Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

SINTERING / POWDER METALLURGY

COMMERCIAL SINTERING OF CHROMIUM POWDER METALLURGY STEELS

COMPANY PROFILE ///

Nitrex

JUNE 2020

thermalprocessing.com

CONTENTS ///

COVER PHOTO: SHUTTERSTOCK (2) / ILLUSTRATION BY RICK FRENNEA

DEPARTMENTS ///

UPDATE ///

New Products, Trends, Services & Developments

Q&A ///

ROBERT ANTOLIK

VP OF SALES /// APPLIED TEST SYSTEMS

RESOURCES ///

Industrial Heating Equipment Association (IHEA)

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

METAL URGENCY ///

Finite element modeling can help engineers choose the proper gas quenching process parameters to ensure mechanical properties are achieved while keeping distortion to an absolute minimum. **20**

HOT SEAT ///

Many issues can be solved with quick detection and determination of problem's cause, followed by prompt corrective action. **22**

QUALITY COUNTS ///

The goal is always to meet customer requirements. The canvas is the workplace, and the tools go beyond just controlling temperature, time, and atmosphere. Human interaction and tool knowledge are also required as theoretical and practical expectations blend to create the correct cycle. **26**

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

FROM THE EDITOR ///

We'll get through this – together

These past few months have definitely been a wild ride for not just the heat-treat industry, but the world in general.

Thermal Processing has not been immune to the repercussions of the COVID-19 pandemic, but in these challenging times, I want to assure you that we are still working hard to bring the latest heat-treat news to you each and every month.

The industry has proven itself to be up to the challenge during the pandemic by deploying its unique services to brainstorm innovative projects designed to usher in a return to safer, less stressful times.

Last month, we shared how Thermal Product Solutions (TPS) had teamed up with a medical research hospital in hopes of using its Gruenberg ovens to disinfect masks for re-use. The results were very promising, and I hope to bring you an update on this development in a future issue.

In other recent developments, Baker Furnace, also owned by TPS and a leading supplier of pollution control equipment, has been working on an incineration solution for infectious medical waste.

As you can see, the heat-treat industry is using its considerable array of knowledge to combat this global threat. With that type of above-and-beyond leadership, the industry will definitely continue to flourish and grow — and no doubt come out of this crisis stronger than ever.

That's a solid reason for *Thermal Processing* to be a visible and viable tool you can use to continue to get your word out to the industry.

Let us be your eyes, ears, and, most importantly, your voice. We are here, first and foremost, to shine a spotlight on your valuable products, services, and know-how to a market that suddenly has limited avenues available to discover it.

Whether it's a powerful ad or an expert article, let us share your insights with the people who are searching for it — now more than ever.

Stay safe and healthy out there, and, as always, thanks for reading!

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

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

Thermal processing

David C. Cooper
PUBLISHER

EDITORIAL

Kenneth Carter
EDITOR

Jennifer Jacobson
ASSOCIATE EDITOR

Joe Crowe
CONTRIBUTING EDITOR

SALES

Dave Gomez
NATIONAL SALES MANAGER

CIRCULATION

Teresa Cooper
MANAGER

Jamie Willett
ASSISTANT

DESIGN

RIck Frennea
CREATIVE DIRECTOR

Michele Hall
GRAPHIC DESIGNER

CONTRIBUTING WRITERS

KATHY C. CHUANG
TIMOTHY J. GORNET
BO HU
HILMAR KOERNER
D. SCOTT MACKENZIE
KATE SCHNEIDAU
JUSTIN SIMS
TONY TENAGLIER
AMBER TIMS
ROLAND T. WARZEL III

Media solutions

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

David C. Cooper
PRESIDENT

Teresa Cooper
OPERATIONS


YOU'VE GOT THE PRODUCTS.
YOU'VE GOT THE SERVICES.
NOW, LET US SHARE YOUR STORY.
Thermal Processing wants to make sure the best possible audience knows your company. Through our print, online, and social media presence, our experienced staff can get your message to an industry that wants to know what you can do.
Thermal processing
To learn more, contact national sales director Dave Gomez at dave@thermalprocessing.com or call 800.366.2185 ext. 207

With a new facility under way in Elgin, Illinois, Bodycote continues to invest in acquiring, updating, and building new facilities with new capacity and more operationally efficient services. (Courtesy: Bodycote)

Bodycote to open new Illinois heat-treatment facility

Bodycote, the world's largest provider of heat treatments and specialist thermal processing services, will open a new state of the art facility in Elgin, Illinois, in the United States.

The new purpose-built facility has been designed as a replacement for Bodycote's aging facility in Melrose Park, Illinois. The Elgin facility is scheduled to be operational in June 2020. It will support manufacturing supply chains in the Midwest region. The Melrose Park facility will be closed once the transfer of customers' work has been completed.

Bodycote continues to invest in acquiring, updating, and building new facilities with new capacity and more operationally efficient services. The new Elgin facility is part of this ongoing strategy to provide the best possible capabilities, mix, and geographical network to better serve customers.

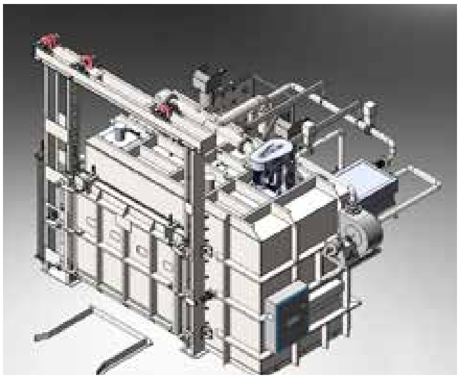
Tom Gibbons, president of Classical Heat Treatment, North America, said, "I am delighted to be able to announce the opening of our plant in Elgin, Illinois. Our investment in the new facility enables us to expand our capacity and improve our ability to deliver high-quality heat-treatment capabilities to our customers."

Bodycote has more than 70 facilities in North America. With more than 180 accredited facilities in 23 countries, Bodycote is the world's largest provider of heat treatments and specialist thermal processing services. Through classical heat treatment and specialist technologies, including Hot Isostatic Pressing (HIP), Bodycote improves the properties of metals and alloys, extending the life of vital components for a wide range of industries, including aerospace, defense, automotive, power generation, oil and gas, construction, medical, and transportation. Customers in all of these industries have entrusted their products to Bodycote's care for more than 50 years.

MORE INFO www.bodycote.com

Gasbarre delivers atmosphere tempering furnace

Gasbarre Thermal Processing Systems recently shipped a custom-built atmosphere tempering furnace to a manufacturer in the aerospace market with captive heat-treating capabilities. With a working load size of 84" wide, 42" deep, and 60" tall, coupled with a max load weight of 6,000 pounds, the furnace is specifically designed for the customer's key manufactured components. The electrically heated furnace has an operating temperature range of 350°F to 1,600°F, and passes uniformity at +/- 10°F per AMS2750E. The system is equipped with custom controls including Eurotherm brand temperature controlling instrumentation, and an Allen-Bradley PLC and HMI. Automatic atmosphere control is included for running under nitrogen, argon, and/or a hydrogen blend. Custom designed atmosphere cooling systems are installed to reduce overall cycle time. Gasbarre was chosen as a partner for its ability to specifically design the equipment around its broad process parameters. The equipment configuration also enabled



Gasbarre's custom-built atmosphere tempering furnace for an aerospace customer has a working load size of 84" wide, 42" deep, and 60" tall, coupled with a max load weight of 6,000 pounds. (Courtesy: Gasbarre)

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

the customer to switch from pit furnace style processing, which eliminated infrastructure costs and maintenance concerns.

With locations in Plymouth, Michigan; Cranston, Rhode Island; and St. Mary's, Pennsylvania, Gasbarre Thermal Processing Systems has been designing, manufacturing, and servicing a full line of industrial thermal processing equipment for nearly 50 years. Gasbarre's product offering includes both batch and continuous heat processing equipment and specializes in temper, tip up, mesh belt, box, car bottom, pit, and vacuum furnaces as well as a full line of replacement parts and auxiliary equipment consisting of atmosphere generators, quench tanks, and charge cars. Gasbarre's equipment is designed by experienced engineers and metallurgists.

MORE INFO www.gasbarre.com

Nitrex unveils new brand identity to reflect new direction

Nitrex, a Novacap portfolio company and the leading global provider of fully integrated heat-treating solutions and technologies, unveiled a new corporate brand identity. This change comes at a time when the company is forging new paths, retooling its product portfolio to align even more closely with customer needs and preferences, and seeking to present a more consistent look and feel across all brands.

"In our 35-year history, Nitrex has evolved from a small family-run business operating in Canada to a global company with an extensive portfolio serving the whole heat-treatment industry," said Nitrex CEO Jean-Francois Cloutier.

"Our portfolio is built on proven science and technology to enhance material strength and optimize performance. The new brand identity we are sharing with you," he continued, "reflects our evolution as a market leader poised for the future, while reaffirming our tradition of innovation, reliability, and quality as well as our customer-focused culture. The new unifying logo will represent the company as a whole, with all its business units. The modern, abstract design of the company's iconic red, yellow, and orange "N" symbol is now rendered as two monochromatic pillars, indicating that Nitrex rests on a solid foundation of science and technology. The pillars stand side by side and stretch out crosswise, evoking the centrality of heat treating as a mission-critical process in manufacturing," said Cloutier.

This new symbol will be adopted by all the Nitrex business units. (Courtesy: Nitrex)

The new symbol will be adopted by all the Nitrex business units. The symbol also plays a functional role as the letter "N" in the Nitrex wordmark used by all business units. For now, the names of the legal entities will not change, so customers, suppliers, and stakeholders can continue to use the existing names and addresses in all official communication. The new wordmark for United Process Controls leverages its well-known trade name, the UPC initials, in combination with the company's best-known brand asset, Marathon Monitors, to form UPC-Marathon.

Also worth noting is the incorporation of the "N" symbol as the final letterform in the new UPC- Marathon wordmark.

"The UPC-Marathon logo may be new and different, but it still speaks to our history and makes the link with the essence of our recognized brand. Operationally, nothing has changed: Our mission is to be the best brand in process controls and automation worldwide. The new logo is a true reflection of our past and our future," said Eric Jossart, VP global sales. "The rebranding unifies our group, while confirming our unique position in the market," said Oliver Caurette, president, United Process Controls.

G-M Enterprises has also traded its metallic graphic for a sleek single-color wordmark using the same typeface as the other logos, with the addition of the tagline A Nitrex Company. "The new logo clearly defines the integration of G-M into Nitrex. As the newest addition to the Nitrex Turnkey Systems portfolio, G-M expands our offering in this category by bringing a new line of innovative vacuum heat-treatment systems to our customers," said Iwo Korwin, president of NTS.

The new tagline is 'Mastering strength. Worldwide.'

"The new tagline charts a bold course for Nitrex. It underscores our commitment to science and technology. By harnessing the latest advances, we will be able to reinvent the methods of strengthening metals and applications, to the greater benefit of our customers. This marks the beginning of a new chapter for Nitrex and its affiliated companies, and we're very excited to finally share it with you. Soon you will see the new logos on all our products and packaging, social media platforms, brochures, stationery and tradeshow booths as well as in our email signatures, and much else. Also, on the horizon is a redesigned website with simplified messaging and a seamless visitor experience. The site will showcase the full suite of solutions, including turnkey heat-treating systems, heat-treating services, and control and automation solutions," said Cloutier.

› Read more about Nitrex in the company profile, page 42.

MORE INFO www.nitrex.com

Can-Eng will refurbish a cast link belt normalizing furnace at its Niagara Falls shops. (Courtesy: Can-Eng Furnaces)

Auto components manufacturer buys Ipsen furnaces

Ipsen confirms the receipt of an order for two TITAN® H6 2-bar vacuum furnaces from a rapidly emerging global automotive components manufacturer with locations in the United States and Asia.

"Despite general market conditions at the present time, we are seeing many forward-looking manufacturers continuing to invest in efficient, high-performance systems for the future," Ipsen USA President and CEO Patrick McKenna said.

The customer awarded Ipsen this order as part of a series of eight furnaces – all provided by Ipsen – over the last two years.

Ipsen's TITAN® was the customer's preferred choice for this series due to the inherent process flexibility and ease of installation anywhere in the world, as well as the local regional support provided by Ipsen's sales and service teams in both the United States and Asia.

Ipsen's TITAN® was a new customer's preferred choice due to the inherent process flexibility and ease of installation anywhere in the world. (Courtesy: Ipsen USA)

MORE INFO www.ipsenusa.com

Can-Eng awarded contract for overhaul, refurbishment

Can-Eng Furnaces International LTD. has been awarded a contract by a major automotive parts supplier for the complete overhaul and refurbishment of a cast link belt normalizing furnace. Designed and manufactured by Can-Eng in 1996, the equipment was originally rated at 27,000 lbs./hr. of hot charged closed die forgings and was known to be one of the largest cast link belt furnaces in the world at the time. The refurbishment will take place in the Can-Eng Niagara Falls shops and will consist of a complete refractory re-line, new combustion, new control panel, and Level II Automation system, plus an added external cooling conveyor. The furnace shell, hearth, and return rolls as well as the ACI HT cast link belt itself will be refurbished to near new condition. The system will employ a furnace charging robot. The entire operation will be completely automated with Can-Eng's PETTM (Process Enhancement Technology) from the furnace charging robot pick position complete through the heat-treatment process.

MORE INFO www.can-eng.com

ATP acquires AKA Calibrations assets, clients

Andrew Bassett, president of Aerospace Testing & Pyrometry, and Bill Stines, president/owner of AKA Calibrations, announced that Aerospace Testing & Pyrometry will

Bill Stines will be taking a role within the ATP organization, which includes special projects and consulting. (Courtesy: ATP)

be acquiring the assets and clients of AKA Calibrations starting June 2020.

Stines approached ATP to acquire his clients because of the same work ethic and dedicated service that AKA Calibrations has provided to his client base.

"This was the only option. Aerospace Testing & Pyrometry has a great reputation in the industry and is a leader in providing superb pyrometry services to their clients," said Stines.

"This is a perfect fit for ATP. Bill's hard work and dedication to his clients over the years is the same approach with our clients," Bassett said.

AKA Calibrations and Aerospace Testing & Pyrometry have worked together over the years and acquiring AKA Calibrations' client base will be a smooth transition. The majority of AKA Calibration accounts will be handled from its Southern Division based out of Tulsa, Oklahoma. Stines will be taking a role within the ATP organization, which includes special projects and consulting.

Aerospace Testing & Pyrometry, Inc. is an ISO/IEC 17025 accredited company specializing in the onsite calibration of temperature processing instrumentation, calibration of vacuum measuring systems, and temperature uniformity surveys for thermal processing equipment. It also specializes in consulting and training in pyrometry specifications, heat treat consulting, and procedure writing and consulting for Nadcap accreditations in heat-treating, non-destructive testing (NDT), welding, brazing, and materials test laboratories. With offices located in Bethlehem, Pennsylvania; Stroudsburg, Pennsylvania; Hartford, Connecticut; Cleveland, Ohio; Tulsa, Oklahoma; Los Angeles, California; Greenville, South Carolina; Bedford, Ohio (Lab); and Muskegon, Michigan; its services have reached throughout the United States, Mexico, Canada, and Europe.

MORE INFO www.atp- cal.com

Gas nitriding furnace installed at Solar Atmospheres

To support an increasing demand for high-value gas nitriding, Solar Atmospheres, Souderton, Pennsylvania, has installed a new, state-of-the-art vacuum gas nitriding furnace, built by sister company Solar Manufacturing.

The front-loading furnace incorporates the latest nitriding and recipe system from Solar Manufacturing. The automated controls meet AMS2759/10, Automated Gaseous Nitriding Controlled by Nitrogen Potential, in addition to the standard AMS2759/6, Gaseous Nitriding of Low-Alloy Steel Parts. The automated control system is useful for single stage, as well as two-stage (Floe) processing. All hot zone components are made completely of graphitic materials inert to the anhydrous ammonia used during the nitriding process.

