fixture starts at thousands of euros, and the life span ranges from two to four years. Considering the fact that the largest installations require over 100 sets to ensure continuity of the production process, the cost of fixturing alone can reach hundreds of thousands of euros a year. The fixturing also affects the amount of direct energy consumption cost because it accounts for 40 to 50 percent of the overall batch weight, thereby generating higher consumption of energy needed to heat up and cool down parts.

The current technology must be appreciated for its huge productivity and minimal per-piece cost. The technology has been used and improved for decades and has been sufficiently mastered. Because of the nature of the process, the ability to further develop and improve the process has hit a wall. Specifically, the increasing needs and expectations of the industry in regard to per-piece quality improvements and reporting, repeatability, flexibility, speed, process continuity, reduction of the total costs of production, and neutrality to the environment cannot be satisfied with traditional methods.

NEW APPROACH TO CASE HARDENING

Single-Piece Flow Case Hardening

The vast majority of weaknesses and limitations of the current case hardening processes are associated with its batch-related nature. Therefore, to eliminate these weaknesses and limitations, it would be ideal if batch processing was eliminated and replaced with a continuous, single-piece flow model. The single-piece flow concept has been around for some time in theory, in industry articles, lectures, and presentations [24], [25]. Various systems, more or less in line with the idea, have been developed, but no device for mass thermal treatment has been constructed that would fully embody the idea to date. Single-piece flow processing should mean that every single piece goes through the exact same positions and process conditions as every other piece. A system where parts are placed on trays, even in single layers, or when parts are processed individually in different process chambers, does not meet the criteria of a single-piece flow system.

Figure 7 shows a vacuum furnace for case hardening of gears or rings using LPC and HPGQ. This system fully meets the criteria of a single-piece flow method and has all the accompanying advantages. The furnace consists of three horizontal chambers: the first one for heating up, the second for low-pressure carburizing, and the third for diffusion and pre-cooling before quenching. Additionally, a separate loading chamber and a quenching chamber (that doubles as an unloading chamber) are connected. Parts are transported between chambers by two vertical transport elevators attached to each side of the system.

The single-piece flow process runs in the following manner:

- A single gear is placed inside a loading chamber.
- It is then transported and loaded into the heating chamber.
- A walking beam mechanism indexes the gear through all the positions until the gear reaches the target carburizing temperature.
- The gear is then transported and indexed through the LPC where the surface is saturated with the right amount of carbon.
- The part is then transferred and indexed through the diffusion chamber where the desired carbon profile is achieved and the temperature is decreased before quenching.
- The gear is then transferred to the gas cooling chamber where it is quenched.

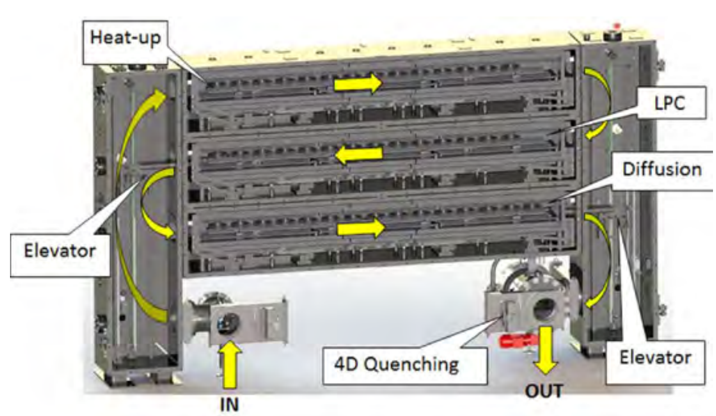

Figure 7: The vacuum furnace for single-piece flow case hardening

Figure 8: 4D quenching chamber for HPGQ

- The gear is then removed from the quenching chamber and is ready for temper.

Each gear follows in sequence and is processed the exact same way with the exact same process parameters, guaranteeing the highest level of precision and repeatability.

Precision and repeatability improve because each part runs individually and is exposed to the exact same temperature and atmosphere. Single parts heat up more quickly and uniformly due to direct radiation and the beneficial effects this direct radiation has on the more consistent conduction of heat within the gear. Moreover, any temperature gradients within the chamber are neutralized because each part goes through all the same positions. It is possible to achieve temperature uniformity as tight as +/-1°C as an average process temperature between parts. The same is true of the process atmosphere, which directly reaches the part surface consistently. Even if the atmosphere composition varies in different places within the chamber, the average value after each gear has gone through all positions is the same. Considering this, it is conceivable to achieve a uniform and repeatable carburized case depth in a single part and consistently throughout the batch of 0.6–0.7 mm (0.025–0.029 inch). This is significantly more precise than the 0.6–0.9 mm (0.025–0.038 inch) range required with today's systems.

4D Quenching

The new concept also allows for significant improvements in the quenching process, specifically the reduction of distortion. This is done primarily using a high-pressure gas quenching system installed in the quenching/unloading chamber (see Figure 8). The system utilizes a proprietary arrangement of cooling nozzles that surround the part and ensures a uniform flow of cooling gas from all sides: top, bottom, and side. This is referred to as "3D" cooling. In addition, a table spins the part, further enhancing quench uniformity. This spinning motion is referred to as the fourth dimension, allowing a "4D" quench of the gears for the best possible uniformity. The cooling nozzles achieve 15 bar quenching results — comparable to oil quenching — without the use of helium (He). Because the cooling nozzles can be adjusted to fit the gear's precise size, quenching is optimized and distortion is significantly decreased. It is anticipated that, compared to oil quench systems, quenching deformation rates for each piece and across the entire batch will easily be cut in half.

Technical and Technological Assumptions

The system was designed using the following criteria for the automotive industry:

- Part diameter: 200 mm (8.0 inches)
- Weight: 3.0 kg (6.6 lbs)
- Tact time: 60 seconds
- Number of parts: 15 (in each process chamber)

A gear with a diameter of 200 mm (8 inches) and weighing 2 kg (4.4 lbs) covers all the gears in passenger car and most truck gearboxes currently manufactured. The optimum duration of the loading-unloading cycle was 60 seconds, which corresponds well to the production cycle of CNC machine tools. An analysis of the part's heating rate and the process of carburizing for 0.4–1.0 mm (0.02–0.04 inch) case required process chambers with 15 index positions. As a consequence, each part has a residence time of 15 minutes in each process chamber. Figure 9 shows the heating curve for a single gear, showing that the process temperature is achieved within 15 minutes. Furthermore, Figure 10 shows the processes of carburizing and diffusion at 1040°C (1904°F), where a carburized case of 0.6 mm (0.025 inch) can be obtained during 30-minute cycles. This is only one example. Other cycle durations and process temperatures can be used to obtain other required case depths.

Figure 11 shows the cooling curve for a single gear in the 4D quenching chamber. The gear's core (the hottest spot) drops below 150°C (302°F) within 40 seconds, well within the system's 60-second tact duration.

Lean Manufacturing

The new concept of single-piece flow case hardening is intended to be installed and operated directly on the manufacturing floor next to a CNC machine and was designed so that its footprint is similar to a CNC machine (see Figure 12). It can be installed on new production floors or at sites previously occupied by other machines, including CNC machines. A newly machined gear can be introduced into and released from the case hardening system every 30–60 seconds. The system can be completely integrated into the continuous, lean production manufacturing line, thus eliminating many, if not all, batch material handling steps.

Also, it should be noted that the system does not use fixtures for load racking. As previously mentioned, this helps reduce operating costs, including the cost to purchase and replace fixtures, as well as the consumption of energy.

Productivity

For a 200-mm (8.0-inch) diameter gear indexing 15 steps within each process chamber, a gear with an effective case depth of 0.6 mm (0.025 inch) can be produced every 60 seconds. The gear will spend 15 minutes in each chamber. This results in approximate production flows of:

- 1 gear/minute
- 60 gears/hour
- 1,400 gears/24 hours
- 10,000 gears/week
- 43,000 gears/month
- Approximately 500,000 gears/year with the continuous operation mode

For gears with a smaller diameter of 100 mm (4 inches) and the same process requirements, the system can be configured for 30 positions and the tact reduced to 30 seconds in each position, resulting in annual output of approximately 1 million parts.

CONCLUSION

Current available case hardening technologies, both batch and continuous, fail to meet current expectations of high-volume automotive gear manufacturers in terms of quality, repeatability, flexibility, and integration of production, as well as environmental friendliness and costs, mainly because parts are arranged as batches on special fixtures for thermal treatment.

The system, developed to be a real single-piece flow case hardening system, provides potential for elimination of the shortcomings of the traditional systems and brings opportunities for significant improvements in the following areas:

- Precision and repeatability of process results
- Reduction of quenching deformations due to 4D quenching
- Integration into continuous production lines — lean manufacturing
- Flexibility and operational speed
- Individual part monitoring and reporting (as opposed to batch monitoring/reporting)
- Elimination of fixtures (cost and energy) and batch material handling logistics
- Elimination of quench oils, washers, and washing fluids
- Elimination of fire and explosion hazards
- Cleanliness of the process — less effect on the environment

All of the aforementioned advantages and opportunities are attractive for modern industry and are now currently being tested and proven in the only full-size test system that currently exists.

This first full-scale production system, called UniCase Master®, has already been built and installed at Seco/Warwick's R&D center. The system consists of the main furnace for heating up, low-pressure carburizing and high-pressure gas quenching (4D quenching), and the tempering furnace (also single-piece flow) with cooling stations and manipulators. Combined together, this serves as a technologically complete, automated, and independent case hardening equipment (see Figure 13 on page 34).