In addition to a forced gas cooling system, the furnace also incorporates Solar Manufacturing's unique convection heating system. This design has significant advantages over conventional retort-type systems in the reduction of cycle time, by as much as 50 percent, resulting in increased efficiency and saving customers time and money.

MORE INFO www.solaratm.com

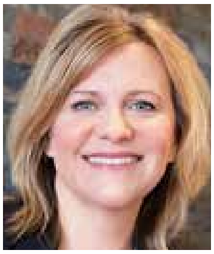
The Solar Atmospheres front-loading vacuum gas nitriding furnace incorporates the latest nitriding and recipe system from Solar Manufacturing. (Courtesy: Solar Atmospheres)

Ipsen USA announces new human resources director

Ipsen has hired Janet Nanni, PHR, SHRM-CP, as its new director of human resources. Nanni stepped into this role after the May 6 retirement of longtime Ipsen HR director Nancy Kolar.

Nanni is responsible for managing all personnel and human resources programs for Ipsen USA, which includes locations in Illinois and Pennsylvania. Before joining Ipsen, Nanni was the director of human resources at Zenith Cutter in Rockford, accountable for global HR initiatives in two countries.

Nanni has more than twenty years of human resources experience in the industrial manufacturing and engineering service industries. She received a Bachelor of Business Administration degree with emphasis in human resources from the University of Wisconsin-Whitewater. She is also a Society of Human Resources Management Certified Professional.



Janet Nanni

Nanni's talent for transforming workplace culture and aptitude for building trust and accountability make her fit for the role.

Ipsen USA designs and manufactures industrial vacuum and atmosphere heat-treating systems, supervisory controls systems and predictive maintenance software platforms for many industries, including aerospace, automotive, commercial heat treating, energy, and medical. With production locations in America, Europe, and Asia, and representation in 34 countries, Ipsen is committed to providing 360° support for customers worldwide.

MORE INFO www.ipsenusa.com

Electrically heated pit furnace used for aerospace fasteners

L&L Special Furnace Co., Inc. has manufactured a fourth high-uniformity, pit-style furnace used for annealing. This furnace has been supplied to an industry leader that manufactures aerospace fasteners and supplies to a worldwide client base.

The annealing process occurs when the parts are evenly heated to 1,400°F/760°C and held for a predetermined amount of time. Temperature uniformity is critical to this process, and both ambient and load temperature must maintain ±10°F throughout the cycle.

The furnace is manufactured in accordance with the ASM2750E pyrometry specification. All thermocouple reference ports along with TUS survey ports and recording devices are included.

There is a five-horsepower, air-cooled turbo convection fan included to aid in temperature uniformity. The system is controlled by Eurotherm controls and a recorder with SCR power controls. There is an audible/visual stack light and element branch indicator located on top of the control panel.

L&L Special Furnace Co.'s model PT2036 Cyclone pit furnace for annealing aerospace fasteners. (Courtesy: L&L Special Furnace Co.)

The branch indicator is a visual indicator to tell that all the elements in the furnace are working correctly.

The fastener parts are placed in baskets and loaded by an overhead crane into the furnace. There are guide bars to ensure that the load is centered and cannot damage the furnace liner.

The program or recipe is entered into the program control, and the cycle is started. At the completion of the cycle, the parts are removed and are ready for inspection and shipment.

This furnace is ideal for production facilities where the operators have sole control of their heat-treating cycle. Options include a variety of control and recorder configurations. All units come with a three-day, all-inclusive startup service available within the continental United States and Canada. International startup and training services are available by factory quote.

The furnace has been surveyed and is capable of ±10°F from 300°F to 1,750°F throughout the work envelope of 20" in diameter by 36" deep. L&L also has many other sizes available.

MORE INFO www.llfurnaces.com

Sintavia achieves Nadcap accreditation for heat treatment

Sintavia, LLC, a leading aerospace and defense additive manufacturer, has achieved National Aerospace and Defense Contractors Accreditation Program (Nadcap) approval for heat treatment at both its Hollywood, Florida, and Davie, Florida, locations. Sintavia is the only company in the world with Nadcap approvals for laser additive manufacturing, electron beam additive manufacturing, and in-house heat treatment.

"Since its founding, Sintavia has always defined itself as the quality leader for aerospace and defense additive manufacturing," said Brian Neff, Sintavia's CEO. "Nadcap approval for our internal heat-treatment capabilities is not only a continuation of this focus, but also will allow Sintavia to provide higher quality production parts more quickly to its customers. Moreover, we are proud of the fact that we are the first manufacturer anywhere in the world to achieve these quality accreditations."

The Nadcap accreditation for heat treatment includes nickel and aluminum alloys, and the initial approval is good through July 31, 2021. In addition to Nadcap approvals for heat treatment and additive manufacturing, the company also holds Nadcap approvals for non-destructive testing and chemical processing through its wholly-owned subsidiary, QC Laboratories, Inc. In the coming months, the company plans also to pursue Nadcap approval for its in-house metallurgical and mechanical testing laboratory, located in Davie, Florida, which is already ISO 17025-certified.

Sintavia is the global leader for metal additive manufacturing in support of the aerospace and defense industry. With high-speed printers co-located alongside precision post-processing equipment, a full complement of mechanical testing equipment, and a full metallurgical and powder laboratory, Sintavia is able to optimize parameters, serially manufacture, and audit quality parts for its aerospace and defense customers. Sintavia holds multiple Nadcap accreditations, as well as AS9100 Rev. D and ISO17025 certifications.

MORE INFO www.sintavia.com

Sintavia is the only company in the world with Nadcap approvals for laser additive manufacturing, electron beam additive manufacturing, and in-house heat treatment. (Courtesy: Business Wire)

One of India's largest air cooler/heat exchanger manufacturers selected a three-chamber CaseMaster Evolution (CMe)® furnace from Seco/Warwick. (Courtesy: Seco/Warwick)

Air cooler/heat exchanger maker picks Seco/Warwick

One of India's largest air cooler/heat exchanger manufacturers selected a three-chamber CaseMaster Evolution (CMe)® furnace from Seco/Warwick which will be used for heat exchangers. The client has decided on Seco/Warwick vacuum technology after a long period of trials with single- and double-chamber furnaces.

The CMe furnace with vacuum loading and cooling chambers is a semiautomatic brazing furnace that is quickly becoming popular especially in automotive, aerospace, and defense industries due to its superb performance and high precision. Here, the client's focus is on increasing production volume of its air cooling/heat exchangers. It's the first vacuum technology overall used by this manufacturer.

The client was previously using single-chamber furnaces but Seco/Warwick's three-chamber technology became attractive, so the client conducted a number of trials at various heat-solution providers before it decided on the Seco/Warwick furnace. The engineering team played a great role in the process with professional support to train the client's crew and acquaint them with the vacuum technology. There was close cooperation on both sides and on all the levels starting with top management and finalizing on operating levels of the production team. Sharing information was transparent and the learning process was smooth.

CaseMaster Evolution–T (CMe-T) – a three-chamber vacuum furnace – delivers economical surface hardening using low-pressure carburizing (LPC) technology and high-pressure nitrogen quenching. The CMe-T furnace can replace existing lines and generators used for mass heat-treatment under protective atmosphere and oil quenching, while ensuring higher precision and process repeatability. This solution stands out not simply because of its three-chamber design, but more significantly because of improved process quality, cost reduction from doubling yields, and increased production flexibility. Further, the CMe-T furnace's intrinsically safe operation and low environmental impact are becoming increasingly important to industry leaders as a whole. These are among the key reasons that aviation and automotive manufacturers are becoming increasingly attracted to CMe-T as the heat-treat solution of choice.

"The client has chosen Seco/Warwick technology after long trials with other single and double chamber solutions from our competitors. Although initially the client focused simply on increasing the volume of production there was the whole spectrum of benefits not offered by the competitors. In a word, the advantage through technology prevailed," said Maciej Korecki, VP vacuum business segment at Seco/Warwick.

"Our engineering team worked closely with the client since this was the first vacuum technology purchased by the manufacturer; furthermore, Seco/Warwick is prepared to provide full customer assistance in implementing both technology and crew training at the site. We are very happy and proud to have successfully implemented another Seco/Warwick solution in India," said Manoranjan Parta, managing director Seco/Warwick India.

With hundreds of systems installed worldwide, Seco/Warwick's high-pressure quench furnaces have a proven record of high-performance technology. CMe technology is successfully used in India, China, North America, and Europe.

The customer was looking for brazing technology for its heat exchangers to increase production volume and tested a number of solutions currently available on the market. Solving the basic client's problem was, however, not enough. The CMe furnace delivers a number of unexpected advantages, including minimizing manual intervention, reducing total cycle times, increasing productivity, improving brazing quality, achieving excellent batch uniformity, reducing operational costs, and saving the environment.

CaseMaster Evolution, including CMe-T version, has been revolutionizing such industries as automotive, defense, hardware, aerospace, and commercial heat treaters. Successful deployment of the first furnace with this technology will increase the client's production capacities and elevate their product quality, providing the client with significant competitive advantages on the Indian and global markets.

MORE INFO www.secowarwick.com

James Sanderson, former Aluminum ET chairman, dies

James Sanderson, a past chairman of the International Aluminum Extrusion Technology Seminar and longtime Kaiser Aluminum employee, passed away on April 19. Sanderson started his career with Kaiser Aluminum in 1970 as the hot mill metallurgist at the Ravenswood, West Virginia, rolling mill and held many key positions within the company. He spent the majority of his career as general manager at the Los Angeles, California, and Sherman, Texas, extrusion facilities and continued as an industry consultant to Kaiser until recently.

James Sanderson

"Jim successfully supported the growth of our markets segments in the truck trailer and automotive applications and ultimately became the technical and quality manager for the engineered products group," said Ray Parkinson, SVP - advanced engineering for Kaiser Aluminum.

Applying his technical expertise across the industry, Sanderson actively represented Kaiser Aluminum at the ASTM International Committee B07 on Light Metals and Alloys dating back to 1998, said Parkinson. In 2014, he was presented with the ASTM Award of Merit and its accompanying title of fellow, ASTM's highest organizational recognition for individual contributions to standards activities. He also received three B07 Awards of Appreciation during his tenure.

As a longtime member of the Aluminum Extruders Council (AEC) he served on the Technical Services Committee and he represented AEC on the ASTM B07 Committee on several technical issues involving detailed specifications that were critical to the 'soft alloy' extruders in the industry.

"Jim had a stellar reputation at AEC — as a doer and a leader who made a difference to all of us. People loved working with Jim and respected his intellect, integrity, and humanity," said ET seminar committee chairman and AEC Business Excellence Steering Committee chairman Craig Werner, VP Extrusion Technology at Kaiser Aluminum.

Throughout his life, Sanderson took the time to mentor those around him and would teach much of his metallurgy knowledge through stories of application. "Jim had a long and exceptional career in our industry and provided critical volunteer service to our industry through his relentless focus on technical standards, his leadership and ongoing efforts to support ETs, and the training and mentoring Jim provided to so many of us. Jim was a critical advocate for our industry and was a model for the best that AEC volunteers can offer and achieve," said Werner. "He was a mentor and friend to me. I was fortunate and made better for having known him."

MORE INFO www.aec.org

New ultra-high purity nitrogen gas generators released

The new nano GEN2 i-4.0 range of nitrogen gas generators provide a wide range of flow rates and purities from 95 percent to 99.999 percent. The fourth Industrial Revolution has arrived as machines are digitally connected to their operators and the GEN2 i-4.0 leads the industry for onsite N2 gas generators. Full communication protocols including modbus, profibus, and other building management system connections can be achieved via an RS485 or ethernet RJ45 port. The WiFi option allows the GEN2 i-4.0 to be accessed, operated, and monitored from anywhere in the world.

With a nano GEN2 i-4.0 gas generator you can expect payback typically between six to 24 months. This unique modular design and energy saving functionality offers a number of significant advantages over delivered gas options as well as traditional generator designs.

The compact system can be installed easily and with a minimum cost and disruption and requires only a pre-treated compressed air system to start production. An on-site generator enables users to fulfill their demand for nitrogen gas on their premises, under their complete control. As a result, companies can generate as much or as little nitrogen as needed at a fraction of the cost of having the gas delivered by an external supplier.

MORE INFO www.n-psi.com

OAO BelAZ selects Seco/Warwick technological line

Belaz, manufacturer of the world's largest vehicle, selected Seco/Warwick as a technology provider. (Courtesy: Seco/Warwick)

OAO BelAZ, a Belarusian dump truck manufacturer, has again chosen Seco/Warwick as its solution provider. The new device, the RLHE electric roller furnace, will be integrated with the technological line for heat treatment of large bearing rings.

The line, based on the RLHE-120.510.20-1000 roller furnace, is designed for heat treatment of large bearing rings with diameter from 980 to 1,180 mm, which are used in the production of the world's largest trucks, the dump trucks working in the mining industry. The whole supplied technological line consists of: a transport system with a set of manipulators, an electric roller furnace type RLHE-120.510.20-1000, a hardening press with matrix instrumentation, and a control system with a master system for data visualization and archiving.

The cooperation between OAO BelAZ and Seco/Warwick began in 2012 with the delivery of a universal pusher aggregate for thermal improvement (quenching and high tempering) and normalization of APH-800 G forgings. Another implemented solution in November 2016 was a roller aggregate for hardening large-size press bearing rings.

The implementation of such a demanding project could only be delegated to a trusted and proven partner, said Chief Engineer O.G. Stjepuk, first deputy general director for technical policy and innovative technologies OAO BelAZ.

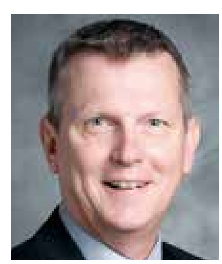
"In producing such powerful trucks, we only reach for precise solutions. We know that because of our stringent requirements, the production line of large-size bearing rings is another extremely difficult project to implement. So again, we trusted the experience of our partner, Seco/Warwick, our long-time collaborator who guarantees meeting the highest requirements that accompany our production."

The experience of the manufacturer of heat-treatment equipment has allowed OAO BelAZ to achieve expected extremely low deformation rates of hardened bearing rings. Results below 0.2 mm of deformation of flatness and ovalization of heat-treated elements were achieved. Precision is key as the Seco/Warwick electric roller furnace will be used for heat treatment in the production of giant dump trucks carrying multi-ton loads in opencast mines. Among these types of vehicles, the BelAZ 75710 model with a payload of up to 450 tons stands out as the most powerful truck in the world.

MORE INFO www.secowarwick.com

STLE elects Paul Hetherington as 2020-21 president

The Society of Tribologists and Lubrication Engineers (STLE) — the technical society serving individuals, companies, and organizations that comprise the tribology and lubrication engineering business sector — announced Paul Hetherington, CLS, manager, technical services, Canada, for Petro-Canada Lubricants Inc., a HollyFrontier Business, and former treasurer, secretary and vice president of STLE, will assume the role of 2020-2021 president effective immediately for a one-year term.



Paul Hetherington

In his new role, Hetherington will serve as the principal executive officer of the society and as chairman of its board of directors. Joining him on the STLE Executive Committee are Vice President Ken Hope, Ph.D. (Chevron Phillips Chemical Co. LP), Secretary Ryan Evans, Ph.D. (The Timken Company), Treasurer Hong Liang, Ph.D. (Texas A&M University), Immediate Past President Michael Duncan, Ph.D. (Daubert Chemical Company Inc.), and STLE Executive Director Edward P. Salek.

"Paul is a recognized thought leader who has served STLE at both the local and national level," Salek said. "He's designed and collaborated on numerous technical and education programs, and his insights will be invaluable as STLE continues to evolve and address the changing needs of our members and their respective industries in today's business environment."