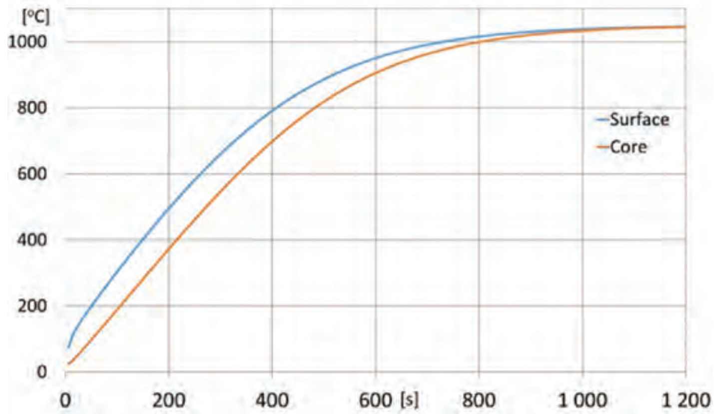

Figure 9: Heating curve, CFD simulation for a single gear, diameter 190 mm, 3.0 kg, $\varepsilon = 0.35$

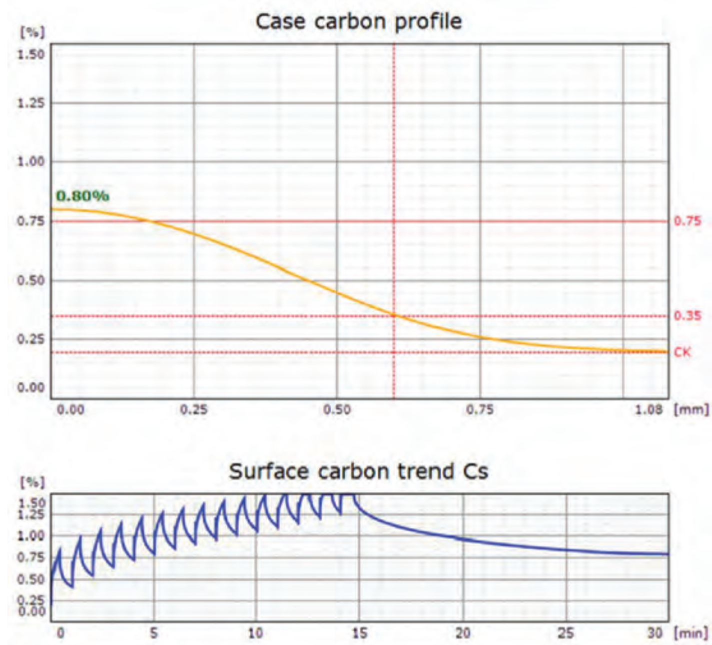

Figure 10: The LPC process at 1040°C for a 0.6 mm case during the total time of 30 minutes; top: the final carbon concentration; bottom: boost and diffusion segmentations

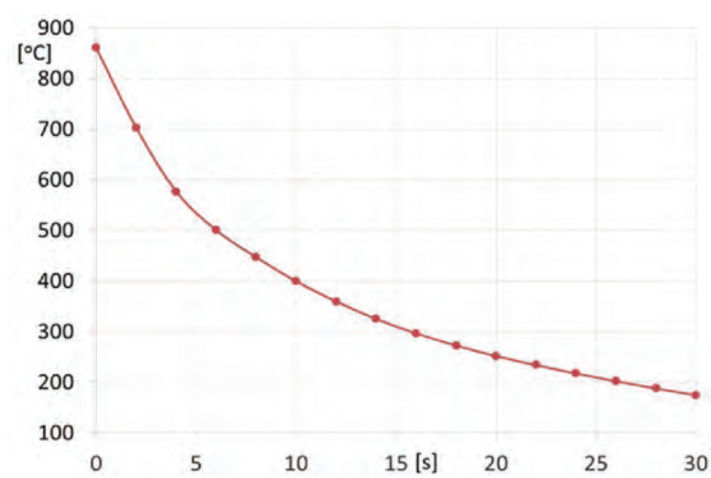

Figure 11: Cooling curve for a core of a single gear, diameter 105 mm, 0.68 kg, α = 750 W/m^{2}K

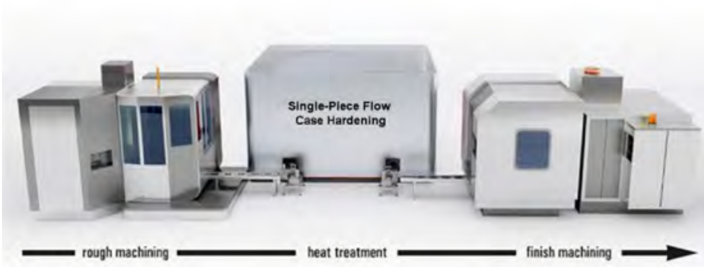

Figure 12: Integration of the new concept of single-piece flow case hardening in lean manufacturing

Since the beginning of 2016, the system has successfully completed numerous technical tests and trials on real gears and rings. The technical features and reliability were proven, reaching a tact time below 60 seconds and corresponding productivity. High-temperature, low-pressure carburizing processes were researched and confirmed, achieving an effective case depth of 0.6 mm at a 60-second tact time. Due to the precise control of the case hardening process, the results, when plotted on a graph, produce almost a single line, with deviations being caused not so much by differences in the actual case profiles, but by the limitations in the hardening measuring equipment itself. In terms of hardening distortion, results after treatment in the UniCase Master® are more than optimistic — being lower, more predictable, and more repeatable than can be achieved after batch oil quenching. In many cases, distortion measurements are comparable with press quenching and are well within specified tolerances. Because of this important and consistent reduction in distortion, final hard machining can be significantly reduced and in some cases, eliminated completely.

The system is currently available for trails in order to prove its effectiveness on particular gears.

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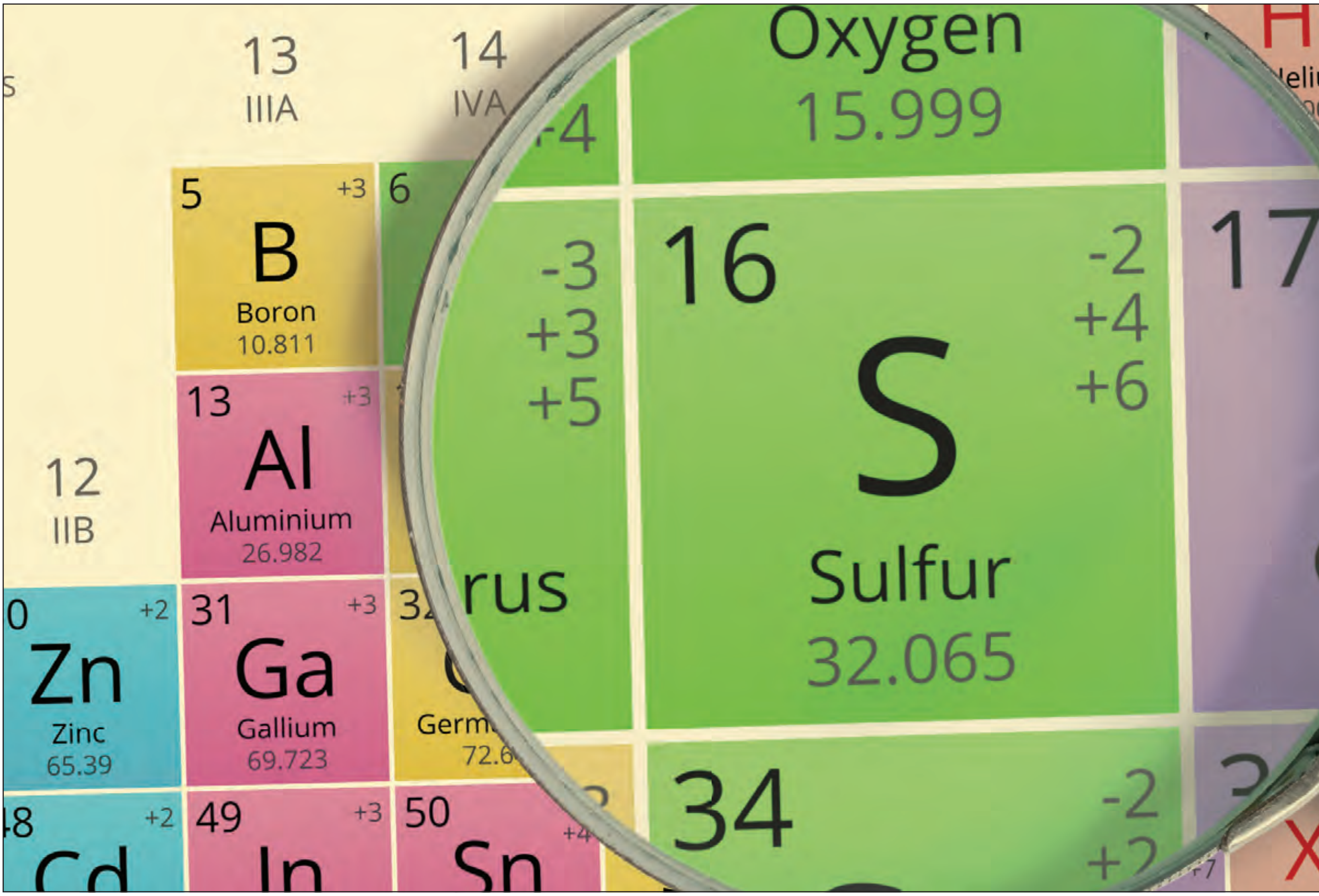


Detrimental Effects of Sulfur on Transverse Impact Properties in Steel Forgings

By Chuck Hartwig

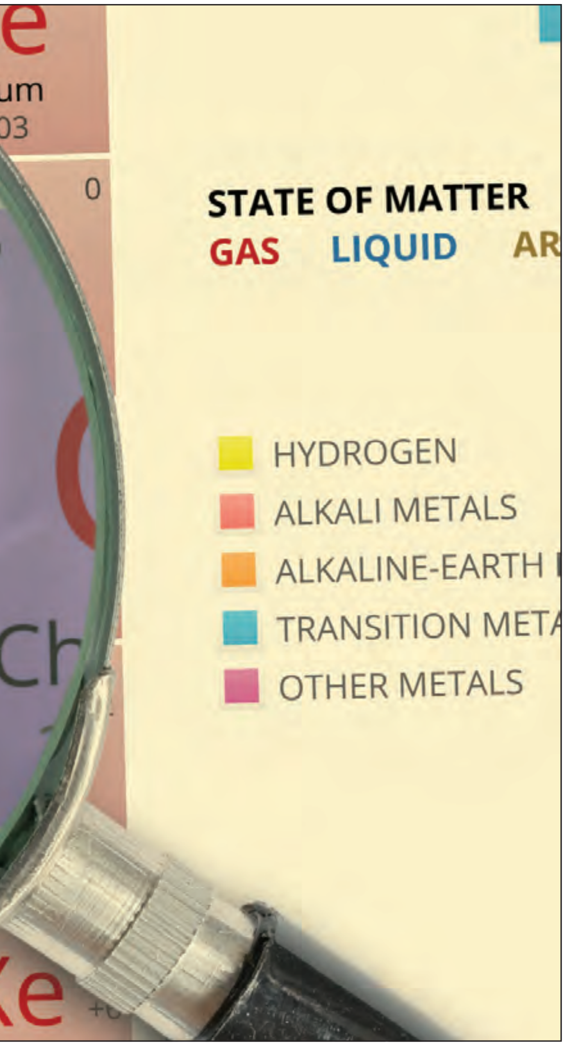
Supplying heat-treated forgings with Charpy impact specifications requires special attention to sulfur content in each heat of steel, even if the levels are within material specification limits.

Anyone who has supplied or processed forgings for the power generation, oil and gas, or shipbuilding industries, among others, is familiar with Charpy impact testing requirements. The test is intended to ensure parts have adequate impact toughness in one or both grain flow orientations. Because this test is usually performed simultaneously with mechanical testing on a lot-by-lot basis after heat treatment, the results are inextricably linked to the quality of the heat treating process employed. A comparative study performed on two similar forgings with well-defined grain flow will show, however, that the sulfur content of the base material can have disastrous effects on Charpy impacts, most notably in the transverse grain flow direction. The cause of these low properties is also evident in the microstructure and fracture characteristics of impact specimens. These effects can be so severe that there is no heat treatment solution to repair the impact performance, and they can occur even at sulfur levels that are within material specification limits for many OEMs.