During his term, Hetherington will lead STLE's volunteers and professional staff in the implementation of a strategic plan that emphasizes education, technical innovation, and global advocacy in the areas of tribology and lubrication. He will represent the society and speak at industry meetings throughout North America and around the world about the positive impact tribology can make in industrial and everyday applications.

"I'm honored to serve as 2020-2021 president of STLE," Hetherington said. "I look forward to leading STLE's efforts as we help our members navigate the new normal and continue to advance tribology in a variety of industries and applications, including manufacturing, metalworking, transportation and power generation."

With more than 39 years of experience, Hetherington has extensive industry knowledge in various reliability initiatives, including the development of several programs such as oil analysis, vibration analysis, thermography, and ultrasonics. Hetherington joined Petro-Canada Lubricants in 2011 as a senior technical services advisor.

The Society of Tribologists and Lubrication Engineers (STLE) is the premier technical society serving the needs of more than 13,000 individuals and 250 companies and organizations comprising the tribology and lubrication engineering business sector.

MORE INFO www.stle.org

Global tool maker buys another furnace from Seco/Warwick

Vector® is Seco/Warwick's most versatile vacuum furnace, a single-chamber HPGQ horizontal configuration loaded with capabilities. (Courtesy: Seco/Warwick)

An international concern with branches in 40 countries producing cutting tools, among other things, ordered another solution from Seco/Warwick.

Vector® is Seco/Warwick's most versatile vacuum furnace, a single-chamber HPGQ horizontal configuration loaded with capabilities. It's been designed and created based on a long and close cooperation with partners across a number of industries and all over the world. Their needs and problems became a challenge which lead to Vector's invention. Seco/Warwick creates individual products that provide customers with reliable, safe, and environmentally friendly solutions for heat treatment and metallurgy, and ensure the economic efficiency of their businesses.

Maciej Korecki, VP, Vacuum Furnace Segment at Seco/Warwick said, "Precision, high uniformity in heat-treated parts, high consistency in workloads, and high speeds in batch processing along with low energy and gas consumption make our product most desirable solution on the market. Often, our clients demand just one thing — for instance, high uniformity in heat-treated parts which solves problems of distortions they experience using different technology. All the other features come as a surprise and an added value."

With hundreds of systems installed worldwide, Seco/Warwick's high-pressure quench furnaces have a proven record of high-performance technology.

The horizontal, front-loading furnace is purpose-built to accommodate the customer's needs with an all-metal hot zone for clean vacuum processing. As with the earlier furnaces, one of which was installed at a different facility, the new furnace includes a convection fan and a pressurized gas quench for quick cooling.

Piotr Zawistowski, president, Seco/Vacuum, said, "This third repeat order is a testament to SVT's on-time delivery and the performance of our Vector vacuum furnace to meet all promised parameters, including producing clean finished parts, all as promised."

Vector high-pressure gas quenching furnaces are an ideal solution for machine tool manufacturers. It is available with curved graphite elements or an all-metal hot zone and can be used for most standard hardening, tempering, annealing, solution heat-treating, brazing, and sintering applications.

Vector's versatility is extended further with additional features.

It can be furnished with Seco/Warwick's optional patented vacuum-carburizing technologies (FineCarb®) and prenitriding (PreNit®) and the SimVac® process simulation package at no additional cost.

MORE INFO www.secowarwick.com

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

Registration open for IHEA Fundamentals for Industrial Process Heating online course

Registration for IHEA's Fundamentals of Industrial Process Heating online learning course is now open for fall 2020. Scheduled to begin October 5, the six-week class will run through November 15. The flexible online format and interactive forums with other students, along with scheduled office hours with the instructor, are just a few of the benefits of this program.

The course, which is taught by industry expert Jack Marino, allows students to learn in a flexible, online format while at home or work. It is an affordable alternative to campus-based classes and allows students to go at their own pace. Throughout the in-depth online course, students learn safe, efficient operation of industrial heating equipment, how to reduce energy consumption, and ways to improve your bottom line.

The curriculum includes the basics of heat transfer, fuels and combustion, energy use, furnace design, refractories, automatic control, and atmospheres as applied to industrial process heating. Weekly coursework, quizzes, and a final project are administered to guide students and evaluate their knowledge of the material. Registration is open through October 1. Cost for IHEA members is $750 or one member voucher, and the cost for non-members is $925. The fee includes an electronic course handbook, course instruction, quizzes and projects, class forums, and the opportunity to contact the instructor. For a complete listing of the topics covered and/or to register, visit www.ihea.org/event/FundamentalsFall20.

IHEA 2020-21 executive officers, Board of Directors announced

IHEA recently announced its 2020-2021 Board of Directors and Executive Officers. The new executive officers are Scott Bishop of Alabama Power Company as president, Jeff Valuck of Surface Combustion as vice president, and Brian Kelly of Honeywell Thermal Solutions as treasurer. Bishop has served as IRED chairman, presented at numerous workshops and seminars, and provided key support in the recent revision of the *Infrared Process Heating Handbook for Industrial Applications.* Michael Stowe of Advanced Energy assumes the role of past president.

"It is an honor to serve as IHEA's president for the 2020-2021 term," Bishop said. "I look forward to continuing the great work IHEA has done for more than 90 years. During this unprecedented time, I would like to encourage our members to be proactive in finding ways to better serve our industry and make an impact."

IHEA also welcomed new board member Alberto Cantu of Nutec Bickley. Cantu began his involvement with IHEA at the 2013 Fall Seminar in Indianapolis where he attended the Electrotechnologies Seminar. He participates on the Safety Standards and Codes committee and recently became involved with the Education committee. He is a lecturer on heat transfer for one of the biggest universities in Mexico and education is a passion for him.

"I am very excited about this new role; I think it will be a great opportunity to connect with colleagues in the industry and help move it forward," Cantu said.

Members continuing their service on the IHEA Board of Directors for 2020-2021 include: Gary Berwick, Dry Coolers; Bob Fincken, Super Systems Inc.; Doug Glenn, Heat Treat Today; Francis Liebens, SOLO Swiss Group; Daniel Llaguno, Nutec Bickley; John Podach, Fostoria Process Equipment, a div. of TPI Corp.; Jason Safarz, Karl Dungs Inc.; and John Stanley, Karl Dungs Inc.

Scott Bishop, the new IHEA president, works for Alabama Power.

Alberto Cantu, IHEA's newest member of the board of directors.

In addition, IHEA current committee chairpersons include: Government Relations Committee led by Jeff Valuck of Surface Combustion Inc; Safety Standards and Codes Committee led by Kevin Carlisle of Karl Dungs; Education Committee led by Brian Kelly of Honeywell Thermal Solutions; Marketing Communication & Membership Committee led by Erik Klingerman of Industrial Heating. The Infrared Division is chaired by Bishop, and the Induction Division is chaired by Stowe.

IHEA 2020 CALENDAR OF EVENTS

OCTOBER 5–NOVEMBER 15

Fundamentals of Process Heating On-Line Course

6 Week Online Course | Registration open until October 1

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

OCTOBER 20–21

Powder Coating & Curing Processes Seminar

Alabama Power Technology Applications Center | Calera, Alabama

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

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

JUSTIN SIMS
MECHANICAL ENGINEER /// DANTE SOLUTIONS

Finite element modeling of the heat-treatment process, using software, can help engineers choose the proper gas quenching process parameters to ensure mechanical properties are achieved while keeping distortion to an absolute minimum.

Nonlinear distortion response during gas quenching

High-pressure gas quenching (HPGQ) is touted as a way to reduce distortion of difficult-to-quench geometries. Quench pressures and quench gas flow velocities are chosen to impart the slowest cooling rate, while still achieving the desired mechanical properties. While it is true that HPGQ imparts a more uniform method of heat extraction when compared to liquid quenching [1-2], due to convective cooling only, that does not necessarily mean less distortion of the component. However, a more uniform quench can result in more consistent distortion. Liquid quenching can lead to inconsistent results due to the chaotic nature of the vapor blanket and the unpredictability of the vapor blanket's degradation into nucleate boiling [2]. Uniformity in this instance is in reference to the heat transfer coefficient witnessed by the surface of the component, not the heat flux through the surface. The heat flux out of the part is a combination of the heat transfer coefficient and the component geometry.

Assuming this heat transfer coefficient can be made perfectly uniform on all surfaces, geometric features will still create nonuniform cooling scenarios [3]. These nonuniform cooling conditions can create nonlinearities in the distortion response of certain geometries. This article will explore one such geometric feature: an eccentric bore. Such a feature should immediately stand out as difficult to quench due to the non-balanced mass distribution.

GEOMETRY AND FINITE ELEMENT MODEL

A 50.8 mm thick, 101.6 mm diameter disk, with a 50.8 mm eccentric bore was used for the modeling study, as shown in Figure 1. The thinnest cross-section measures 6.35 mm. The thickest cross-section measures 44.45 mm. The geometry was chosen for the nonuniform heating/cooling which occurs due to the nonsymmetric mass distribution. The disk is made from Ferrium® C64™. The chemical composition of Ferrium C64 is shown in Table 1. Ferrium C64 was chosen for this study due to its high hardenability, negating the distortion effect of different phases forming from different cooling rates.

PROCESS DESCRIPTION

Using the DANTE heat-treatment simulation software, the disk was subjected to a range of possible HPGQ HTCs: 10, 25, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 W/m²K. Generally, HTCs of 200, 400, 700, and 1000 W/m²K correspond to quench pressures of 2, 6, 10, and 20 bar, respectively. However, this relationship will vary depending on the flow pattern and velocity profile of the quench gas in the vessel and around the component.

DISTORTION FROM COMMON GAS QUENCHING RATES

The distortion mode of interest for this study was out-of-round of the eccentric bore. The distortion was determined by the difference of

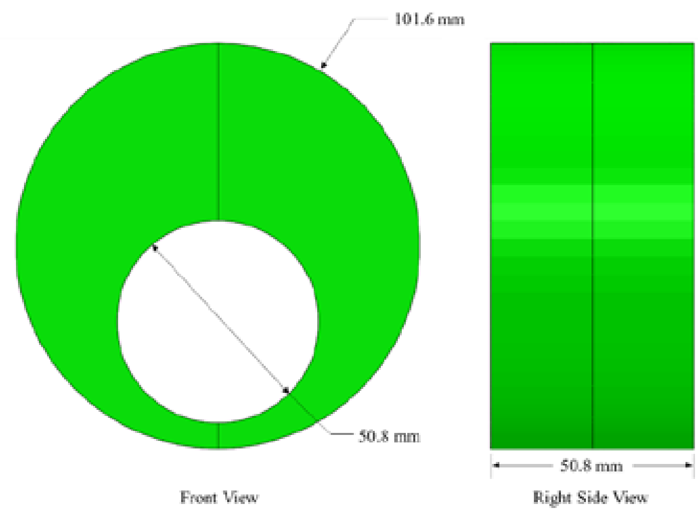


Figure 1: Model geometry, with dimensions, used for study.

Ferrium® C64™ Chemical Composition (nominal wt. %)

Fe	C	Co	Cr	Ni	Mo	W	V
Bal.	0.11	16.3	3.5	7.5	1.75	0.2	0.02

Table 1: Chemical composition of Ferrium C64.

the distances B_1-B_2 and A_1-A_2, as shown in the Figure 2 inset. Figure 2 shows the results from the study, plotted as out-of-round distortion (μm) versus HTC (W/m²K).

It is commonly assumed that if a component is quenched slower; i.e., a lower HTC value, less distortion will occur. As can be seen in Figure 2, the highest HTC nearly produced the least amount of out-of-round distortion. The only HTCs that produced less distortion in this case can be associated with an air cool (10, 25, and 50 W/m²K). The most distortion occurred from an HTC of 400 W/m²K, which is approximately equivalent to a six-bar quench.

HTC COMPARISON

A comparison between three HTC values — 100 (HTC100), 400 (HTC400), and 1000 (HTC1000) — during the martensite transformation is needed to understand why HTC400 results in more distortion than HTC1000. From an analysis of the model results, it was determined that the bore becomes distorted due to the martensite transformation stretching the bore in the vertical direction as the transformation proceeds from the thin to thick section. The distor-

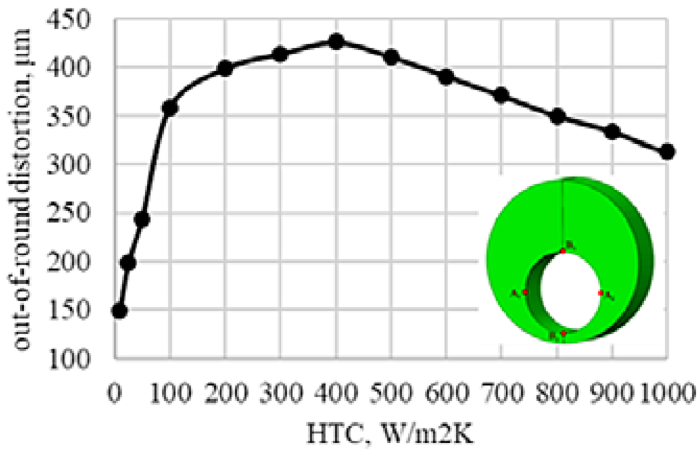


Figure 2: Out-of-round distortion of the coupon bore as a function of the heat transfer coefficient.

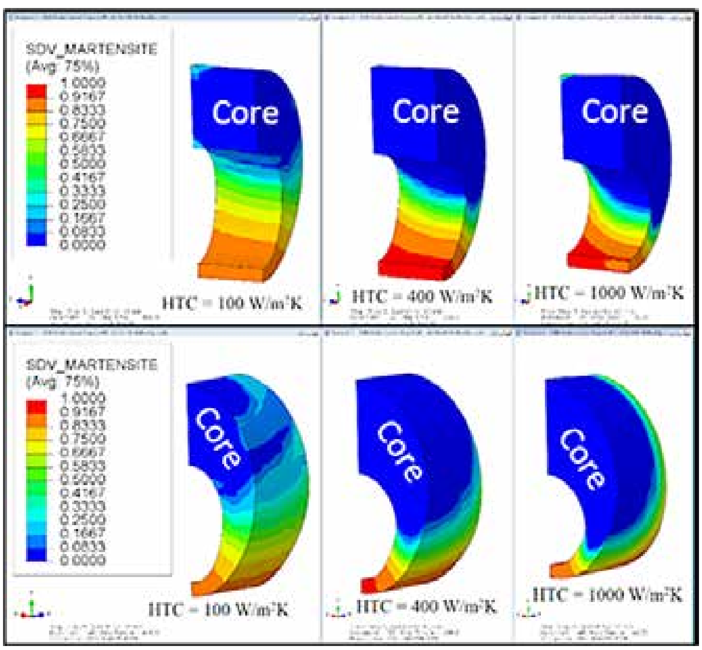


Figure 3: Martensite prediction for the 3 cases as martensite reaches its maximum value.

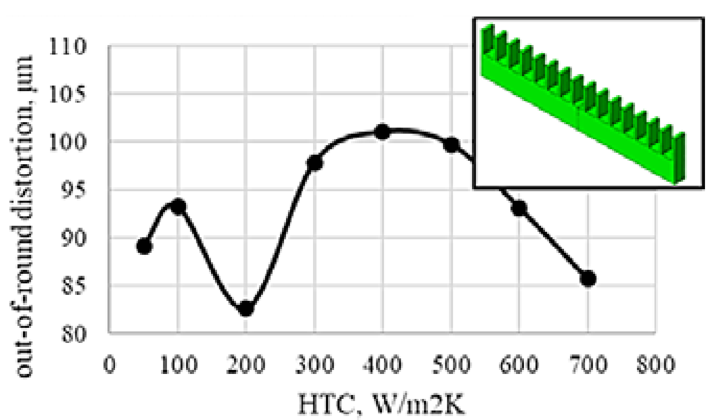


Figure 4: Predicted bow distortion of finned coupon, shown in the insert, as a function of the heat transfer coefficient.

tion can be offset by transformations occurring simultaneously in the thin and thick sections. This behavior can be witnessed in the three cooling rates, with seemingly minor differences resulting in significantly different results.

Even though the transformation appears similar between HTC400 and HTC1000, as shown in Figure 3, there are two major differences that contribute to the increased distortion of HTC400. First, there is a steeper transformation gradient from the surface to the core for HTC1000, resulting in less transformation per volume around the bore, when compared to HTC400. Second, there is transformation occurring in the thick section of HTC1000 while the bore is transforming. This behavior helps offset the elongation of the bore that leads to the out-of-round distortion. The distortion is a maximum in HTC400 because the transformation is relatively uniform from the surface to the core, but there is a steep transformation gradient in the circumferential direction. This behavior means that HTC400 transforms large volumes of material as the transformation front progresses around the bore, incrementally stretching the bore.

HTC100 shows a substantial amount of martensite transformation occurring in the thick section as the bore is transformed, with a very shallow transformation gradient in the circumferential direction. It is this behavior, the transformation happening almost simultaneously throughout the part, that leads to reduced distortion.

Another difficult-to-quench geometry is shown in the inset of Figure 4. This geometry cools much faster on the side with the fins, due to the increased surface area provided by the fins. This geometry also has a nonlinear distortion response to uniform heat transfer coefficients in the range of HPGQ, as shown in Figure 4. The distortion evaluated for this case was bow distortion of the coupon in the longitudinal direction. This example shows that nonlinear responses to high pressure gas quenching are not unique to the geometry presented in the study but exist in most difficult to quench geometric features.

The study presented here shows there is no easy way to determine a suitable gas pressure and velocity profile when turning to high-pressure gas quenching to reduce distortion in difficult-to-quench geometries. While an understanding of the mechanisms responsible for particular distortion modes is critical in the decision-making process, the ability to evaluate numerous conditions before any parts are processed should not be underestimated. The out-of-round distortion, and any shape-change distortion, is mainly due to the nonuniform, solid-state phase transformations, both to and from austenite. If nonuniformities cannot be avoided due to geometric features, the slowest rate possible should not automatically be considered to result in the least amount of distortion. Finite element modeling of the heat-treatment process, using software such as DANTE, can help the engineer choose the proper gas-quenching process parameters to ensure mechanical properties are achieved while keeping distortion to an absolute minimum.

REFERENCES

[1] V. Heuer, K. Loser, and D.R. Faron, "Low Distortion Heat Treatment of Transmission Components", AGMA Technical Paper, October 2010.

[2] Tim Yu, Tony Yu, and D. Herring, "Low-Pressure Carburizing and High Pressure Gas Quenching", Heat Treating Progress, September/October 2003, p 37-41.

[3] Z. Li, "Heat Treatment Response of Steel Fatigue Sample During Vacuum Carburization and High Pressure Gas Quenching Process," Proceedings of MSEC2015, Charlotte, NC, June 2015.

ABOUT THE AUTHOR

Justin Sims is a mechanical engineer with Dante Solutions, where he is an analyst of steel heat-treat processes and an expert modeler of quench hardening processes using Dante software. Project work includes development and execution of carburization and quench hardening simulations of steel components and analysis of heat-treat racks and fixtures. He has a mechanical engineering degree from Cleveland State University.

D. SCOTT MACKENZIE, PH.D., FASM
SENIOR RESEARCH SCIENTIST–METALLURGY /// QUAKER HOUGHTON INC.

Many issues can be solved with quick detection and determination of problem's cause, followed by prompt corrective action.

Troubleshooting induction hardening problems – Part III

In previous columns, I have provided some detail on the sources of problems with induction hardening. While I have tried to be inclusive, there are many sources of problems with induction hardening that are not limited to quenching. In this column, I am providing a summary of the possible problems, possible causes, and a list of possible corrective actions. This list is not inclusive but should cover most of the induction-hardening related problems.

I hope that this chart will be of benefit in reducing induction hardening problems. Should you have any comments, or suggestions for future columns, please contact the author or the editor.

ABOUT THE AUTHOR

D. Scott MacKenzie, Ph.D., FASM, is senior research scientist-metallurgy at Quaker Houghton Inc. For more information, go to https://home.quakerhoughton.com/

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Distortion and Cracking	Low concentration	Increase concentration by adding polymer
	Incorrect quenchant	Change to proper polymer (slower)
	Low quenchant temperature	Increase quenchant temperature
	Low part exit temperature	Increase concentration Shorten time in quenchant
	Degraded quenchant	Dump and recharge
	Overheated part	Reduce heating and heating dwell time Verify part centered in coil or uniform spacing from coil Verify that proper coil is used Verify that proper program is used for part Verify power supply is operating within specification Increase delay before quenching dwell time
	Material defect	Check for laps and seams in part Verify no gouging or machining tool marks
	Non-uniform agitation	Verify operation of quench ring Verify no clogged holes Improve uniformity of quenchant

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Corrosion	Inhibitor depletion	Add recommended corrosion inhibitor per quenchant manufacturer's suggestions
	Low polymer concentration	Increase concentration
	Biological contamination	Add biocide Use biostable quenchant
	Material incompatibility (machine)	Add recommended corrosion inhibitor per quenchant manufacturer's suggestions Verify equipment grounds
	Contamination (inorganic build-up)	Use reverse osmosis (RO water) as make up or initial charge Monitor fluid conductivity Partial dump and recharge using RO water Verify water softeners or RO generation units working properly Add recommended corrosion inhibitor per quenchant manufacturer's suggestions

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Excessive Drag-Out or Consumption	High part exit temperature	Increase dwell time in quench Decrease concentration
	High polymer concentration	Decrease concentration Change to lower solids polymer
	Insufficient drainage	Increase drainage dwell time Use air knife to clean parts and reduce polymer consumption

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Low Hardness or Properties	Incorrect quenchant	Use proper quenchant
	Too high concentration	Add water to reduce concentration
	Quenchant temperature too high	Reduce temperature
	Inadequate quenchant agitation	Verify quenchant flowing uniformly (no holes plugged) Increase flow or pressure
	Underheated part	Increase heating or dwell time Verify power supply is operating within specification Verify proper coil and program are used for hardening operations Verify distance from coil
	Contamination	Clean parts prior to induction hardening Verify skimmers working properly Eliminate contamination (dump and recharge)

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Biological and Odor Problems	Microbiological contamination	Add biocide Clean system removing biomass Use biostable quenchants Examine source and treat with biocide Eliminate contamination of quenchant by coolant Clean parts prior to induction hardening Filter quenchant to 6-8 microns Agitate system on regular basis
	High part exit temperature	Increase dwell time in quench Decrease concentration
	Polymer on tempered part	Clean part prior to tempering Use air knife to clean parts and reduce polymer consumption Increase ventilation
	Poor ventilation	Increase ventilation over induction hardening machine and temper furnace

PROBLEM	POSSIBLE CAUSE	CORRECTIVE ACTION
Foaming	Air entrainment	Verify system quenchant level Verify pump seals Verify no vortex on inlet Reduce spray pressure Add defoamer
	Contamination	Clean parts prior to induction hardening Verify skimmers working properly Eliminate source of contamination Add defoamer
	Low quenchant level	Increase quenchant level Verify no inlet vortex Add defoamer


HIGH TEMPERATURE HEAT TREATMENT IS OUR SPECIALTY.
Across International equipment features targeted and precise temperature control, high quality components, and sophisticated features, all at a great price.
Across International
ACROSS INTERNATIONAL
Material Processing Equipment
AcrossInternational.com
For all your heat treatment needs, choose Across International.
888-988-0899
@acrossinternational
Online 10% off Coupon: REFERRAL20

TONY TENAGLIER
HEAT TREAT PROCESS ENGINEER ///
HITCHINER MANUFACTURING

The goal is always to meet customer requirements. The canvas is the workplace, and the tools go beyond just controlling temperature, time, and atmosphere. Human interaction and tool knowledge are also required as theoretical and practical expectations blend to create the correct cycle.

The art of heat treat: The framework

I was once taught that heat treat is an art as much as it is a science in achieving the results required for the application of the parts. At first this was not clear, despite my academic education in material science engineering. Sure, I learned in class that nothing is perfect in accordance to textbook theory. And that not many practical situations involve sophisticated laboratory equipment and setup of highly controlled variables, but I was not fully aware why it is viewed as an art as much as it is a science until some experiences that helped shape my understanding.

This is not to say that practical situations are wildly out of control. There are still variables to be controlled in the practice such as temperature, time, atmosphere, and so on in heat treating. These variables affect the product most and customers already call them out in their requirements. However, there are other variables which also make an impact that sometimes get overlooked and need to be coordinated into the picture.

An example is how parts are racked to minimize distortion or furnace design considerations. Or the integration of the employees with the equipment. It is also beyond just the "artist's" tools of equilibrium phase diagrams and "TTT" (time, temperature, transformation) curves that constitute the heat-treat cycle; The control thermocouple depth, power going into each zone of the furnace, and PID settings on the temperature controller are amongst additional variables.

There is a balance of theoretical and practical considerations to paint a successful heat-treatment process.

PAINTING 1

Theory: Why Heat Treat

As-cast properties of parts are not desirable for end use applications. Often, the microstructure needs rearrangement to produce desirable properties of the parts in service. Whether it be hardness-related or toughness of the material, common heat-treat tools to achieve these properties are the use of equilibrium phase diagrams and the TTT curves. The equilibrium phase diagram indicates which temperature ranges are most appropriate for hardening or solution temperatures and what phases are present at a given composition and temperature. The TTT curves provide insight as to quench speed requirements and cross-section ability to achieve specific microstructures to yield desired properties.

The cycles are often black and white and hardly ever change based on customer specifications proven long before I was born (I'm a millennial…). Thus, the role of the engineer today is about ensuring these requirements are met in a process that is repeatable and consistent.

Theory says to use the tools, but the engineer must realize when best to bring each tool out. Hitchiner's method of controlled changes on the new Ipsen vacuum heat-treat furnaces demonstrated the importance of using a variety of practices and tools to get the right results. (Courtesy: Ipsen)

Application: Workplace Culture

However, when trying to color in between the black lines, there is a balance of what is stated in the requirements compared to how it gets performed. Equipment and parts do not move without the effort of calculated and voluntary human interaction. From how the operator sets up loads to maintenance personnel working on the furnace, there are many things to consider outside of the temperature, time, and atmosphere requirements for a successful heat-treat cycle.

I realized the most important variable to realize during the workday and orchestrate into the heat-treat picture was probably that of human relations. Someone once told me that 10 percent of one's job was comprised of technical knowledge while the remaining 90 percent was that of knowledge in interpersonal interactions.

Now, not to argue whether it's 90.5 percent or even 9 percent, the lesson I learned was that there is an art to working with others. Often this is quickly realized in disagreements about what to do next in a problem-solving situation. If a part is distorted from, say, vacuum heat-treat, you can consider the approach of changing how it is racked, adjust the pressure quench or even the blower speed, all while making sure there is no loss in material properties. What to change first seems arbitrary sometimes and becomes more a question of what the rest of the team would want to consider first. Reducing the argon pressure or even slowing the blower down could be appealing to the operation manager wanting to reduce the cost to run after being yelled at by the owner the previous day about utility costs being high last month. Depending on who is involved on the team, and even the mood they are in for a given day, personalities can influence the decision to be made for the process.

PAINTING 2

Theory: Tuning the furnace temperature tolerance/The Tools

Even though today's furnaces are built with great skill and precision to maintain temperature tolerances and control, there are still adjustments that need to be performed when a brand-new furnace has been installed. There are tools such as the ability to adjust the percentage of power into the zones of the vacuum furnace, PID settings in the controller, and the depth of the control thermocouple. These are factors to consider when performing the "TUS" (temperature uniformity survey) for the most stringent requirements of AMS2750 preventing overshoot of any thermocouple above the uniformity tolerance.

Application: Tuning the furnace temperature tolerance / The Practice

The theory says to use the tools, but the engineer must realize when best to bring each tool out. As in any experiment, it is good to control each variable one at a time to realize the effects of each. The power percentage tool could be used to tighten the temperature tolerance in each zone in a multipoint TUS. The adjustment of the load control thermocouple could move the tolerance band up or down to get it within the min and max tolerance. The PID settings could help in adjustment of the thermocouples reaching setpoint and not overshooting.

Our method of controlled changes on the new Ipsen vacuum heat-treat furnaces began with the starting point of the control thermocouple being fixed, using the same PID settings from the factory testing, and simply adjusting the percentage of power going to each zone to achieve the uniformity. One variable that was also carefully considered was the mass around the thermocouple. Since the parts were relatively thin, the use of heat sinks was not practical. In order to make the tolerance requirement, the setup was carefully reviewed to ensure a "similar mass" was around the thermocouple.

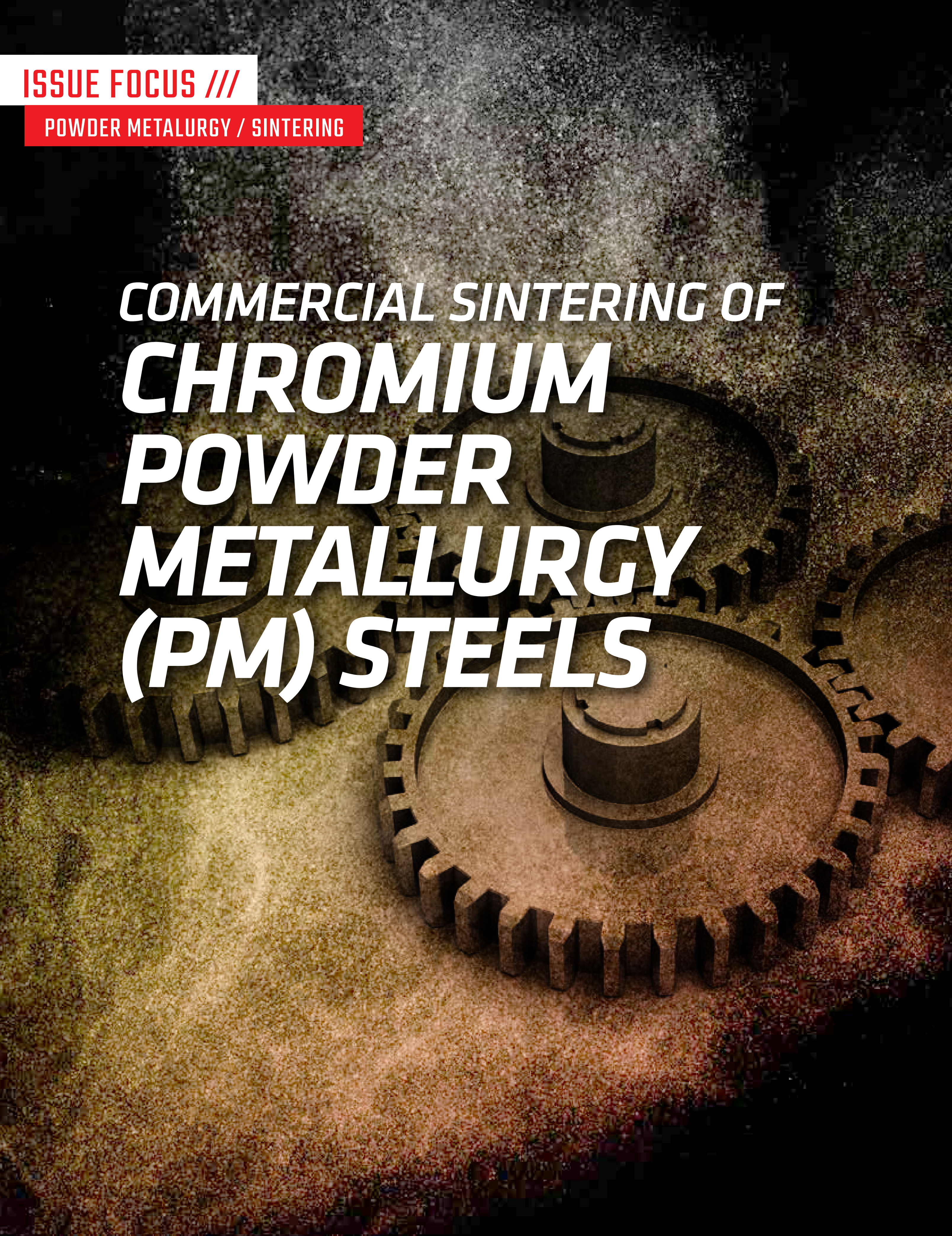
PAINTING THE OVERALL PICTURE

Every day brings a new set of challenges, but the goal is always the same black and white requirements provided by the customer. As an artist has a vision in their mind for what they want to paint, the heat-treat engineer has the vision for how the process is to play out. The canvas is that of the workplace and the tools are beyond just the primary colors of controlling temperature, time, and atmosphere. A manipulation of other variables such as human interactions and knowledge of when to use specific tools is also required. Both theoretical and practical expectations span the palette of colors to spread with a brush across the heat-treat cycle.