Characteristic:	Forging A	Forging B
Weight	110 pounds	70 pounds
Alloy	4140	4140
Cross section*	4.5 inch	3.9 inch
Shape of sample removal location	Cylindrical	Cylindrical
Heat treat process	N,Q**,T	N,Q**,T
Sulfur content range	.003-.004%	.016-.020%

Table 1: Comparison of Forgings A and B used in this study

*Section thickness at location of specimen removal
**Polymer quench



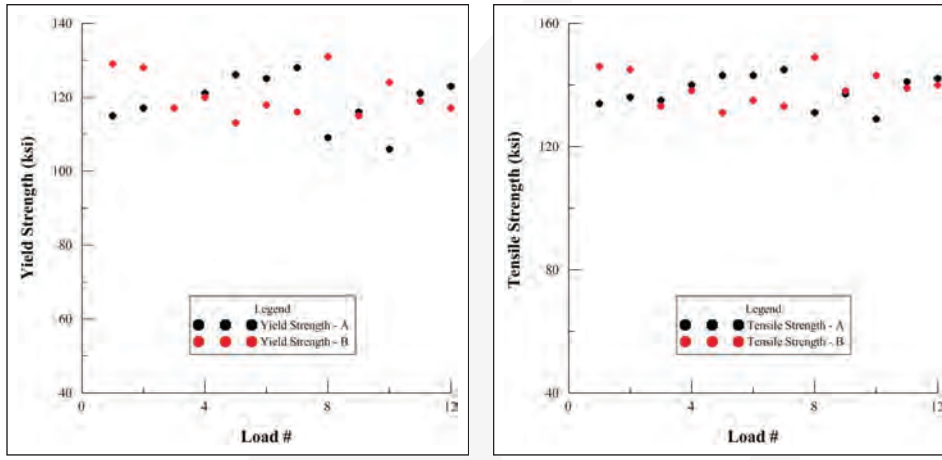


Figure 1: Yield strength and tensile strength data from 12 furnace lots of Forgings A and B

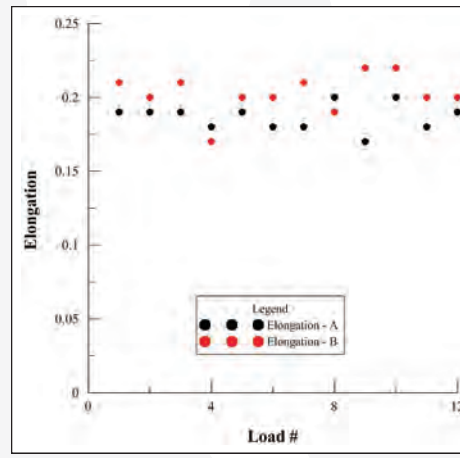


Figure 2: Elongation data from 12 furnace lots of Forgings A and B

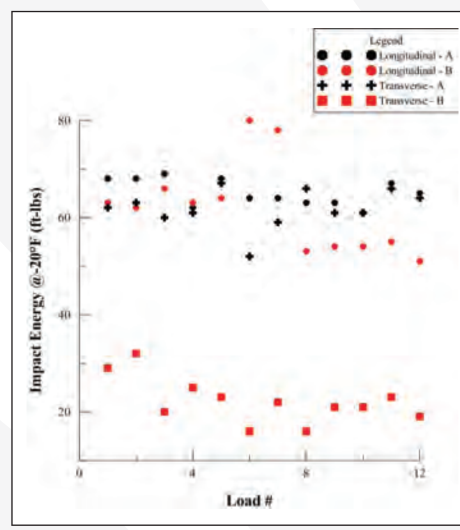


Figure 3: Charpy impact data from 12 furnace lots of Forgings A and B

For the study, two similar 4140 steel forgings were used — denoted A and B for the purposes of this work. The characteristics of each are displayed in Table 1. The data acquired from each forging was from several different heats of material. Most important to the outcome, Forging B was consistently supplied with at least four times the sulfur content of Forging A.

Both forgings were processed to the same end-use specification using the same equipment and process parameters. Note that Forging A is over ½ inch thicker and 40 pounds more massive. Given these physical characteristics, it would be anticipated that Forging A presents more of a challenge in terms of attaining mechanical impact properties assuming similar heat treat parameters.

When considering the mechanical test values obtained from each forging across 12 furnace lots, nothing appears to be out of the ordinary. All testing for the data displayed in Figures 1 and 2 was done in the longitudinal grain flow direction. All data points meet the specification requirements.

The problem caused by the higher sulfur content of Forging B does not manifest itself until testing transverse Charpy impacts. The data displayed in Figure 3 shows both transverse and longitudinal data plotted side-by-side. Note that the longitudinal values are relatively unaffected — each test met the specification requirements for this characteristic. In fact, the transverse values for Forging A were nearly identical to the longitudinal values. It was only the transverse orientation Charpy impacts for Forging B that consistently suffered.

Upon examination of the transverse impact fracture surfaces from the Charpy samples, there is a drastic difference in appearance between the two samples. The specimens from Forging A exhibit a fine grain structure with notable shear lips, which are typical of a ductile fracture, whereas the sample from Forging B appears more coarse-grained, similar in appearance to a split piece of wood. This sample shows no shear lips, indicating nearly 100-percent brittle fracture. Each of these specimens is displayed in Figure 4.

A closer examination of the unetched Forging B sample shows the culprit of the low transverse impact properties — manganese sulfide (MnS) inclusions that take on stringer-type morphology and align themselves longitudinally, thereby having a detrimental effect only on the transverse impact properties. (See Figure 5.)

Using scanning electron microscopy, it is possible to see the failure mode in clear detail. The MnS inclusions form micro-voids in the steel matrix, which act as crack nucleation sites and greatly weaken the impact strength in the transverse direction. Figure 6 shows one of these micro-voids left behind by a partially torn-out MnS inclusion — the presence of which was confirmed by energy dispersive spectroscopy (EDS).

While this study highlights the mechanisms by which MnS inclusions hinder transverse impact properties, the fact that this can happen is not a new finding. What is of critical importance as a takeaway from this work is that the problematic impact failures due to the presence of MnS inclusions can indeed occur at sulfur levels considered to be low by many standards. Indeed, many material specifications allow 0.025 percent as a maximum limit for sulfur. This work, along with other experiences in commercial heat treating, suggest that only steels with less than 0.012 percent sulfur

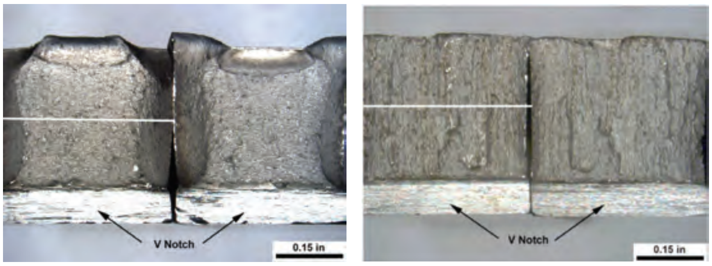


Figure 4: Impact specimens post-fracture from Forging A (left) and Forging B (right)

should be used when impact properties are critical. Phosphorous also must be considered, but that is beyond the scope of this work.

While it is permissible to use grades with sulfur between 0.012 percent and 0.025 percent for many specs, it is critical to consider the downstream process ramifications of doing so, as it risks impact failure and poor overall process capability with respect to impact properties, even if passing results are attained on a particular test piece that is being used to represent an entire heat treat lot of forgings.

A final point of consideration with this analysis is that while many specifications only call for longitudinal impacts, it is possible for many forgings to have a poorly defined grain flow at the specimen location for longitudinal impacts. Therefore, the problem highlighted in this study will also affect longitudinal results in these cases because some degree of transverse grain flow is picked up in the samples.

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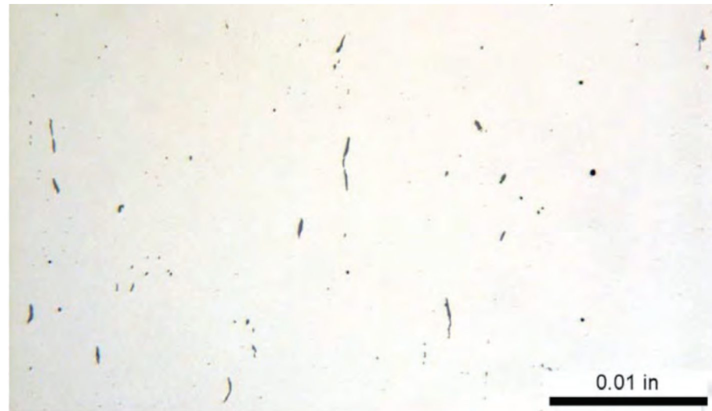


Figure 5: Unetched microstructure of Forging B impact specimen showing numerous MnS stringer inclusions (at 100x)

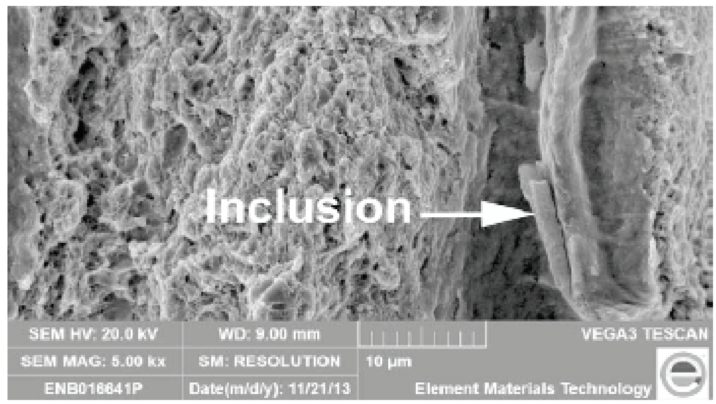
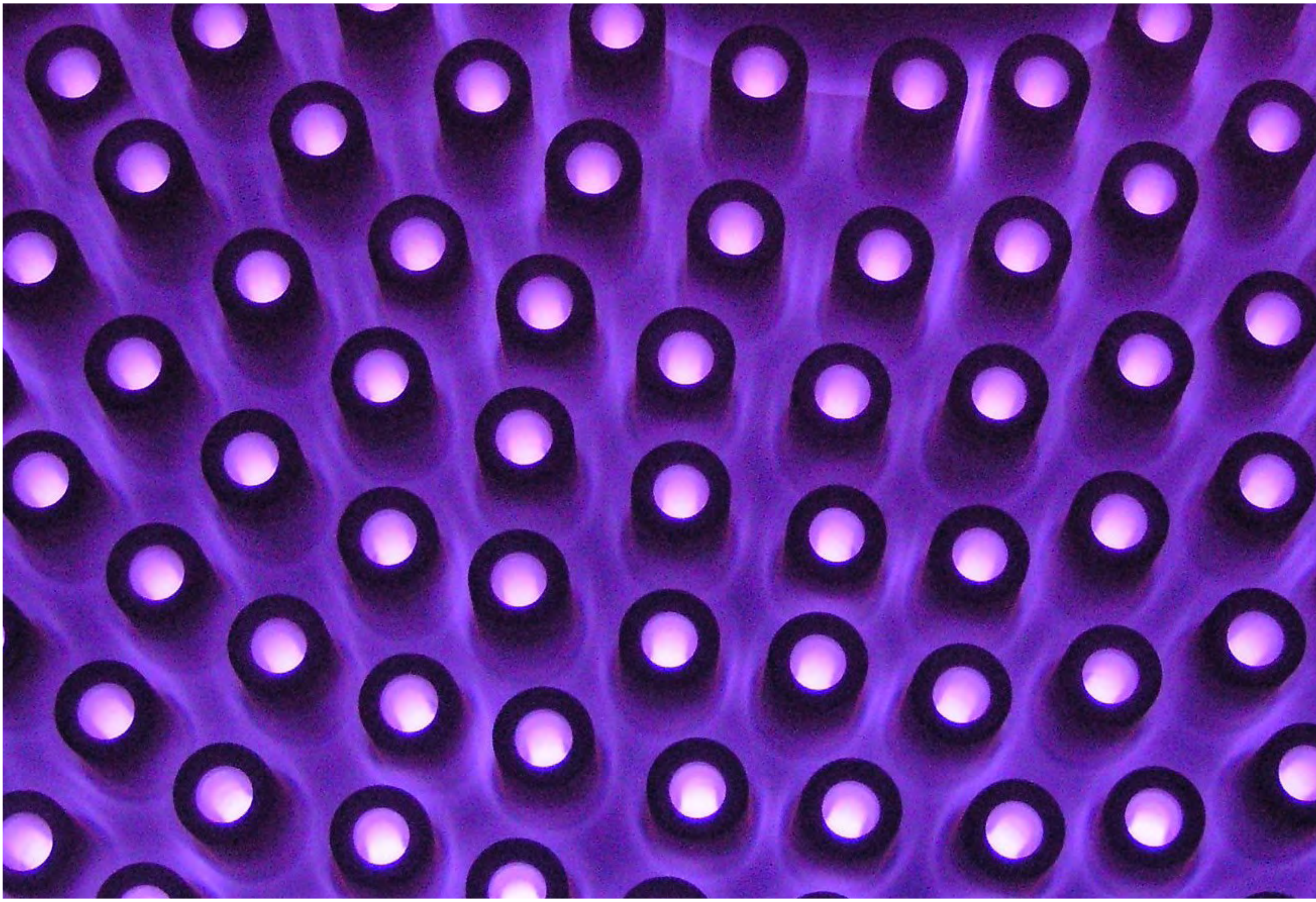


Figure 6: At 5000x, SEM view shows micro-void formed by MnS inclusion as well as a fragment of the inclusion left behind



Carburizing and Nitriding Treatment Modeling

By Nicolas Poulain

The finite element method can provide insights needed by engineers to calibrate thermal processes, whether it's carburizing or nitriding, and maximize the benefits of the heat treatment.

Carburizing and nitriding treatments have the same goal: increase hardness on the surface while keeping the core ductility. Carburizing is a process where the part is placed in a confined environment regulated by its carbon content. By adjusting the parameters such as temperature and time, the carbon will diffuse into the part to a certain thickness. While the carbon content (%C) is fairly known at the locations where the carbon has diffused, it is harder to anticipate how far the carbon has diffused. The nitriding process uses the same concept but with nitrogen instead of carbon. The simulation of this process is helpful for the engineer to optimize the process. This article presents two examples to illustrate the carburizing and nitriding heat treatment processes.

CARBURIZING OF A BEVEL GEAR

The bevel gear is a typical mechanical part produced in large quantities. This component will have to sustain continuous loading and unloading cycles generated by the contact with another moving metallic (hard) part (see Figure 1a). To avoid both damage of the surface and fatigue cracks, hardness on the surface and ductility in the core of the material are required.

Although high-carbon steel would bring the requested surface toughness, fatigue properties would likely not be acceptable. On the other hand, low carbon could manage fatigue but marks would soon show on the surface. A possible solution to this dilemma is to use different carbon content on a different area of the part. This can be achieved

Figure 1a

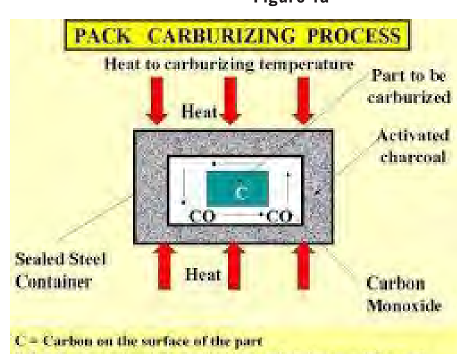
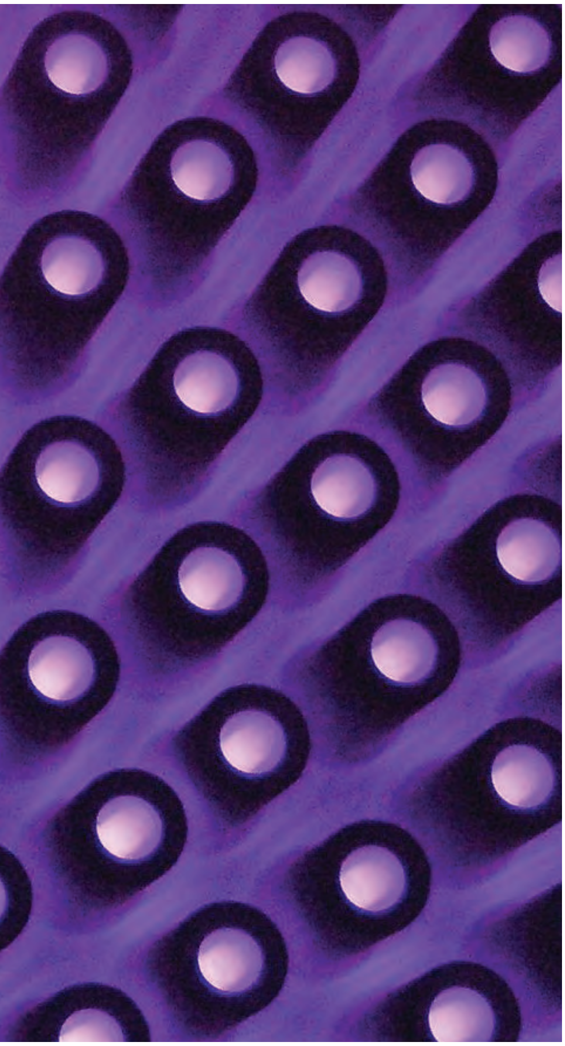


Figure 1b



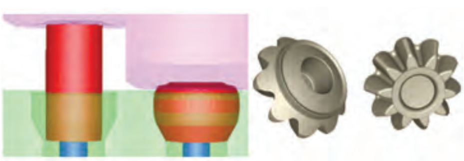


Figure 2

through the carburizing process (see Figure 1b). A low-carbon steel is maintained in a container filled with high-temperature carbon monoxide. After several hours, the carbon content increases on the surface area of the part, providing the expected properties.

Net shape or near net shape is the forging of choice for such a part, which implies the use of a cold or warm forging process. In the presented example, the forging is a two-stage warm forging followed by the piercing of the central hole (see Figure 2). Simulations have been performed with Transvalor's FORGE® simulation package. An elasto-visco-plastic material model was used, and flow curves come from JMatPro® simulation software (Sente Software).

The challenge for the simulation, apart from having the proper models to describe the diffusion of the carbon element into the part, is the software's ability to refine the mesh in the areas where the diffusion occurs. The FORGE software's unique capability to deal with large mesh with short computational time is key for this type of simulation.

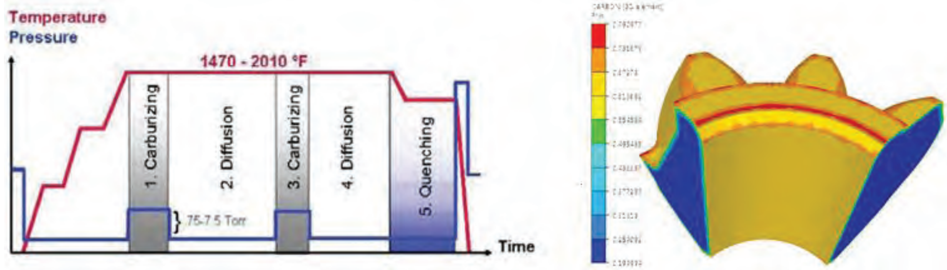


Figure 3

At each time step, the carbon content is updated based upon the solution of a diffusion-type equation.

$$\partial C \partial t = \nabla . (D . \nabla C) \qquad \text{Equation 1}$$

In Equation 1, C is the carbon content and D is the diffusivity, which varies as a function of the temperature. The input data used for the simulation setup are the furnace temperature and carbon content. Typical temperature cycle is shown in Figure 3, as well as carbon distribution at the end of the process.

The increase in carbon content has a positive effect on the quenchability of the part. Figure 4 shows the quenchability difference between a 0.2% carbon steel and a 0.7% carbon steel content. As shown in Figure 4, for a 10-second cooling, a low-carbon steel (0.2%C) produces ferrite, then pearlite and Bainite, while a high-carbon steel (0.7%C) produces martensite only.

The result of the carburizing has been used as an input for the quenching simulation with heat transfer coefficients (HTC) corresponding to the typical oil quenching used for this type of bevel gear. The results show that the martensite phase has been created on the surface and other phases in the core (see Figure 5). Figure 5 also shows the residual stress (first principal stress) distribution after quenching, with blue showing the compression and red showing the tension.

With the FORGE software, the evolution of metallurgical structures according to time is represented by a TTT (temperature-time-transformation) diagram. This diagram is obtained in an isothermal quenching condition. It gathers the curves that connect the corresponding points at each required temperature:

- Starting transformation time
- Ending transformation time
- Intermediate times corresponding to intermediate rates (10 percent, 90 percent)

In reality, quenching is never purely isothermal. The FORGE software uses an approach based on the additivity principle, which consists of breaking the thermal process down into elementary stages. The theory was introduced by W.I. Pumphrey and F.W. Jones and used by C. Aliaga. This approach, called "fictitious time," separates incubation and growth. Growth will start when incubation, defined by the Scheil model, has ended.

The last step of this study was the tempering. The purpose of this stage is to release residual stresses created during the quenching process. To achieve that, the part is held at a warm temperature (150°C to 200°C) for a certain time. A longer time in the furnace leads to higher temperature and homogenization of the temperature in the part, which in turn leads to higher efficiency for stress relaxation and hardness reduction. The objective of the engineer through the simulation is to find the right balance between hardness and residual stresses. To simulate this process, the Jaffe-Gordon tempering model has been implemented and coupled with material behavior adapted to a very low strain rate. Figure 6 shows the results obtained with typical time and temperature values. It can be seen that both stress relaxation and hardness decrease significantly.

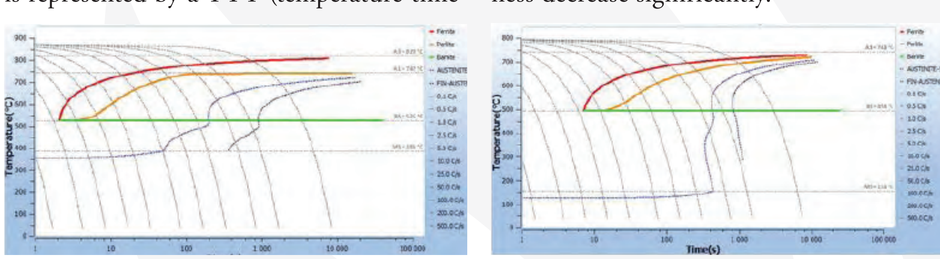


Figure 4

NITRIDING OF AN AEROSPACE GEAR

Nitriding can be applied on various metals under various conditions. It consists mostly in diffusing nitrogen into the surface of a steel part at about 550°C to harden the surface and improve its mechanical properties. This process has many advantages for fatigue, wear, friction, corrosion, and a relatively good assessment of the induced distortions. However, this process remains long and expensive, with about 100 hours of nitriding treating, less than 1 mm in depth.