Thus, you have the art of heat treat.

ABOUT THE AUTHOR

Tony Tenaglier is the heat treat process engineer at Hitchiner Manufacturing. He earned both a B.S. in material science engineering and an M.A. in psychology. You can contact Tenaglier at tony_tenaglier@hitchiner.com.



COMMERCIAL SINTERING OF CHROMIUM POWDER METALLURGY (PM) STEELS

A recent study showed that pre-alloyed chromium steels could be conventionally sintered under standard industry conditions present today.

By ROLAND T. WARZEL III, AMBER TIMS, and BO HU

Chromium was introduced as a potential alloying element for powder metallurgy (PM) steels in the 1990s. Since then, numerous chromium-containing alloy systems have been introduced and standardized in the North American market. While applications have been successful in using the benefits of these materials, the overall growth has been limited due to perceived concerns relating to the oxidation sensitivity of chromium-containing materials during sintering. In this study, test specimens were prepared from the FL-5108 and FL-5305 material systems and sintered in various commercial sintering furnaces located at North American PM-component manufacturers using their current sintering conditions. Results of the study show that most commercial sintering conditions in North America are adequate to achieve the expected mechanical properties and microstructures for these materials.

INTRODUCTION

As chromium is a carbide-stabilizing element, it is commonly used in wrought low-alloy steel production to provide improvement in hardness and strength over plain carbon steels [1]. Numerous, low-alloy steel compositions using chromium are available and well-documented on the benefits they provide with regards to strength, toughness, and hardenability. In concentrations above 11 percent with iron, chromium can provide stainless properties through the formation of an adherent chromium-rich oxide surface film. Stainless steel materials are one of the largest applications of chromium in wrought-steel metallurgy.

Chromium was first used by PM in the creation of stainless steel powders in the 1930s [2]. Initially, elemental powders were mixed to make the stainless steel compositions.

However, these mixes were quickly replaced via water atomization due to the long sintering times required to achieve chemical homogenization. Water-atomized stainless steel powders were introduced in the 1940s. Further research resulted in powder manufacturing improvements resulting in improved powder properties. This improvement allowed for the first major growth in PM stainless steel to happen in the 1980s with the adoption of antilock brake sensor rings manufactured by ferritic PM stainless steel [2]. Further adoption of stainless steel PM solutions followed soon after with exhaust flanges and sensor bosses.

The initial studies completed on how best to use chromium in PM low-alloy steel compositions followed a similar trend to PM stainless steels. Initial studies looked at using master alloys or ferroalloys containing chromium in combination with traditional low-alloy base irons to create new low-alloy steel compositions [3]. As the chromium was tied with other materials, typically high-temperature sintering was required in order to achieve sufficient diffusion of the chromium. In many cases, the time and temperature required did not allow for full homogenization to take place, so the full benefit of chromium was never realized. Attempts were also made using oil atomization to manufacture chromium alloys, although these materials did not reach full commercial benefit [4-5].

For the pre-alloying technique, alloying elements are added to the molten steel and stirred with argon prior to water atomization. Pre-alloying results in a homogenous distribution of alloying over each powder particle. Traditionally, pre-alloyed PM steels used molybdenum, nickel, and manganese in different levels to provide numerous alloying compositions. These alloying elements were chosen due to their impact on hardenability and the ability to sinter in a wide range of sintering atmospheres, particularly those containing high amounts of oxygen. With the advent of nitrogen/hydrogen sintering atmospheres and the resultant low dew points, elements that were more sensitive to oxygen were able to be explored for new alloys. Pre-alloyed chromium-containing alloying systems were introduced in the late 1990s as a new alloying family [6].

When the new alloys were introduced, instructions were given with regards to the requirements for the sintering atmosphere [6-10]. Thermodynamic calculations were made for the recently introduced alloys to determine the theoretical allowable partial pressures of oxygen in the sintering atmosphere for conventional sintering temperatures of 1,120 °C (2,050 °F). The focus on oxygen in the sintering atmosphere is important as the partial pressure of oxygen in the sintering atmosphere determines whether a metal is oxidized or if the metal oxide is reduced. This chemical reaction happens in accordance with Equation 1.

$$Me + \tfrac{1}{2} O_2 \leftrightarrow MeO \qquad \textbf{Equation 1}$$

After the de-lubrication step in sintering, the oxide layer requires removal in order to allow the particles to neck together, forming the strong bonds that will be the foundation for the final strength of the component. With oxygen-sensitive elements such as chromium, the partial pressure of oxygen must be low in order for the oxides to be sufficiently reduced. As dew point is more commonly used to monitor the sintering atmosphere, the oxygen-partial pres-

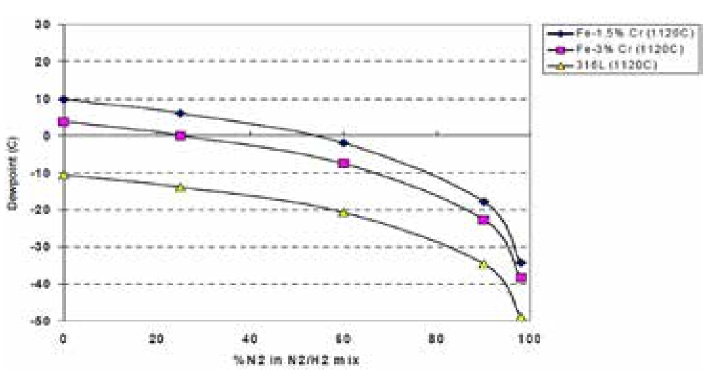


Figure 1: Dewpoint vs. N2/H2 atmosphere composition for the sintering of FL-5208, FL-5305, and SS316 [7-8].

sures were used to calculate the maximum allowable dew points for successful sintering of chromium containing materials [8]. Examples of the dew-point curves generated are shown in Figure 1.

As hydrogen is the more expensive constituent of a nitrogen/hydrogen sintering atmosphere, most component manufacturers use just enough during sintering to accomplish the oxide reduction process. With the pre-alloyed chromium materials, stricter requirements for dew point are required as the hydrogen level is reduced as shown in Figure 1. As much focus was put on this, the initial acceptance of these materials was slow, although many components were successfully realized [11-12]. One of the main reasons for the slow acceptance of these pre-alloyed chromium materials was the reported controls required on sintering atmosphere.

As the majority of sintering atmospheres in North America used a synthetic blend of pure nitrogen and hydrogen, a blind-sintering study was conducted to assess the current sintering situation in North America. Five component manufacturers who are known to sinter in a nitrogen/hydrogen atmosphere agreed to participate in the blind study. These locations would be compared against two locations with many years of experience in sintering chromium-containing materials. The commercial-sintering locations were not made aware of the composition of the bars they were sintering other than they were low-alloyed PM steels. Results show the chromium materials were able to be sintered easily and minimum properties as stated in MPIF Standard 35 were met for all but one location [13].

Base Powder	Chromium	Molybdenum	Manganese	Carbon	Oxygen
Astaloy® CrA	1.8	-	0.08	0.004	0.10
Astaloy® CrM	3.0	0.5	0.07	0.005	0.13
ASC100.19	-	-	0.05	0.003	0.07

Table 1: Chemical Compositions of Base Powders (w/o).

MPIF	Base Powder	Copper	Graphite	Lubricant
FL-5108	Astaloy CrA	-	0.8	0.6
FL-5305	Astaloy CrM	-	0.5	0.6
FC-0208	ASC100.29	2	0.8	0.6

Table 2: Mix Compositions (w/o).

Sintering Location	Peak Temperature	Time at Temperature
Höganäs North America	1120 °C (2050 °F)	30 minutes above 1093 °C (2000 °F)
Höganäs Asia	1120 °C (2050 °F)	30 minutes above 1093 °C (2000 °F)
A	1130 °C (2070 °F)	30 minutes above 1093 °C (2000 °F)
B	1130 °C (2070 °F)	20 minutes above 1093 °C (2000 °F)
C	1120 °C (2050 °F)	26 minutes above 1093 °C (2000 °F)
D	1147 °C (2090 °F)	26 minutes above 1093 °C (2000 °F)
E	1160 °C (2120 °F)	20 minutes above 1093 °C (2000 °F)

Table 3: Sintering Conditions per Locations.

EXPERIMENTAL PROCEDURE

For this study, two pre-alloyed chromium powders were evaluated in MPIF standard compositions [13]. A plain, iron-based copper steel was also evaluated at the same time as a reference material. The chemistries of the base powders used for the study are shown in Table 1.

From these base powders, premixes were manufactured using synthetic graphite (F-10, Imerys) and lubricant (Intralube® E, Höganäs). To manufacture the copper steel, water-atomized copper powder was used (Cu-165, Royal Metal Powders). The mix compositions are shown in Table 2.

For each mix, flat, un-machined tensile specimens and rectangular impact specimens were compacted to a green density of 6.9 g/cm^3[14].

As the purpose of this study was to evaluate the response of the chromium materials to various sintering conditions, a number of locations were used to conduct the sintering. Two Höganäs Technical Centers (North America and Asia) sintered bars as a baseline for the study. Five PM component manufacturers were sent green specimens to perform sintering at their standard conditions in production mesh-belt furnaces. They were not made aware of the exact composition of the bars. The instructions for sintering were to process the bars at their standard manufacturing conditions and report what conditions were used. As they were not aware of the presence of chromium in the alloys, no adjustments were made to their furnaces to accommodate the presence of chromium in two

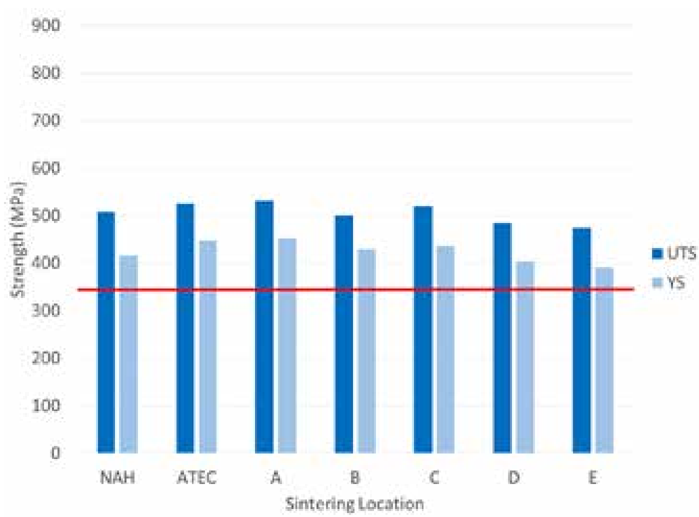


Figure 2: FC-0208 tensile results, red line MPIF minimum yield strength (340 MPa).

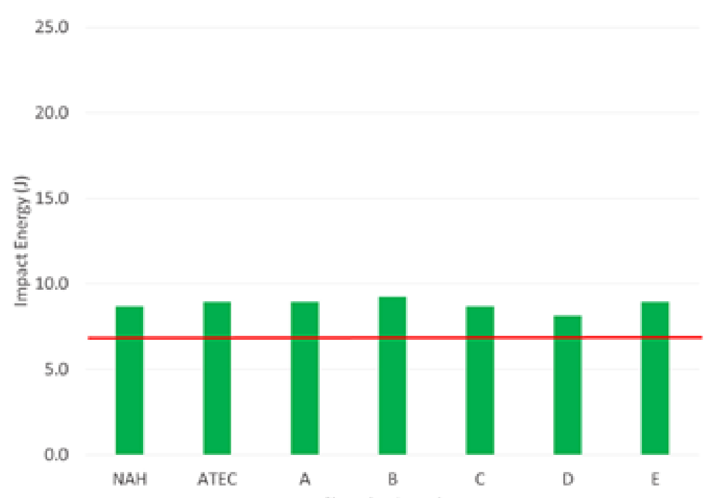


Figure 3: FC-0208 Impact results, red line MPIF typical value (7 J).

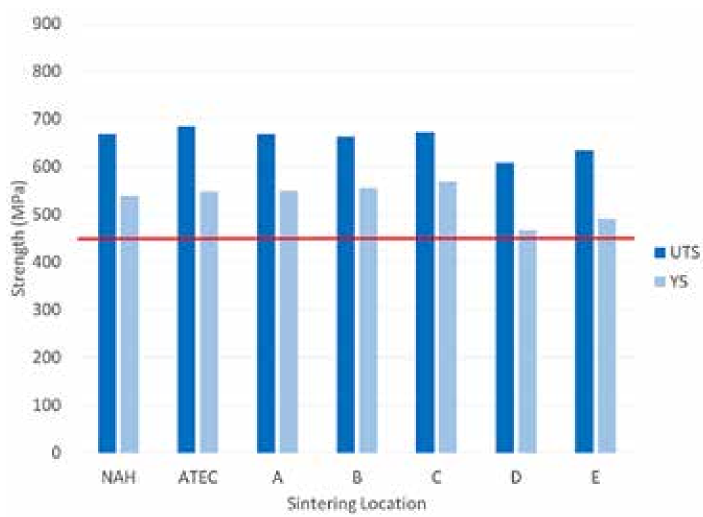


Figure 4: FL-5108 tensile results, red line MPIF minimum yield strength (450 MPa).

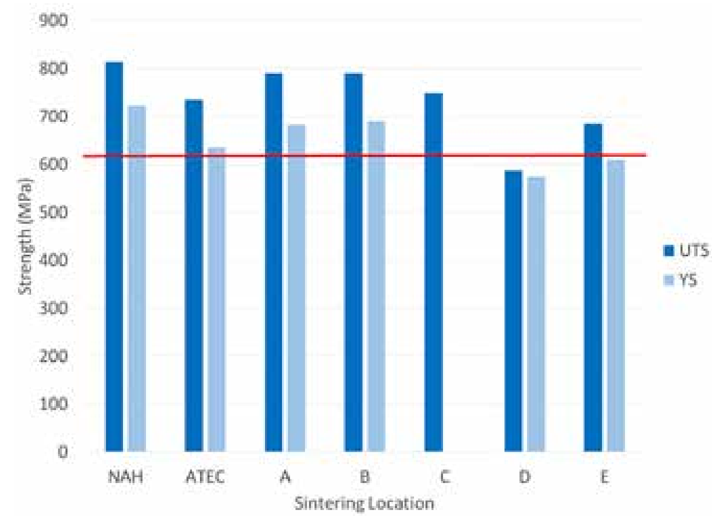


Figure 6: FL-5305 tensile results, red line MPIF minimum yield strength (620 MPa).