On the surface, a thin white layer from 0 to 30 microns composed of nitride ε and nitride γ' is formed. Nitrogen diffuses from this white layer in a solid solution of ferrite to form what is called the diffusion layer, which is about 0.1 mm to 1 mm thick (see Figure 7). Some of this freely diffusing nitrogen element precipitates with various elements of the alloy, including carbon. The carbon diffusion plays an important role, even without carbon enrichment of the part. Because of nitrogen and carbon precipitates, the gradient created in the freely diffusing carbon generates a diffusion of the dissolved carbon, which can modify the chemical composition of the alloy at equilibrium. The presence of nitrogen precipitates is the reason for hardening and the generation of compressive stresses.

This study was part of the Definit project, which consisted of adapting the dedicated 1D nitriding simulation tool, developed at ParisTech university, to a fully industrial 3D simulation package (FORGE), and challenging against the experiments. For the finite element method (FEM) simulation, the problem is solved by adding several variables at each element: content of free nitrogen elements, free carbon elements (free means dissolved here, free to diffuse), and the content of phases and precipitates. The evolution of free carbon and nitrogen contents is computed at each node by solving two diffusion problems, described by the diffusion-type equation previously mentioned. *C* represents the chemical element concentration free to diffuse (carbon or nitrogen), and *D* represents the diffusivity.

$$\partial C/\partial t=\mathrm{div}(D\,\overrightarrow{\mathrm{grad}}(C)) \quad \text{Equation 2}$$

The composition of the metal in the element is computed depending on temperature, carbon content, and nitrogen content. Precipitates can form or dissolve, also modifying the free carbon and nitrogen contents. All data needed to compute the metal evolution can be obtained with JMatPro or ThermoCalc® software. The chemical composition computed at each mesh element enables local volume variation computation and hardness estimations. This type of computation, as explained earlier, requires a fine mesh in order to gather accurate results. In this example, the mesh size must be at least smaller than 0.2 mm for a 1 mm diffusion layer.

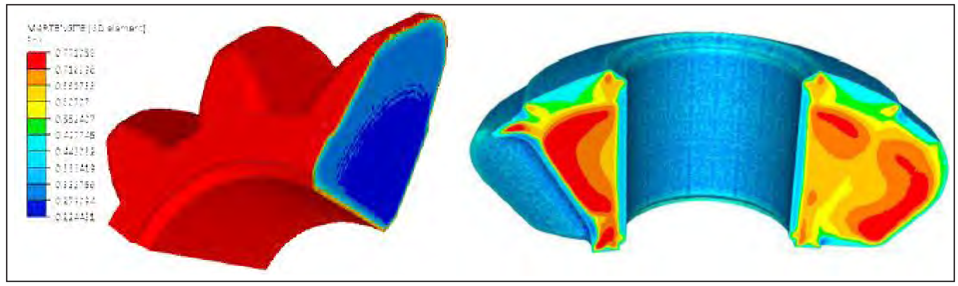


Figure 5

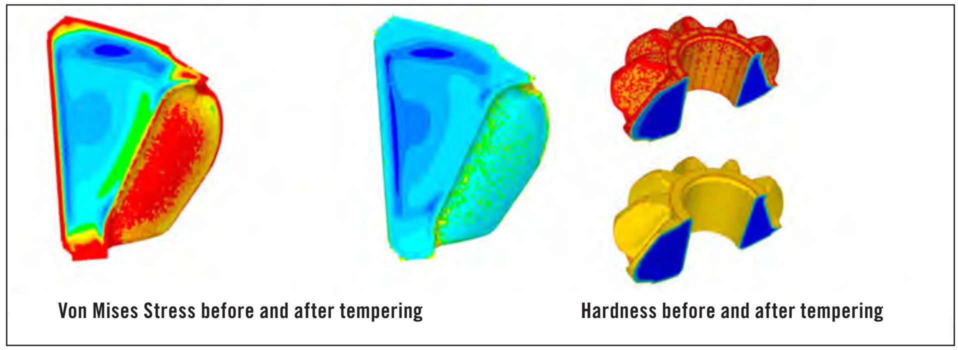


Figure 6

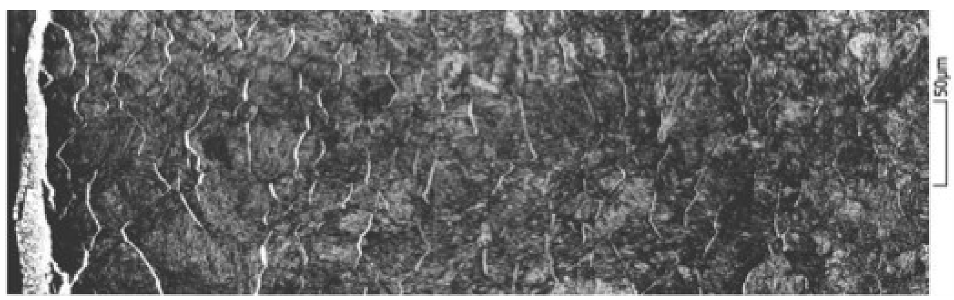


Figure 7

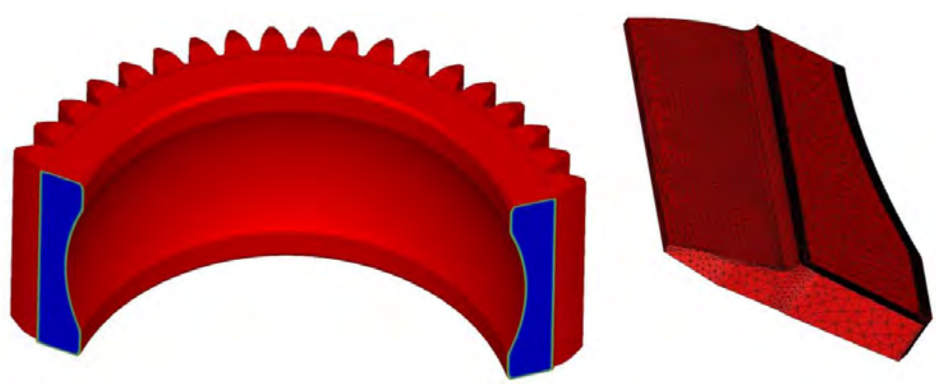


Figure 8

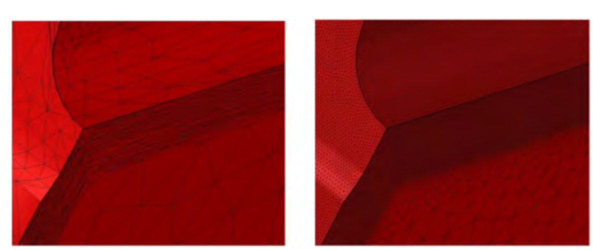


Figure 9

With courtesy of Airbus Helicopters (one of the partners in the Definit project), the results obtained on a fully nitrided gear are presented in Figure 8.

For the simulation standpoint, the anisotropic re-meshing is key to describe the phenomenon occurring within the diffusion layer. With the automatic re-meshing technique available in the FORGE software, a mesh size of 0.05 mm can be reached for a total of 22,000 nodes in the mesh. In comparison, 1.5 million nodes total with an isotropic mesh would be needed to obtain the same precision. Figure 9 shows the comparison of meshes, with the anisotropic mesh on the left and the isotropic mesh on the right-hand side.

With the results of the free carbon and free nitrogen diffusion in the material, the new chemical composition of the metal and the presence of precipitates in the diffusion layer can be computed. Figure 10 shows the carbon, nitrogen, and precipitate contents as a function of depth in the graph with the location of each component on the left-hand side.

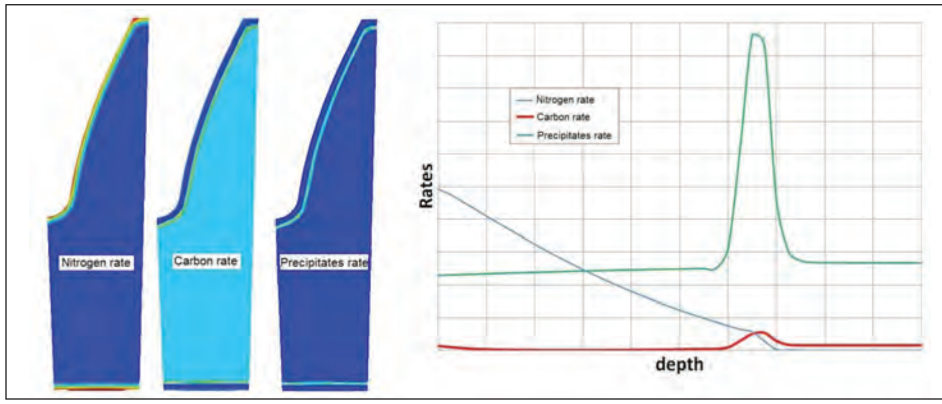


Figure 10

CONCLUSION

The benefits of simulation for forging processes are no longer challenged in the industry. After decades of development, forging is fairly well-simulated, but new challenges have emerged. The microstructure of the final parts is a crucial aspect of the forging that industrial manufacturers must master in order to compete. The weight reduction of the transportation systems is a major challenge for the forging industry, and the margin reduction prohibits the traditional trial and error on the shop floor. Simulation is the only way to obtain quick responses to these challenges with limited investment.

The two industrial studies presented here have been performed with the commercial software FORGE. It shows that developments from the research have been implemented successfully and are now available for industrial manufacturers. New projects will lead simulation to new challenges that will need to be tackled through shared efforts from the research and the commercial simulation software vendors.

ABOUT THE AUTHOR: Nicolas Poulain received his degree in material science from Polytech Montpellier, France, in 2005 and received his Master of Business Administration (MBA) degree from University of Phoenix in 2013. He has over 10 years of experience in FEM solutions for material forming simulations. Poulain is the technical manager for Transvalor Americas Corp., a subsidiary of Transvalor SA in Americas, based in Chicago, Illinois. Transvalor has been a key player in the material forming simulation industry since 1984. The company has a tight partnership with the French School of Mines Lab (CEMEF) where more than 100 scientists work with industrial partners on material physics and physical/mechanical modeling. Transvalor's material forming simulation software portfolio spans solid and liquid metals as well as polymers and a number of industries (forging, cold forming, metal casting, and injection molding). For more information, go to www.transvalor.com.

Heat Treat Equipment – REF #101
Phone: 734-331-3939 • Fax: 734-331-3915
Email: john@heattreatequip.com
Website: www.heattreatequip.com

Premier Furnace/BeaverMatic Inc. – REF #102
23850 Freeway Park Drive
Farmington Hills, Michigan 48335
Phone: 248-596-9000 • Fax: 248-596-9001
Email: sales@premierfurnace.com

The W.H. Kay Company – REF #103
30925 Aurora Road, Cleveland, OH 44139
Phone: 440-519-3800 • Fax: 440-519-1455
Email: sales@whkay.com
Website: www.whkay.com

Park Thermal – REF #104
257 Elmwood Ave #300, Buffalo, NY 14222
Phone: 905-877-5254 • Fax: 905-877-6205
Email: jmistry@parkthermal.com
Website: www.parkthermal.com

BATCH OVENS & BOX TEMPERING FURNACES

54" wide x 72" long x 84" high, Despatch Walk-In Oven Gas, 500 F. **REF #102**
8" 18" 8" Lucifer Elec. 1250 F. **REF #103**
12" 16" 18" Lindberg Elec. 1200 F. **REF #103**
12" 16" 18" Lindberg (3) Elec. 1250 F. **REF #103**
30" 48" 22" Dow Elec. 1250 F. **REF #103**
34" 19" 33" Poll.Ctrls Burnoff Gas 900 F. **REF #103**
36" 36" 35" Despatch Elec. 400 F. **REF #103**
36" 36" 120" Steelman Elec. 450 F. **REF #103**
36" 48" 36" Grieve Elec. 350 F. **REF #103**
36" 60" 36" CEC (2) Elec. 650 F. **REF #103**
37" 19" 25" Despatch Elec. 500 F. **REF #103**
37" 25" 37" Despatch Elec. 850 F. **REF #103**
37" 25" 50" Despatch Elec. 500 F. **REF #103**
38" 20" 24" Blue-M Elec. 1200 F. **REF #103**
38" 26" 38" Grieve Elec. 1000 F. **REF #103**
48" 24" 48" Blue-M Elec. 600 F. **REF #103**
48" 30" 42" Despatch Gas 850 F. **REF #103**
48" 48" 48" CEC (N2) Elec. 1000 F. **REF #103**
48" 48" 60" Gasmac Burnoff (2) Gas 850 F. **REF #103**
48" 48" 72" Despatch (2) Elec. 500 F. **REF #103**
48" 48" 72" Lydon Elec. 500 F. **REF #103**
54" 108" 72" Despatch Elec. 500 F. **REF #103**
56" 30" 60" Gruenberg Elec. 450 F. **REF #103**

BOX FURNACES

J.L. Becker Slot Forge Furnace, 1986, Brand New, Never Used **REF #101**
L & L Special Furnace Electrically Heated Box Furnace, 1991 **REF #101**
J.L. Becker Box Temper Furnace, 1989 **REF #101**
Sunbeam Electric Box Furnace, good running condition **REF #101**
Surface 30-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Surface Combustion 30-48-30 Gas Fired Temper Furnace, good/ very good condition **REF #101**
Surface 30-48-30 Gas Fired Temper Furnace, good/ very good condition **REF #101**
24" wide x 48" long x 18" high, Lindberg batch temper, Gas, 1400 F. **REF #102**
30" wide x 48" long x 26" high, BeaverMatic batch temper, Gas, 1400 F. **REF #102**
8" 18" 8" Blue-M Elec. 2000 F. **REF #103**
12" 24" 8" Lucifer-Up/Down (Retort) Elec. 2150/1400 F. **REF #103**
12" 24" 8" C.I. Hayes (Atmos) Elec. 1800 F. **REF #103**
12" 24" 12" Hevi-Duty (2) Elec. 1950 F. **REF #103**
12" 24" 12" Lucifer-Up/Down Elec. 2400/1400 F. **REF #103**
3" 24" 12" Electra-Up/Down Elec. 2000/1200 F. **REF #103**
15" 30" 12" Lindberg (Atmos) - Retort Elec. 2000 F. **REF #103**
17" 14.5" 12" L & L (New) Elec. 2350 F. **REF #103**
22" 36" 17.5" Lindberg (Atmos) Elec. 2050 F. **REF #103**
24" 36" 18" Thermnlyne (2) - Unused Elec. 1800 F. **REF #103**
36" 48" 24" Sunbeam (N2) Elec. 1950 F. **REF #103**
36" 72" 42" Eisenmann Kiln (Car) Gas 3100 F. **REF #103**
60" 48" 48" Recco (1998) Gas 2000 F. **REF #103**
60" 96" 60" Park Thermal Elec. 1850/2200 F. **REF #103**
126" 420" 72" Drever "Lift Off"-Atmos (2 Avail) Gas 1450 F. **REF #103**
13" 14" 12" ELECTRIC 1300°F **REF #104**
10" 10" 18" ELECTRIC 2000°F **REF #104**
22" 36" 22" ELECTRIC 1600°F **REF #104**
12" 6" 8" ELECTRIC 2000°F **REF #104**
12" 8" 18" ELECTRIC 2800°F **REF #104**
20" 13" 36" ELECTRIC 1850°F **REF #104**
12" 18" 18" ELECTRIC 1250°F **REF #104**
4" 10" 4" ELECTRIC 2000°F **REF #104**
22" 10" 8" ELECTRIC - C/W STAND 1250-2000°F **REF #104**
15" 8" 30" ELECTRIC - ATMOSPHERE 1950°F **REF #104**
11" 11" 17" ELECTRIC - CABINET 2000°F **REF #104**
33" 40" 48" ELECTRIC 500°F **REF #104**
18" 18" 30" ELECTRIC - GLO BAR 2900°F **REF #104**
30" 30" 54" ELECTRIC - AGING 500°F **REF #104**
30" 30" 54" R ELECTRIC - AGING 500°F **REF #104**
30" 30" 54" ELECTRIC 500°F **REF #104**
24" 18" 24" NATURAL GAS - BATCH FURNACE **REF #104**
24" 18" 24" NATURAL GAS - BATCH FURNACE **REF #104**
36" 30" 84" ELECTRIC 1200°F **REF #104**
24" 24" 24" ELECTRIC 2000°F **REF #104**
29" 22" 36" NATURAL GAS 1250°F **REF #104**
12" 11" 24" ELECTRIC - BOX 2000°F **REF #104**
24" 24" 24" ELECTRIC - GAS MAC 850°F **REF #104**
18" 12" 12" ELECTRIC 2100°F **REF #104**
48" 30" 36" ELECTRIC - ATMOSPHERE TEMPERING **REF #104**
50" 24" 29" NATURAL GAS 1250°F **REF #104**
36" 18" 24" ELECTRIC 1250°F **REF #104**
17" 17" 36" NATURAL GAS 1250°F **REF #104**
15" 6" 10" ELECTRIC 1850°F **REF #104**
6" DIA 48" ELECTRIC - TUBE FURNACE 1200°C **REF #104**
7" 4" 14" GAS **REF #104**
10" DIA 18" GAS - FORGE FURNACE **REF #104**
9" 6" 15" GAS - FORGE FURNACE **REF #104**
6" 6" 15" GAS - FORGE FURNACE **REF #104**
12" 10" 20" ELECTRIC - SPEEDY MELT FURNACE 2000°F **REF #104**
12" 9" 18" ELECTRIC **REF #104**
12" 12" 18" NATURAL GAS 1250°F **REF #104**
14" 14" 18" ELECTRIC - GLOBAR 2500°F **REF #104**
17" 17" 17" ELECTRIC - HITEMP KILN 2200°F **REF #104**
35" 24" 60" ELECTRIC 1430°F **REF #104**
10" 9" 14" ELECTRIC - FRONT DOOR LOADING 2000°F **REF #104**
12" 12" 24" ELECTRIC - 13KW 2300°F **REF #104**
12" 12" 24" ELECTRIC - 20KW 2000°F **REF #104**
18" 12" 24" ELECTRIC 2000°F **REF #104**
36" 24" 56" ELECTRIC 800°F **REF #104**
24" 24" 36" ELECTRIC - CYCLONE 1250°F **REF #104**
24" 36" 30" ELECTRIC RE-CIRC. BOX FURNACE 2000°F **REF #104**
18" 20" 45" ELECT. RE-CIRC. W/ FLAME CURTAIN & BASKET 2000°F **REF #104**
12" 12" 18" ELECT. RE-CIRC. BATCH (MATCH PAIR WITH I3958) 1250°F **REF #104**
12" 12" 18" ELECT. RE-CIRC. BATCH (MATCH PAIR WITH I3957.) 1250°F **REF #104**

CAR BOTTOM FURNACES

Holcroft 48-144-48 Car Bottom Furnace **REF #101**
Sauder 48-144-48 Car Bottom Furnace **REF #101**
48" 48" 72" GAS FIRED CAR BOTTOM 2000°F **REF #104**
130" 72" 216" GAS FIRED CAR BOTTOM 2000°F **REF #104**
130" 72" 215" GAS FIRED CAR BOTTOM 2400°F **REF #104**
108" 36" 192" GAS FIRED CAR BOTTOM 2400°F **REF #104**
72" 48" 216" GAS FIRED CAR BOTTOM 2000°F **REF #104**

CHARGE CARS

Surface Combustion 30-48 Charge Car (Double Ended), fairly good condition **REF #101**
Atmosphere Furnace Company 36-48 Charge Car (Double Ended) **REF #101**
Surface Combustion 30-48 Charge Car (Double Ended) **REF #101**

CONTINUOUS ANNEALING FURNACES

Wellman Continuous Mesh Belt Annealing Furnace **REF #101**
Aichelin-Stahl Continuous Roller Hearth Furnace & Conveying System, 1996 **REF #101**
Park Thermal Continuous Mesh Belt Furnace, 2005, Excellent Condition – New – Never been used **REF #101**

CONTINUOUS HQT FURNACES

Tokyo Gasden Ro Continuous Mesh Belt HQWT Furnace Line, 1989 **REF #101**

CONTINUOUS TEMPERING FURNACES

Surface Combustion Mesh Belt Temper Furnace **REF #101**
J.L. Becker Conveyor-Type Temper Furnace with Ambient Air Cool Continuous Belt, 1997 IQ Furnaces **REF #101**
Surface Combustion 30-48-30 Pro-Electric IQ Furnace **REF #101**
AFC 36-48-30 IQ Furnace with Top Cool **REF #101**
AFC 36-48-30 IQ Furnace **REF #101**
Surface Combustion 30-48-30 IQ with Top Cool, Excellent Condition, 2000 **REF #101**
Surface Combustion 30-48-30 IQ Furnace, Excellent Condition **REF #101**

DRAW TEMPER FURNACES

24" wide x 48" long x 18" high, Lindberg batch temper, Gas, 1400 F **REF #102**
30" wide x 48" long x 26" high, BeaverMatic batch temper, Gas, 1400 F (NEW) **REF #102**
18" 12" 30" ELECTRIC 1250°F **REF #104**
16" 15" 12" ELECTRIC - BOX DRAW 1250°F **REF #104**
36" 16" 24" ELECTRIC - BOX DRAW 1250°F **REF #104**
12" 18" 16" ELECTRIC - BOX DRAW 1400°F **REF #104**
30" 20" 48" ELECTRIC - BOX DRAW 1250°F **REF #104**
24" 18" 36" NATURAL GAS ROLLER DRAW 1400°F **REF #104**
30" 30" 48" NATURAL GAS 1200°F **REF #104**
60" 40" 60" NATURAL GAS - DRAW FURNACE 800°F **REF #104**
29" 16" 36" ELECTRIC - DRAW/TEMPER 1400°F **REF #104**
54" 54" 150" ELECTRIC 900°F **REF #104**
24" 18" 10 FEET ELECTRIC 500°F **REF #104**
30" 24" 72" GAS - GRAVITY FEED DRAW 1350°F **REF #104**
12" 14" 12" ELECTRIC - WATER COOLED FAN 1200°F **REF #104**