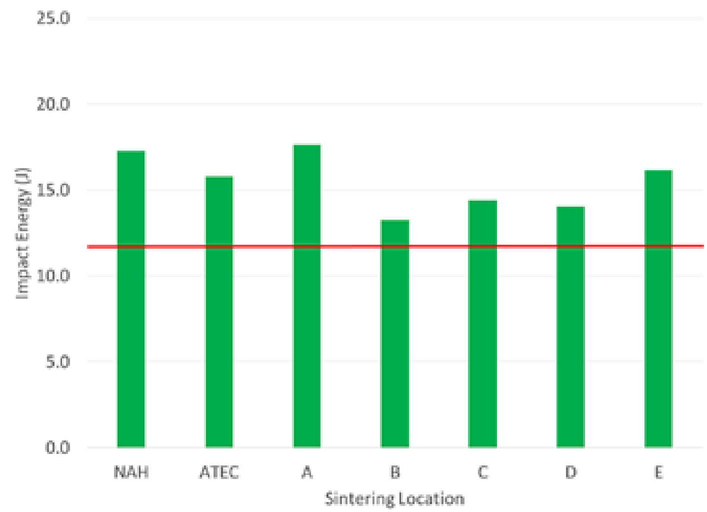


Figure 5: FL-5108 impact results, red line MPIF typical value (12 J).

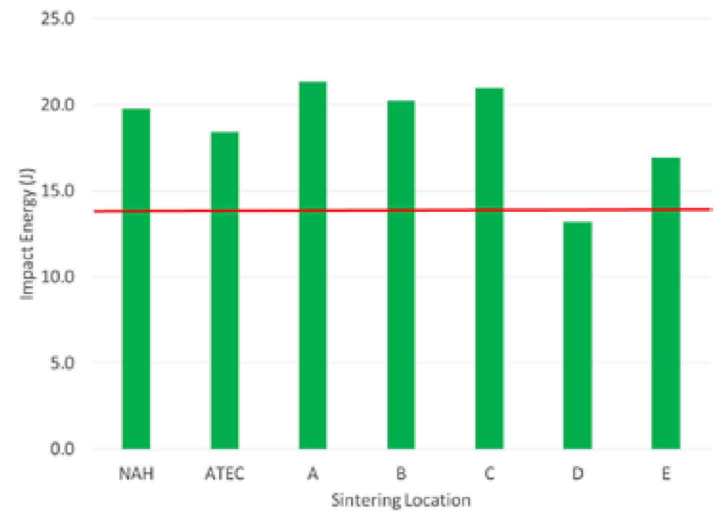


Figure 7: FL-5305 impact results, red line MPIF typical value (14 J).

Location	Density g/cm^3	Apparent Hardness HRB	Carbon %	Oxygen %
NAH	6.72	82	0.81	0.010
ATEC	6.73	81	0.80	0.013
A	6.72	83	0.83	0.011
B	6.72	82	0.80	0.010
C	6.70	79	0.81	0.016
D	6.68	78	0.82	0.010
E	6.69	80	0.80	0.010

Table 4: FC-0208 Density, Apparent Hardness and Chemistry.

With oxygen-sensitive elements such as chromium, the partial pressure of oxygen must be low in order for the oxides to be sufficiently reduced.

of the material systems. For confidentiality reasons, the component manufacturers have been given a letter code. The sintering conditions used in this study are summarized in Table 3.

All of the atmospheres were predominately nitrogen with a small amount of hydrogen (3-10 v/o). Standard cooling speeds were used in all cases.

After sintering, the specimens were evaluated for tensile and impact properties in accordance with ASTM E8 and E23 respectively [15-16]. Apparent hardness, micro-indentation hardness, and sintered-density measurements were done in accordance with MPIF standards [14]. The carbon and oxygen levels were determined on the impact specimens in accordance with ASTM E1019 [17]. Microstructure determination was made using light-optical microscopy.

RESULTS

The tensile results for the FC-0208 material are shown in Figure 2.

The tensile properties for the FC-0208 material all met the MPIF minimum for yield strength. All locations, except for location E, were above 400 MPa for yield strength. The impact results for the FC-0208 are shown in Figure 3.

For the FC-0208, all of the lab results met the typical value for impact energy at this density level. All of the labs were similar in the impact value. The results for density, hardness and chemistry of the FC-0208 are shown in Table 4.

The physical and chemical properties of the FC-0208 materials were similar for all sintering locations.

The tensile results for the FL-5108 are shown in Figure 4.

The tensile results of the FL-5108 all met the MPIF minimum for yield strength. In this case, location D was nearest to the minimum yield strength requirement. The impact results for the FL- 5108 are shown in Figure 5.

All of the sintering locations were above the typical value for impact energy. The physical and chemical results of the FL-5108 materials are shown in Table 5.

Location	Density g/cm³	Apparent Hardness HRB	Carbon %	Oxygen %
NAH	6.89	86	0.77	0.044
ATEC	6.94	91	0.77	0.057
A	6.86	93	0.79	0.038
B	6.92	91	0.78	0.059
C	6.88	92	0.77	0.055
D	6.93	88	0.79	0.068
E	6.88	88	0.77	0.044

Table 5: FL-5108 Density, Apparent Hardness and Chemistry.

Location	Density g/cm³	Apparent Hardness HRB	Carbon %	Oxygen %
NAH	6.84	26	0.43	0.067
ATEC	6.87	17	0.45	0.074
A	6.85	23	0.43	0.052
B	6.88	23	0.45	0.071
C	6.91	33	0.43	0.069
D	6.90	14	0.42	0.089
E	6.86	17	0.44	0.068

Table 6: FL-5305 Density, Apparent Hardness and Chemistry.

The density and hardness levels were similar between the sintering locations. As expected, the oxygen levels were elevated compared to the FC-0208. However, all of the values were typical for this material system and sintering conditions.

The tensile results for the FL-5305 are shown in Figure 6.

The tensile results for the FL-5305 were more mixed compared to the other materials. There were three locations that did not meet the minimum yield-strength requirement. The tensile bars sintered at location C did not yield and no values were measured. Location E was just short of the minimum required value for this material. The impact energy results for the FL-5305 material are shown in Figure 7.

For the FL-5305, one sintering location did not meet the MPIF typical value for impact energy (Location D). The other locations were well above the typical value stated in MPIF Standard 35. The physical and chemical properties for the FL-5305 are shown in Table 6.

The apparent hardness measurements showed a large range between the sintering locations. The apparent hardness ranged from a low of 14 HRC to a high of 33 HRC. All of the carbon levels were similar. The oxygen levels after sintering were higher than the FL-5108 as expected but within the typical range for this material and sintering conditions.

DISCUSSION

Each of the material groups was evaluated for variation on the ultimate tensile strength within the group and then compared. The average strength results, the overall variation, and the coefficient of variation for each material group are shown in Table 7. There were two statistical outliers in the FL-5305 data set and were removed for the data presented in Table 7 and Figures 8 and 9.

Calculation of the overall variation and the coefficient of variation found the FL-5305 to have higher variation compared to the FC-0208 and FL-5108. The FL-5305 data contained more than twice the variation compared to the other two materials even with the statistical outliers removed.

Analysis was also conducted for overall variation to determine

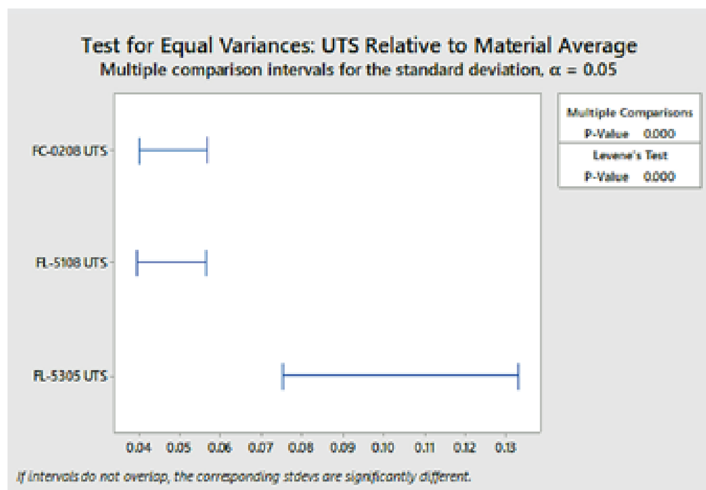


Figure 8: Test for equal variances for UTS relative to material average.

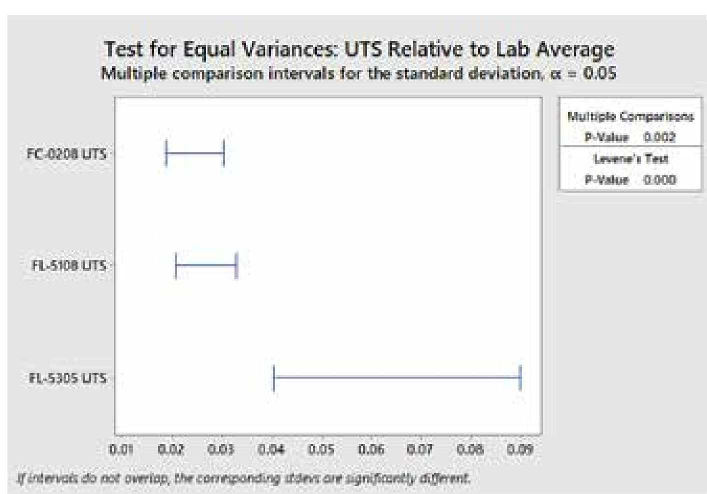


Figure 9: Equal variances for UTS relative to sinter location average.

Property	FC-0208	FL-5108	FL-5305
UTS Average (MPa)	506	657	742*
Overall Variation, Std. Deviation	23	30	71.5*
Coefficient of Variation	0.05	0.05	0.10*

*outliers removed from the data set

Table 7: Overall Variation and Variation Coefficient.

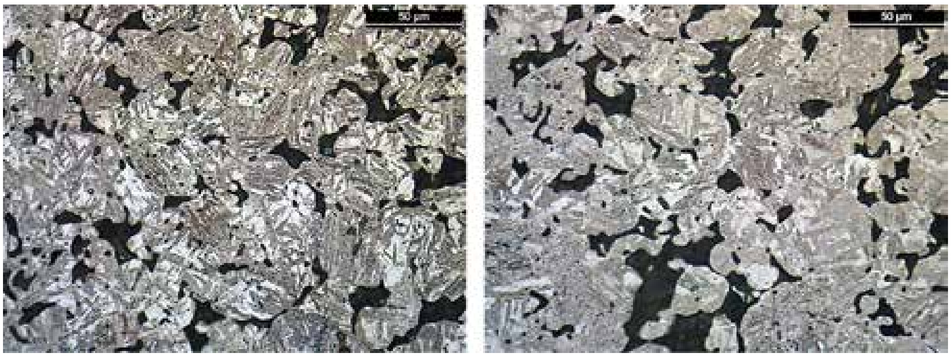


Figure 10: FL-5305 (left: North American Höganäs; right: Location D).

Figure 11: FL-5305 microstructure from Location C.

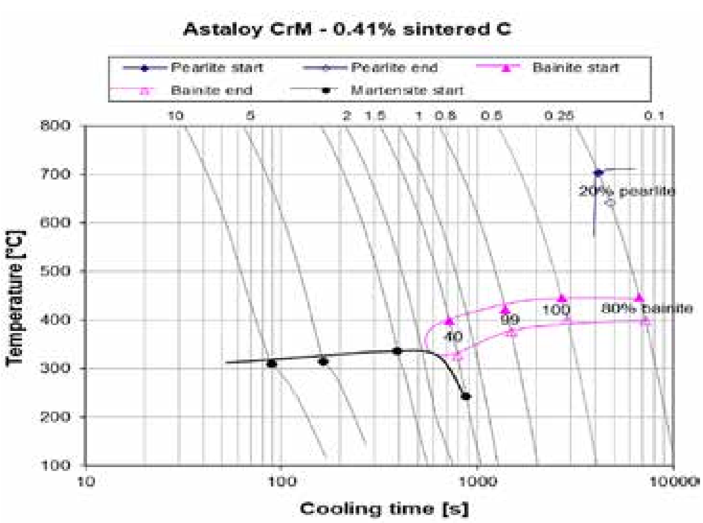


Figure 12: CCT diagram for FL-5305 with 0.4% sintered carbon [19].

if the difference in variation between material groups was statistically significant through test for equal variances. The data is shown in Figure 8.

The difference in overall variation between the FL-5305 and the other two material groups was found to be statistically significant using a confidence level of 95 percent. To determine variation within sinter locations, a test for equal variance was again performed. Those results are shown in Figure 9.

The difference within sinter location variation between the FL-5305 and the other two material groups was found to be statistically significant using a confidence level of 95 percent. There was no statistical difference observed between the FC-0208 and the FL-5108 material groups within sinter location variation as their confidence intervals overlap using a 95-percent confidence level. The statistics confirm what was easily observed through a quick glance at the strength data.

Along with the ultimate tensile strength values, the apparent hardness values of the FL-5305 also had a wide range even though the density and carbon values were similar. As expected, the hardness values directly related to the resultant microstructure. For these bars, the higher apparent hardness values correlated directly to the amount of martensite in the material. Photomicrographs for the lowest strength (Location D, 587 MPa) and highest strength (North American Höganäs, 794 MPa) sintering locations are shown in Figure 10.

There was a difference in the amount of martensite present for these two sintering locations. For location D, the amount of martensite was significantly lower compared to the bars sintered at North American Höganäs. When using color segmentation analysis to determine the phase percentage, the amount of martensite was found to be 5 percent for location D compared to 20 percent for North American Höganäs. As Location C did not yield during tensile testing, these bars were also evaluated for microstructure. A photomicrograph for this material is shown in Figure 11.

Here, a predominately martensitic microstructure was observed. While this resulted in the highest apparent hardness value for the different sintering locations, the ultimate strength was only fourth highest between the labs. This is likely due to the dog-bone tensile specimen used.

MPIF Std. 10 indicates that martensitic materials tested using this specimen configuration typically result in lower values than a machined round specimen. The tensile bars were also not tempered after sintering, which also plays a role in the lower tensile results for Location C [18].

From the microstructure analysis, it was found that Location C and Höganäs North America had higher cooling rates during sintering compared to the other locations. Evaluating the microstructures of Location C and Höganäs North America against the continuous cooling transformation diagram for this material system and carbon level (Figure 12), the microstructure indicates location C had a cooling rate of approximately 1°C/s, Höganäs North America was approximately 0.8°C/s and Location D was 0.5°C/s.

Location A, which had a high-tensile strength of 789 MPa to location D, did not show a large difference in microstructure. Both materials are shown in Figure 13.

As the amount of martensite was similar in each location, microstructure phase formation doesn't entirely explain why location D had the lowest ultimate tensile strength values. The sintered oxygen levels (Table 6), which in turn relate to sintering connection formation, were also highest for location D.

The microstructure sensitivity for the FL-5305 is an order of magnitude higher compared to the other two materials evaluated. Both the FC-0208 and FL-5108 exhibited a pearlitic microstructure, and no large differences were observed between the highest and lowest strength sintering locations. Photomicrographs for these material systems are shown in Figures 14 and 15.

For the FL-5108, again location D had the lowest strength results and highest sintered oxygen values. However, the values were in line with the other sintering location as shown through the variation analysis of the results.

The FC-0208 and FL-5108 were both very similar in the variation-in-strength results and microstructure. They are also very similar in hardenability as documented in MPIF Std 35. The FL-5108 value isn't listed; however, a similar alloy (FL-5208) was used for comparison understanding it would be slightly higher due to the addition of molybdenum. The comparison of hardenability is shown in Figure 16.