ENDOTHERMIC GAS GENERATORS

- Lindberg 1500 CFH Endothermic Gas Generator, 1992, good condition … **REF #101**
- Lindberg 1500 CFH Endothermic Gas Generator, 1996, excellent condition … **REF #101**
- Surface Combustion 5600 CFH Endo. Gas Generator … **REF #101**
- Surface Combustion 5600 CFH Endo. Gas Generator … **REF #101**
- Surface Combustion 5600 CFH Endo. Gas Generator … **REF #101**
- Surface Combustion 5600 CFH Endo. Gas Generator … **REF #101**
- Rolock Inc. 2000 CFH Endothermic Gas Generator … **REF #102**

EXOTHERMIC GAS GENERATORS

- J.L. Becker 12,000 CFH Exothermic Gas Generator w/ Dryer, w … **REF #101**
- Thermal Transfer 30,000 CFH Exothermic Gas Generator, 1994, excellent condition … **REF #101**
- Seco Warwick 2000 CFH Exothermic Gas Generator … **REF #102**
- Sunbeam 2000 CFH Exothermic Gas Generator … **REF #102**
- Alhern 6000 CFH Exothermic Gas generator … **REF #102**
- J L Becker 6000 CFH Exothermic Gas Generator … **REF #102**
- JL Becker 6000 CFH Exothermic Gas Generator … **REF #102**

FLUIDIZING BED FURNACE

- 14” 30 DIA 5” ELECTRIC 1600ºF … **REF #104**

FREEZERS

- Webber 36-48-36 Chamber Freezer, 1980 … **REF #101**
- Cincinnati Sub Zero 36-48-36 Chamber Freezer, 1995 … **REF #101**

MESH BELT FURNACES

- 17” 8” 10’ ELECTRIC 600ºF … **REF #104**
- 23” 4” 10’ NATURAL GAS 1250ºF … **REF #104**
- 24” 12” 96” ELECTRIC 500ºF … **REF #104**

MESH BELT BRAZING FURNACES

- Lindberg Continuous Mesh Belt Brazing Furnace … **REF #101**
- J.L. Becker 26” Mesh Belt Brazing Annealing Furnace, 2007 … **REF #101**
- 10” J.L. Becker Mesh Belt Furnace with Muffle, 1988 … **REF #101**
- 24” J.L. Becker Mesh Belt Furnace … **REF #101**
- Premier Furnace 14” wide mesh belt Aluminum Brazing Furnace 1400 F … **REF #102**
- Alhern 20” wide mesh belt Copper Brazing, Annealing Furnace 2100 F … **REF #102**
- J L Becker 20” wide mesh belt Copper Brazing, Annealing Furnace 2100 F. … **REF #102**
- JL Becker 20” wide mesh belt Copper Brazing, Annealing Furnace 2100 F. … **REF #102**
- Alhern 28” wide mesh belt Copper Brazing, Annealing Furnace 2100F. … **REF #102**

MISC. EQUIPMENT

- Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36”W x 48”L work area … **REF #101**
- Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36”W x 48”L work area … **REF #101**
- Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36”W x 48”L work area … **REF #101**
- Atmosphere Furnace Co. 36-48 Scissors Lift Holding Stations, 1987, 36”W x 48”L work area … **REF #101**
- Atmosphere Furnace Co. 36-48 Scissors Lift Holding Stations, 1987, 36”W x 48”L work area … **REF #101**
- Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers … **REF #101**
- Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers … **REF #101**
- Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers … **REF #101**
- Surface Combustion 30-48 Scissors Lift Table, 48-inch rail length … **REF #101**
- Airco Flo meter panel# 1 … **REF #102**
- Airco Flo meter panel# 2 … **REF #102**
- Smart Skim unit … **REF #102**
- 8xxx 2.400 CFH 12 oz (2) North American 1/3HP … **REF #103**
- 8xxx 3.000 CFH 12 oz (3) North American 1/2HP … **REF #103**
- 8xxx 5.400 CFH 4 oz North American 1/3HP … **REF #103**
- 8236 12.000 CFH 12oz (3) North American 1/2HP … **REF #103**
- 8712 15.600 CFH 37 oz, North American 5HP … **REF #103**
- 8193 19.500 CFH 32 oz, Spencer 5HP … **REF #103**
- 8245 23.400 CFH 8 oz. North American 1,5HP … **REF #103**
- 8185 24.000 CFH 24 oz. Buffalo Forge 7.5HP … **REF #103**
- 8251 45.600 CFH 16 oz. Spencer 5HP … **REF #103**
- 8252 66.000 CFH 24 oz . Snencer(New) 10HP … **REF #103**
- 8253 66.000 CFH 24 oz. Spencer 10HP … **REF #103**
- 8250 150.000 CFH 16 oz. Hauck 15HP … **REF #103**

OVER - UNDER FURNACES

- 12” 11” 48” GLO BAR ELECTRIC 3000ºF … **REF #104**
- 9.5” 9.5” 18” COILED ELEMENTS ELECTRIC 2300ºF … **REF #104**
- 22” 11” 14” COILED ELEMENTS ELECTRIC 2200ºF … **REF #104**
- 12” 7” 30” ELECTRIC - CRESS … **REF #104**
- 18” 12” 24” ELECTRIC 2100/1250ºF … **REF #104**
- 12” 12” 36” ELECTRIC 2300/1250ºF … **REF #104**

PARTS WASHERS

- J.L.Becker Gas-Fired Tub Washer … **REF #101**
- 48-72-48 Gas Fired Spray Washer … **REF #101**
- Dow Furnace Co. 30-48-30 Electrically Heated Spray, Dunk & Agitate Washer … **REF #101**
- Atmosphere Furnace Co. 36-48-30 Spray/Dunk Washer **REF #101**
- Atmosphere Furnace Co. 36-48-30 Spray/Dunk Washer **REF #101**
- Surface Combustion 30-48-30 Electrically Heated Spray Dunk/ Dunk Washer … **REF #101**
- Surface Combustion 30-48-30 Electrically Heated Washer … **REF #101**

PIT FURNACES

- Lindberg 28” x 28” Pit-Type Temper Furnace … **REF #101**
- 14” 60” Procedyne - Fluidised Bed Elec. 1850 F. … **REF #103**
- 16” 20” Lindberg Elec. 1250 F. … **REF #103**
- 22” 26” L & N Elec. 1200 F. … **REF #103**
- 28” 48” Lindberg Elec. 1400 F. … **REF #103**
- 38” 48” Lindberg Elec. 1400 F. … **REF #103**
- 40” 60” L & N -Steam/N2 Elec. 1400 F. … **REF #103**
- 40” 60” Wellman-Steam/N2 Elec. 1400 F. … **REF #103**
- 48” 48” Lindberg (Atmos) - Fan Elec. 1850 F. … **REF #103**
- 20” 48” ELECTRIC 1200ºF … **REF #104**
- 30” 36” NATURAL GAS 1250ºF … **REF #104**
- 24” 30” ELECTRIC 1400ºF … **REF #104**
- 16” 18” GAS - CYCLONE 1300ºF … **REF #104**
- 28” 96” NATURAL GAS 1400ºF … **REF #104**
- 24” 28” ELECTRIC - HOMO CARBURIZING 1400ºF … **REF #104**
- 16” 30” ELECTRIC SALT POT 1650ºF … **REF #104**
- 22” 36” 22” ELECTRIC SQUARE PIT 1600ºF … **REF #104**
- 6” 4” 16” ELECTRIC VACUUM PIT 2400ºF … **REF #104**
- 24” 24” ELECTRIC 1400ºF … **REF #104**
- 12” dia 18” ELECTRIC - HOMO PIT 1200ºF … **REF #104**
- 30” 30” 30” ELECTRIC 800ºF … **REF #104**
- 30” DIA 30” ELECTRIC - PIT CYCLONE 1250ºF … **REF #104**
- 12” 20” ELECTRIC - KEYHOLE 1250ºF … **REF #104**
- 4.5” 24” 4” ELECTRIC - SQUARE PIT … **REF #104**
- 24” 48” 24” ELECTRIC - SQUARE PIT 1200ºF … **REF #104**
- 18” 18” 18” ELECTRIC - TOP LOAD 2000ºF … **REF #104**
- 16” Dia. 20” ELECTRIC - CYCLONE 1250ºF … **REF #104**
- 22” Dia 26” ELECTRIC - CYCLONE 1250ºF … **REF #104**
- 22”Dia 26” ELECTRIC 1250ºF … **REF #104**
- 8”dia 9”deep ELECTRIC - TEMPERING 1250ºF … **REF #104**
- 35” 60” GAS … **REF #104**
- 28”DIA 28” ELECTRIC - CYCLONE PIT 1250ºF … **REF #104**

VACUUM FURNACES

- Brew/Thermal Technology Vacuum Furnace … **REF #101**
- Abar Ipsen 2-Bar Vacuum Furnace, 1986, good condition … **REF #101**
- 24”W x 36”D x 18”H Hayes (Oil Quench) Elec. 2400 F. … **REF #103**
- 48” Dia 60” High Ipsen (Bottom Load) Elec. 2400 F. … **REF #103**

ATMOSPHERE GENERATORS

- 750 CFH Endothermic Dow Elec. … **REF #103**
- 750 CFH Endothermic Insen Gas … **REF #103**
- 1000 CFH Exothermic Gas Atmosphere … **REF #103**
- 1000 CFH Ammonia Dissociator Lindberg Elec. … **REF #103**
- 1000 CFH Ammonia Dissociator Drever Elec. … **REF #103**
- 1500 CFH Endothermic (Air Cooled) Ipsen Elec. … **REF #103**
- 1500 CFH Endothermic Ipsen Gas … **REF #103**
- 3000 CFH Endothermic air Cooled) Lindberg Gas … **REF #103**
- 3000 CFH Endothermic (Air Cooled) Lindberg (2) Gas … **REF #103**
- 3000 CFH Endothermic (Air Cooled) Lindhera Gas … **REF #103**
- 3600 CFH Fnclothermic (Air Cooled) Surface (2) Gas … **REF #103**
- 3600 CFH Endothermic Surface Gas … **REF #103**
- 5600 CFH Endothermic Surface (3) Gas … **REF #103**
- 6000 CFH Nitrogen Generator (2000) Gas Atmospheres Gas … **REF #103**
- 10 000 CFH Exothermic Seco-Warwick Gas … **REF #103**

INTERNAL QUENCH FURNACES

- 24 inch wide, 48 inch long, 18 inch high, Lindberg, Gas, 1850 F. … **REF #102**
- 24”W 36”D 18”H Dow (Slow Cool) Line Elec. 2000 F. … **REF #103**
- 24”W 36”D 1 8”H Ispen T-4 - Air Cooled Gas 1850 F. … **REF #103**
- 24”W 36”D 18”H Ispen T-4 - Air Cooled Gas 1850 F. … **REF #103**
- 24”W 36”D 18”H Isoen T-4 - Air Cooled Gas 1850 F. … **REF #103**
- 24”W 36”D 18”H Ispen T-4 - Air Cooled Gas 1850 F … **REF #103**
- 30”W 48”D 30”H Surface Allcase Elec. 1750 F. … **REF #103**
- 30” 30” 48” NATURAL GAS 1750ºF … **REF #104**
- 12” 10” 24” ELECTRIC - BABY PACEMAKER 1850ºF … **REF #104**
- 45” 40” 72” ELECTRIC - ALUMINUM QUENCH 1250ºF **REF #104**
- 12” 9” 18” IPSEN 2000ºF … **REF #104**
- 87” 36” 87” SURFACE COMBUSTION W/ 12,500G. QUENCH 1850ºF … **REF #104**
- 62” 36” 62” SURFACE COMBUSTION W/ 9,500G. QUENCH 1850ºF … **REF #104**
- 62” 36” 62” SURFACE COMBUSTION W/ 9,500G. QUENCH 1850ºF … **REF #104**
- 15” 12” 30” Electric c/w load carts 1850ºF … **REF #104**

CONTINUOUS/BELT FURNACES + OVENS

- 5”W 36”D 2”H BTU Systems (Inert Gas) Rec. 1922ºF … **REF #103**
- 12”W 48”D 2”H Lindberg (Inert Gas) Elec. 1022ºF. … **REF #103**
- 12”W 15’D 4”H Sargent&Wilbur’94(Mufflel) Gas 2100ºF. … **REF #103**
- 16”W 24’D 4”H Abbott-Retort (1996) Elec 2400ºF. … **REF #103**
- 24”W 12’D 6”H Heat Industries Elec. 750ºF. … **REF #103**
- 24”W 40’D 18”H Despatch Elec. 500ºF. … **REF #103**
- 60”W 45’D 12”H Roller Hearth Annealer (Atmos) Gas 1700ºF … **REF #103**

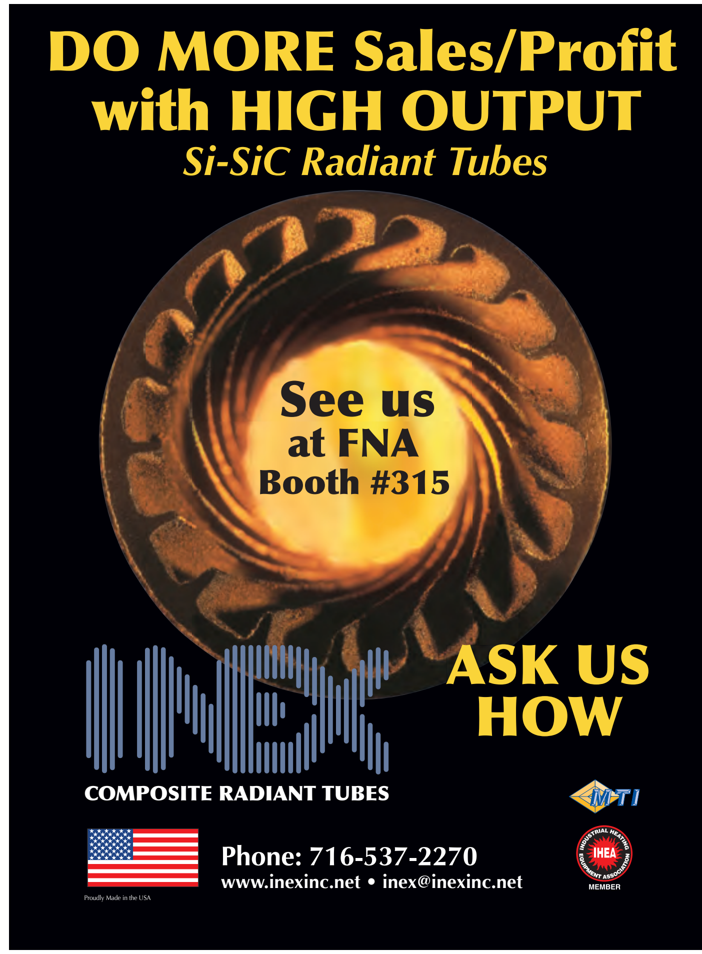
MARKETPLACE

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

AD INDEX

COMPANY NAME — PAGE NO.

Aerospace Testing & Pyrometry 13
AFC Holcroft .... BC
Ajax-Tocco Magnethermic.......... 14
ALD Thermal Treatment Inc.......... 1
Avion Manufacturing.......... 9
BOS Services Company 9, 50
Custom Electric Manufacturing.......... IBC
Dalton Electric Heating Co Inc 37
ECM-USA Inc.......... 43
EFD Induction 17
Fabtech '16 30
Heavy Carbon Company.......... 47
Induction Tooling, Inc. 42
Inductoheat.......... 50
Inex 51
Ipsen USA .... IFC, 50
Lindberg/MPH.......... 3
Lucifer Furnaces, Inc. 50
Pinson Valley Heat Treating 11, 50
Pinson Valley Heat Treating 50
Premier Furnace Specialists Inc.......... 5
Solar Atmospheres.......... 31, 50
Solar Manufacturing.......... 7
Specialty Steel Treating 35
Stor-Loc 50
The Duffy Company 47
The Herring Group Inc. 50
Thermo-Calc Software Inc 25
Verder Scientific Inc. 15
Wickert USA.......... 51



GEORGE BARBOUR
PRESIDENT, HEAVY CARBON CO. LLC

PLEASE TELL US A LITTLE ABOUT HEAVY CARBON CO.

The company began in 1995 as an idea for carburizing steel at a cleaner, faster rate of carbon penetration through a steel surface. This discovery was found many years earlier while building an experimental rotary retort furnace for General Motors. The mechanics of that furnace failed, but the atmosphere system for it was and still is successful, because while using a low flow of atmosphere with a high carbon potential, this atmosphere will penetrate a dense load of parts with a high carbon content without soot formation.

WHAT IS HEAVY CARBON CO.'S ENDOCARB SYSTEM?

In 1997, the Euclid Heat Treating Co. (EHT) was interested in a faster, cleaner atmosphere system and invited me to test out the Endocarb system at their plant. EHT has been helpful during the 15 years of testing. Using the same idea of creating an atmosphere in a rotary retort, the Endocarb unit with a retort is heated to a high temperature to crack an air/gas mixture before entry into the furnace. The high temperature used to crack the air/gas mixture is not lost because it is not cooled down as in a typical endogas operation with an endo generator. The temperature inside the Endocarb retort is always at 1825°F while an atmosphere reaction in a furnace may take place at a temperature as low as 1500°F. The higher reaction temperature will create a cleaner, more penetrating atmosphere. This is a big advantage for carburizing at a low temperature.

HOW WOULD MANUFACTURERS BENEFIT FROM THE ENDOCARB SYSTEM?

Unlike an endo generator, the Endocarb unit can be easily started and stopped at any time. There is almost no maintenance of this system with a long life expectancy, and the shorter carburizing cycles will use less power and gas.

The Endocarb system is crucial for the carburizing of large gears that require an effective case depth (ECD) over 0.1000 inch. At 0.1000-inch ECD and deeper, the carburizing time can be reduced by about seven hours a day without downtime for soot removal while improving the quality of the part. The deeper the case required, the bigger the savings. Carburizing time reduction starts at about 0.040 inch, but the Endocarb system improves other types of atmosphere heat treating as well.

HOW DOES THE ENDOCARB SYSTEM REDUCE CARBURIZING TIME?

The furnace must remain clean with an atmosphere that will remain reactive. Too much carbon will cause soot to form and interfere with the reaction. By cracking the atmosphere in a retort at a high temperature before entering the furnace makes it is easy to control the carbon potential, dew point, and CH_4. The Endocarb system is used to create this carburizing atmosphere. By using only a hydrocarbon gas and air in the Endocarb retort, it is possible to carburize with a carbon potential (CP) that is well into the soot range. Carbon control is a key factor for quality atmosphere. This atmosphere is different than using endogas from an outside endo generator as in standard carburizing. Standard carburizing will crack the atmosphere inside the furnace with a temperature that is normally lower than the 1825°F in the Endocarb retort. And as the CP rises in excess, air is entered to bring it down. The Endocarb unit creates its own carburizing atmosphere and controls it by changing the air/gas ratio that enters the retort. The only gas used in the Endocarb unit is what is needed to hold the CP as programmed — never too much. This saves gas.

Cracking the atmosphere in the retort and controlling the CP before entry into the furnace enables a higher CP use. The higher CP will create a higher rate of penetration into the steel surface. Thus, an ECD is reached up to about 30 percent faster. This means that less gas and power is used because less time is needed to reach the ECD. Using a boost/diffuse system also eliminates the need for a soot burnout every week. This boost/diffuse system is unique in that it is programmed to operate in half-hour increments with about two-thirds of that time in boost at a high CP and one-third in diffuse at a lower CP. The furnace is continuously purged of soot while maintaining a high CP in the load.

HOW IS THE BURNER TUBE PROTECTED AGAINST BURNOUT OR MELTDOWN?

A silicon carbide burner tube was installed in the Endocarb system. This allows for a higher operating temperature without fear of failure. Concern of losing the catalytic affect of the nickel in the alloy burner tube was overcome by installing small alloy rods with a high nickel content in the atmosphere area. This was easy to do, and it is easy to replace them if needed. It takes about one minute to replace one even at high temperatures. This idea could be used in a furnace if more catalytic action is needed.

TO TAKE ADVANTAGE OF THE BENEFITS OF USING THIS SYSTEM, HOW WOULD YOU APPROACH A FURNACE MANUFACTURER?

This system can be installed in most any carburizing furnace. A furnace manufacturer will not offer this system because it is not their equipment, but any furnace company is capable of installing it while building a new furnace if requested. The Endocarb system can make their furnace more productive, save time and money, and provide a short return on investment.

FOR MORE INFORMATION and to watch a video of the Endocarb system, go to www.heavycarbon.com

To Lower Your Gear Heat Treat Costs...THINK Custom Electric

When you need precise temperature control and heating compatible with any furnace atmosphere,
Think Custom Electric.

When you are looking to maximize electric furnace performance, reduce downtime and save money,
Think Custom Electric.

When you are looking for the best electric heating solutions, custom-built to your gear heating requirements,
Think Custom Electric.

Custom Electric designs and manufactures original equipment and replacement heating elements for any size or shape furnace. Our Ni/Cr and Fe/Cr/Al elements handle service temperatures up to 2500° F. Our rod overbend elements are precision formed on CNC machines for easy installation and replacement. Our expanded Midwest factory handles any size order and on-time-ships elements anywhere in North America.

Custom Electric has 44-years experience and a demonstrated performance record. Most importantly, we want to be your heating element supplier and will work hard to make this happen. Whenever you think about heat treating gears in electric furnaces,
Think Custom Electric.

®

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