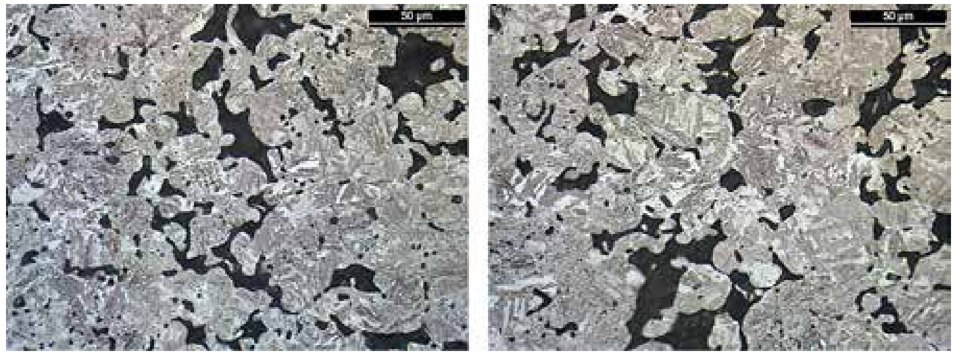


Figure 13: FL-5305 Microstructures (left: Location A, 789MPa; right: Location D, 587 MPa).

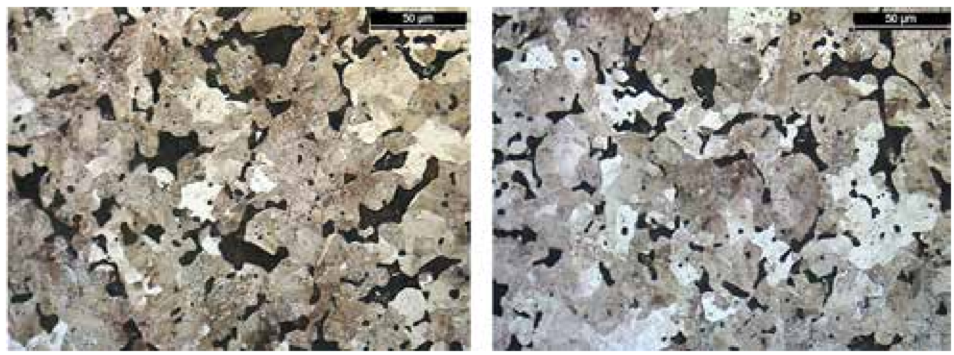


Figure 14: FL-5108 microstructures (Left: Höganäs Asia, 685 MPa; Right: Location D, 608 MPa).

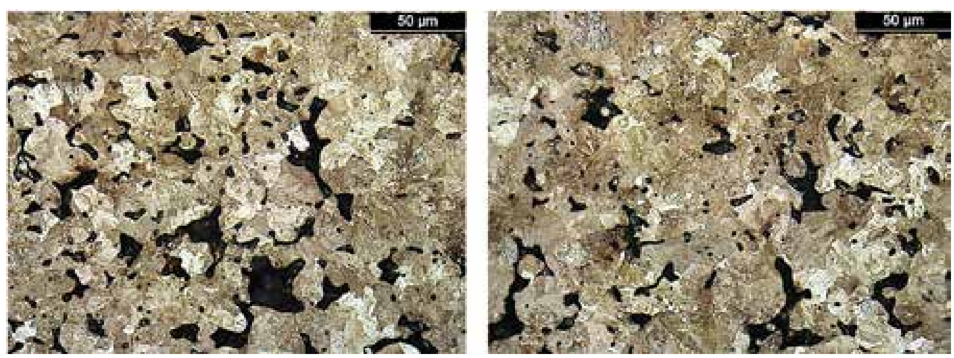


Figure 15: FC-0208 microstructures (Left: Location A, 532 MPa; Right: Location E, 474 MPa).

CONCLUSIONS

From this study, it was shown that prealloyed chromium steels could be conventionally sintered under standard industry conditions present today. Without special consideration for the atmosphere, properties achieved met what is required by industry standards. The lower chromium containing material (FL-5108) was comparable for strength variation with the PM industry's most common material (FC-0208). More variation was observed between the sintering locations when sintering the higher chromium containing FL-5305. As this material has higher hardenability, it is more susceptible to cooling rate differences. Comparison on the microstructure between the low- and high-strength sintering locations found differences in the microstructure formed. In order to achieve the as-sintered properties listed in MPIF Standard 35, care should be taken to ensure the proper cooling rate is being used.

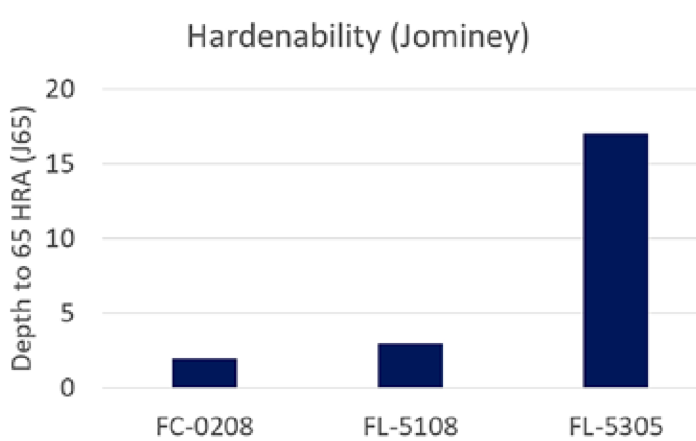


Figure 16: Jominey Hardenability comparison [13].

ACKNOWLEDGEMENTS

The authors would like to acknowledge the component manufacturers who participated in this sintering study. This study would not have been possible without their efforts to sinter the test specimens. The authors would also like to thank Christopher Malec of North American Höganäs for his assistance in the statistical analysis of the strength data.

REFERENCES

[1] G. Totten and M. Howes, Steel Heat Treatment Handbook, First Edition, 1997, Marcel Dekker, New York, NY.

[2] E. Klar, P. Samal, Powder Metallurgy Stainless Steels, First Edition, 2007, ASM International, Materials Park, OH.

[3] D.J. Schaeffler, A. Lawley, R.J. Causton, "Low Carbon P/M Alloy Steels",

Advances in Powder Metallurgy & Particulate Materials, compiled by J.M. Capus and R.M. German, Metal Powders Industries Federation, Princeton, NJ, Vol. 5, p. 93, 1992.

[4] M. Ichadate, et al, "Sintering of Oil Atomized Low Alloy Steel Powders", Horizons on Powder Metallurgy, Part 1, p. 57-60, 1986.

[5] I. Karasuno, "Some Properties of Oil Atomized Low Alloy Steel Powders Containing Chromium", Horizons on Powder Metallurgy, Part 1, p. 53-56, 1986.

[6] C. Lindberg, "Mechanical Properties of a Water Atmized Fe-Cr-Mo Powder and How to Sinter It", Advances in Powder Metallurgy & Particulate Materials, compiled by C.L. Rose and M. H. Thibodeau, Metal Powders Industries Federation, Princeton, NJ, Vol. 7, p. 229, 1999.

[7] B. Lindqvist, "Chromium Alloyed PM Steels – A New Powder Generation", EuroPM 2001, European Powder Metallurgy Association, Vol. 1, p.13, 2001.

[8] B. Lindqvist and K. Kanno, "Considerations when Sintering Oxidation Sensitive PM Steels", Advances in Powder Metallurgy & Particulate Materials, compiled by V. Arnhold, C.L. Chu, W. Jandeska, and H.I. Sanderow , Metal Powders Industries Federation, Princeton, NJ, Part 13, p. 278, 2002.

[9] R. Frykholm, P. Johansson, O. Bergman, "Considerations when Sintering Chromium- Alloyed PM Steels", Sintering 2005, Grenoble, France.

[10] O. Bergman, B. Lindqvist, S. Bengtsson, "Influence of Sintering Parameters on the Mechanical Performance of PM Steels Prealloyed with Chromium", PM 2006, Busan Korea.

[11] I. Howe, T. Haberberger and R. Cerini, "Composite Assembled Cam Shafts", SAE Small Engine Tech Conference, Society of Automotive Engineers, Detroit, MI, 2008.

[12] D. Milligan, I. Hower, T. Haberberger and R. Cerini, "Lean Cr Containing PM Materials for Optimized Cost Performance", SAE Small Engine Tech Conference, Society of Automotive Engineers, Detroit, MI, 2008.

[13] MPIF Standard 35, Material Standard for PM Structural Parts, 2018 Edition, Metal Powder Industries Federation, Princeton, NJ.

[14] Standard Test Methods for Metal Powders and Powder Metallurgy Products, 2016 Edition, Metal Powder Industries Federation, Princeton, NJ.

[15] ASTM International Standard E 8-16, Standard Test Method of Tension Testing of Metallic Materials.

[16] ASTM International Standard E 23-16, Standard Test Methods for Notched Bar Impact Testing of Metallic Materials.

[17] ASTM International Standard E 1019-11, Standard Test Method for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques.

[18] R. Warzel III and A. Neilan, "Effect of Composition and Processing on the Precision of Sinter Hardening Powder Metal (PM) Steels", Advances in Powder Metallurgy & Particulate Materials, compiled by D. Christopherson & R.M. Gasior, Metal Powder Industries Federation, Princeton, NJ, 2013, part 5, pp. 62-73.

[19] Höganäs PM School Handbook, Metallography – Handbook For Sintered Components, 2015, Höganäs AB, Höganäs Sweden.

ABOUT THE AUTHORS

Roland T. Warzel III, Amber Tims, and Bo Hu are with North American Höganäs in Hollsopple, Pennsylvania. This paper was originally presented at POWDERMET2019, Phoenix, Arizona, and is included in the Advances in Powder Metallurgy & Particulate Materials – 2019, Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-0669.

LASER SINTERING OF THERMOSET POLYIMIDE COMPOSITES

Determining if laser sintering can be applied to high-temperature thermoset polyimides to enhance covalent bonding between layers through the curing of the reactive endcaps, as compared to conventional thermoplastic polymers that display poor z-directional mechanical properties.

By KATHY C. CHUANG, TIMOTHY J. GORNET, KATE SCHNEIDAU, and HILMAR KOERNER

Selective laser sintering (SLS) is an additive manufacturing technique that builds 3D models layer-by-layer using a laser to selectively melt cross sections in powdered polymeric materials, following sequential slices of the CAD model. SLS generally uses thermoplastic polymeric powders, such as polyimides (i.e. nylon), and the resultant 3D objects are often weaker in their strength compared to traditionally processed materials due to the lack of polymer inter-chain connection in the z-direction. Previous efforts showed the challenges of printing a melt- processable RTM370 imide resin powder terminated with reactive 4-phenylethynylphthalic anhydride by LS, due to its inherently low viscosity of these oligomers. This paper presented the first successful 3D printing of high temperature carbon fiber filled thermoset polyimide composites, followed by post cure cycles to promote additional crosslinking for achieving higher temperature (T_g = 370°C) capability. The processes to build tensile specimens and a component by LS, and the characterization of RTM370 imide resin by DSC and rheology as well as evaluation of the LS printed polyimide composite specimens by SEM and mechanical tests will be discussed.

1 INTRODUCTION

Selective laser sintering (SLS) is an additive manufacturing technique that builds 3D models by using a laser to selectively melt a cross section in powdered polymeric materials layer-by-layer, following the slice of each computer-aided design (CAD) scan. The most commonly used polymers for SLS are polyamides 11 and 12 powders with use temperature ranged from 150-185°C [1-2]. Recently semi-crystalline PEEK of varied LS-grade powders, with a melting temperature (Tm) of 343-370°C, have to be heated to 380°C to be manufactured into 3D objects by a more elaborate high temperature LS (HT-LS) machine and process to afford products with a glass transition temperature (T_g) of 150°C [3-4]. However, the 3D objects build by these thermoplastic polymers are often weak in their strength compared to traditionally processed materials due to the lack of polymer inter-chain connection in the z-direction. There are attempts to process epoxy resin by SLS [5] or impregnating liquid epoxy into green parts built by SLS using polyamide mixed with carbon fiber [6]. However, the real incentive of developing a SLS process for thermoset resins lies in the potential of raising the use temperature to 250-300°C for 3D-printed objects and the prospect of printing polymer carbon fiber composites for aerospace applications. Previously we reported the challenges of attempting to print a melt-processable RTM370 imide resin powder terminated with reactive phenylethynyl (PEPA) groups into thermoset polyimides by LS [7].

As described in previous reports, we realized the viscosity of resin designed originally for resin transfer molding (RTM) was too low, and the laser apparently only melted the resin without curing the reactive PEPA endcap. As a result, the LS-printed resin chips could not hold much integrity upon postcure above 250°C. To overcome the low viscosity of the resin, the standard RTM370 resin was further staged for 2-4 hours at 300°C to promote chain extension while still maintaining melt-processability and avoiding extensive crosslinking of PEPA endcap.

Figure 1: A small build chamber in a build piston.

2 EXPERIMENTATION

Standard RTM370 resin produced by Imitec Inc. was further staged for 2-4 hours at 300°C to promote chain extension while avoiding extensive crosslinking of the PEPA endcaps for use in LS. Short carbon fibers (length ~60μ) were obtained from Advanced Laser Materials, LLC (now part of EOS North America). Carbon fiber (35 wt%) was added to the RTM370 resin further staged at 300°C for three hours, and then dry blended in a rotating drum tumbler to ensure a consistent blend. To save the materials used for this LS study, SinterStation 2500 was retrofit with a small 10 x 10 cm build chamber (Figure 1) out of the original build piston. Both the build piston/cylinder and the feed cartridges would need to be modified. The temperature of the part bed is monitored and controlled by an infrared sensor. The temperature of the feed cartridge is also measured by a thermocouple. The rheology was performed in the parallel plate geometry with 1g of imidized powder at a ramping rate of 4°C/min and frequency at 10 rad/sec, using an Ares Rheometer. The differential scanning calorimetry (DSC) was conducted on TA Instruments Q1000 with 5°C/min heating rate. The thermal conductivity was measured on a C-Therm TCi thermal conductivity analyzer. AccPyc II Pycnometer by Micromeritics was used to measured porosity in LS disk.

3 RESULTS AND DISCUSSION

3.1 Laser Sintering of RTM 370 Resin

Our previous attempt to produce durable resin chips by LS using "as received" RTM370 powder indicated that its viscosity (~30 poise) was too low for LS, because it was originally designed for resin transfer

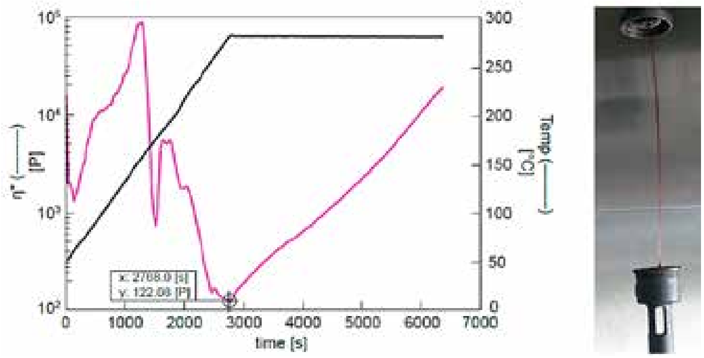


Figure 2: Viscosity of RTM370 resin staged at 300°C for 2.5 h and the filament formation.

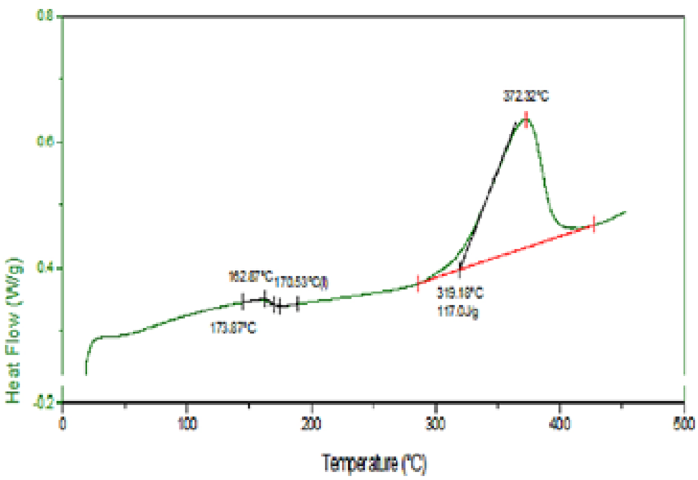


Figure 3: DSC of RTM370 resin after staging at 300°C for 2.5 h.

PARAMETER SET I

- **Part Bed Temperature: 180 °C 180°C**
- **Laser Power: 25W 25W**
- **Scan Speed: 1016 cm (400 in/s) 10,180 cm/s (400 in/s)**
- **Scan Spacing :0.076 cm (0.003 in)**

Table 1: Parameter Set I.

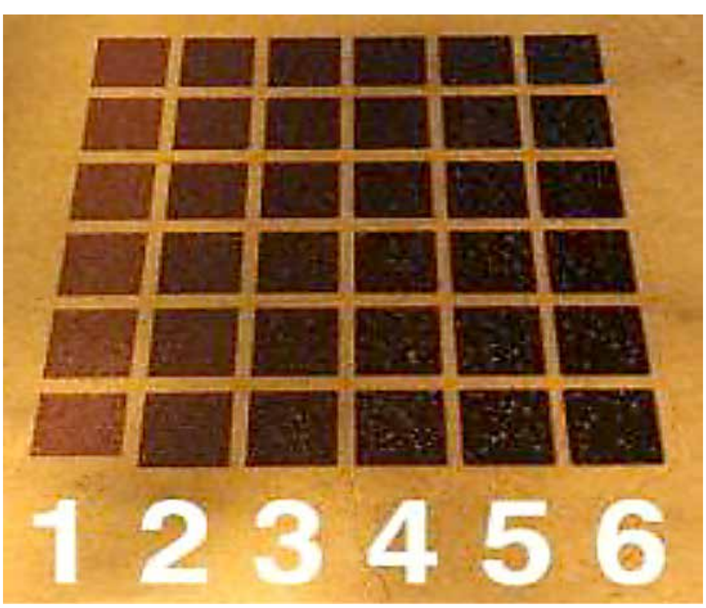


Figure 4: LS printed resin chips.

PARAMETER SET II

- **Part Bed Temperature: 180 °C**
- **Laser Power: 25W**
- **Scan Speed: 1016 cm/s (400 in/s)**
- **Scan Spacing :0.0076 cm (0.003 in)**

Table 2: Parameter Set II.

Figure 5: Carbon-fiber-filled RTM370 composite chips by LS.

Figure 6: Carbon-fiber-filled LS-printed disk (left) and neat resin disk (right).

molding (RTM) application. Therefore, RTM370 resin was further staged at 300°C for 2.5 hours to afford a resin with higher viscosity, indicative of higher chain extension as evidenced by the formation of a filament inside the rheometer (Figure 2). A DSC thermogram showed a T_g of ~170°C and a PEPA endcap curing at 372°C (Figure 3).

Using the parameter listed in Table 1, several sets of 6 resin chips (1-6 scans) were produced by LS using further staged RTM370 resin, and they appeared very uniform (Figure 4). However, when warming to 200°C in an oven, the resin chips appeared to soften. Then the chips started to melt and lose integrity when reaching 250°C, indicating that the PEPA endcaps probably have not been fully cured.

3.2 Laser Sintering of RTM 370 /Carbon Fiber Composites:

To improve the stiffness of the build layers, RTM370 resin was mixed with 35 percent carbon fibers (~60 μl in length) and dry blended for printing composite specimens by LS. The single layer square samples all scanned successfully (Table 2) and exhibited greater green strength (Figure 5) than any of the neat resin with or without further staging at 300°C in previous LS runs. It is believed that the filled carbon fibers not only provide the stiffness but also significantly improve the heat transfer to the resin/fiber mixture on the powder bed upon irradiation of the laser. The depth of penetration (chip thickness) also increased with a greater number of scans, although a DSC thermogram still showed significant exotherm of the uncured PEPA endcap at 370°C, indicating that the green composite disks are not fully cured yet. The thermal conductivity of the carbon fiber-filled RTM370 LS disk in Figure 6 (0.6 W/m.K, porous) is almost three times that of a neat resin disk (0.2 W/m.K, dense). The porosity of the LS disk is ~54% based on gas pycnometer measurement.

3.3 Laser Sintering of Composite Specimens:

I) 100 μm Thickness Layers: With the success of producing the single scan composite chips with integrity, the objective shifted to

PARAMETER SET III

- Part Bed Temperature: 180 °C
- Feed Temperature: 90 °C
- Layer Thickness: 100 μm (0.004")
- Laser Power: 25W
- Scan speed: 106 cm/s (400"/s)

Table 3: Parameter Set III.

Figure 7: Composite feed bed cracking due to high heat.

Figure 8: Layers shifting during the build and post-building.

focus on building composite specimens and parts by LS. The initial build parameters used is listed in Table 3.

A layer of material was spread across the build platform and heated up to the specified temperature to observe changes in state. During the addition of a powder layer, the material was not rolling well in front of the roller/spreader but instead was "bulldozing." Due to the change in the location of the thermocouple to control the feed temperature, it was thought that the powder may be overheating. Over several build attempts, the feed temperature was dropped to 70°C, and the feed heater output limit was dropped from 60 percent to 20 percent to prevent the feed area from melting. If the temperature of the feed powder gets too high, it can cause the powder to agglomerate and/or melt. An indicator of the powder temperature getting to high is the feed bed "cracking" shown in Figure 7.

A number of builds were attempted at these conditions, but in all cases, the layers would shift as the roller/spreader assembly moved across the build area. The layer shifting can also be caused by shear forces generated between the previously melted layer and the new powder being applied to the build area. This is most evident when the material does not roll easily and instead bulldozes. This shifting is shown during the build and post-build in Figure 8.

II) 125μm Thickness Layers: To build thicker layer, the laser power was increased to 31W, (Table 4) and multiple runs of tensile bars were attempted. More layers could be successfully completed compared to the 100μ layer builds.

The layer shifting was decreased, but warping and curling was seen during the build. Curling is generally a temperature issue caused by non-uniform cooling that contributed to parts curling or warping like a banana in the build area (Figure 9). The part then "rocks" as the roller/spreader assembly moves across the part bed.

PARAMETER SET IV

- Part Bed Temperature: 180 °C
- Feed Temperature: 90 °C
- Layer Thickness: 125 μm (0.005")
- Laser Power: 31.3W
- Scan Speed: 1016 cm/s (400"/s)
- Scan Spacing : 0.076 cm (0.003")
- Number of scan: 2

Table 4: Parameter Set IV.

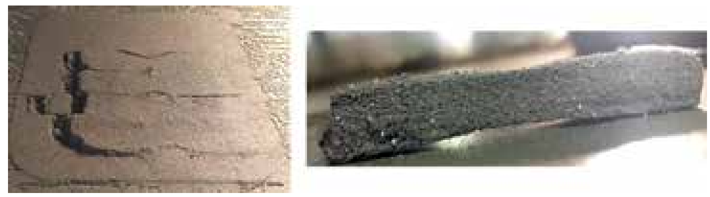


Figure 9: Warping during the build and sample curling post-building.

PARAMETER SET IV

- Part Bed Temperature:180°C
- Feed Temperature: 90°C
- Layer Thickness: 150μm (0.006 in)
- Laser Power: 38W
- Scan Speed: 1016 cm/s (400"/s)
- Scan Spacing: 0.076 cm (0.003 in)

Table 5: Parameter Set V.

Figure 10: Tensile specimens during LS build process and after post-build.

It was determined that the curling may be due to the lack of dedicated part piston and cylinder heating in the small build volume retrofit. The machine would be preheated for 2-4 hours at the set temperatures to allow for all of the metal parts to come to equilibrium and heat soak in an attempt to minimize curling. While the curling was becoming much less visible, there was still layer-shifting occurring.

III) 150 μm Thick Layers: The layer thickness was increased to 150 μm, and the experiments were repeated by increasing the laser power to 38W (Table 5). With the modified feed cartridge, it was difficult to keep the thermocouple precisely located to just below the surface of the powder. This resulted in issues with consistent feed-temperature control. However, a number of subscale tensile specimens (Figure 10) for postcure and mechanical tests were successfully 3D printed, along with a few round disks (25 mm diameter x 2 mm thick) and 0.6 cm cubes printed for characterization using the parameters listed in Table 5.

IV) Particle Size Analysis: A particle size analysis was conducted on the carbon-fiber-blended material. It was noticed that two new peaks appeared at 254 μm and 1,054 μm (Figure 11), relative to the original batch of RTM 370 powder with a single peak at 70 μm between 40-120 µm prior to further staging at 300°C (Figure 12). These are likely due to agglomeration of resin particles after additional staging/heating, as well as carbon-fiber entanglement during the dry blending of the fiber with resin powder. The surface roughness of LS-printed composite specimens may be the result of uneven particle size distribution/ agglomeration as compared to the more uniform neat LS disks. The layer thickness would be increased to account for the difference.

3.4 Characterization of LS-Printed Tensile Specimens:

Half a dozen dogbone subscale specimens (6.5cm x 0.9 cm x 0.5cm thick, neck width 0.3 cm) were printed following the protocol described in the previous section. The as-print specimens were subjected to multi-step gradual temperature rise (3-5°C/min) and constant temperature holds with final post-cure at 343°C (650°F) for 16 hours in order to complete the total cure of PEPA endcaps and achieve optimal mechanical properties. A test of dogbone specimens misbehaved when testing at room temperature. However, all tensile testing at 288°C (550°F) fractured nicely at the mid-section of dogbones as shown in Figure 13a-13c, and a SEM micrograph of the fractured LS-printed composite (Figure 14) revealed milled fibers were incorporated into the LS-printed specimens. Furthermore, Table 6 indicated that the samples retained similar tensile strength at 288°C as well as at room 19°C.

3.5. Laser Sintering of Composite Parts

Following the success of printing composite specimens at 150µm thick layers, efforts began to focus on printing subscale components such as a bracket, using the same parameters. Initially the bracket was attempted to be constructed at a 50 percent scale. The part was able to complete, but the warping and shifting were too much to consider it a successful part. (Figure 15a). Using longer heat soak times helped somewhat, but not until there was full thermal control in the piston and cylinder heater temperature control as well as the overhead part bed heating (Figure 15b). Eventually, the 30 percent scaled geometric bracket was built well as successful 3D components by LS (Figure 15c). The "green" bracket was subjected to multi-step post-cure cycles by heating gradually at 3-5°C/min from room temperature along with multiple holds at steady temperature for an extended period of time and a final post-cure at 365°C for 16 hours to complete the total curing of a PEPA endcap to form a crosslinked network, while avoiding a dimensional change due to softening at an elevated temperature during the process. No noticeable dimensional change was observed in the post-cured parts. This is the first known high-temperature polyimide composite parts (Tg = 370 °C) printed by laser sintering in the additive manufacture field that can be used for >300°C aerospace applications.

4 CONCLUSION

This project was initiated to determine if laser sintering can be applied to high-temperature thermoset polyimides to enhance covalent bonding between layers through the curing of the reactive endcaps, as compared to conventional thermoplastic polymers that display poor z-directional mechanical properties. A melt-processable RTM370 imide resin originally designed for resin transfer molding (RTM) [8] and resin film infusion (RFI) [9] was dry blended with 35 wt% finely milled carbon fibers and used as a feedstock for laser sintering. Using a laser power of 25-38W and a bed temperature of 180°C along with a feed temperature of 80°C, tensile specimens and subscale composite brackets were successfully printed into green parts (not fully cured) by laser sintering. The filled carbon fibers apparently impart not only the stiffness but also higher heat transfer efficiency to enable building thicker layers, as compared to the neat resin in the LS process. To complete the total cure of the PEPA endcaps, the green parts were subjected to slow, multiple-stage, post-cure to form a fully crosslinked network as the

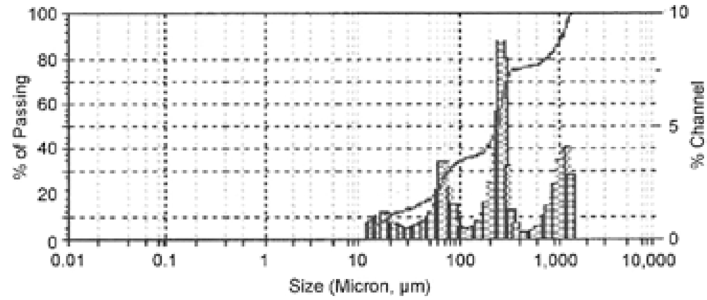


Figure 11: Particle size distribution of further staged RTM370 blended with milled carbon fiber.

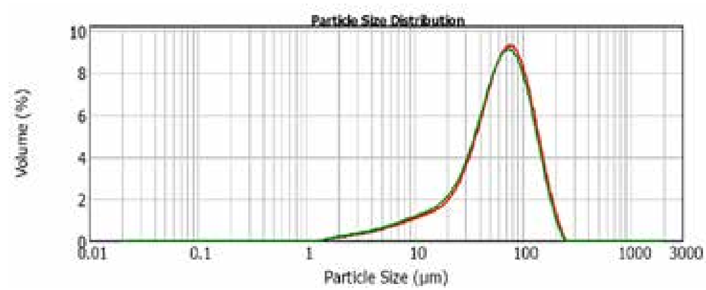


Figure 12: Original particle distribution of RTM370 for RTM process.

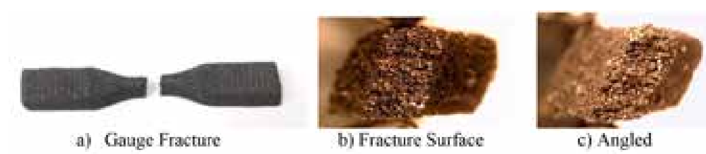


Figure 13: Fracture surfaces of dogbone subscale tensile specimens.

Figure 14: SEM micrograph showed milled carbon fibers at fracture surface.

TENSILE PROPERTY OF LS-PRINTED SPECIMENS		
SAMPLE NO.	**TEST TEMPERATURE**	**STRENGTH, (MPa)**
A-1	292 °C (558 °F)	22.78
A-2	289 °C (552 °F)	28.09
B-1	289 °C (552 °F)	26.67
B-2	287 °C (549 °F)	26.22
Average		26 ± 2
C-1	19 °C (66 °F)	23.04
C-2	19 °C (66 °F)	26.09
Average		25 ± 2

1) Test rate: 0.127 cm/min (0.5 in/min); Grip pressure: 1.38 MPa (200 psi)
2) Furnace temperature equilibrated and specimens conditioned 15 min before testing
3) Sample A, B, and C belongs to 3 different built lots of similar size and thickness

Table 6: Tensile Property of LS-Printed Specimens.

Figure 15: Stages of composite brackets printed by LS.

final parts without any significant dimensional change. Essentially, a thermoset polyimide composite 3D network was achieved by using melt-processable imide oligomers terminated with reactive PEPA endcaps for LS processing. To the best of our knowledge, this paper demonstrates the first major advance in the additive manufacturing of high temperature polyimide composites with glass transition temperature (Tg) of 370°C printed by LS. Another advantage of this major breakthrough is that these thermoset oligomers can be 3D-printed by a regular laser sintering machine, without the need of using the high temperature laser sintering process (HT-LS, 250-380°C) required for processing commercial thermoplastic PEEK with 150-185°C use temperature. In essence, this research ushers in a new era of using additive manufacturing to produce high temperature thermoset polyimide composite parts for >300°C applications.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the funding support from Air Force Research Labs at Wright-Patterson Air Force Base in Dayton, Ohio, for this project. In addition, we would like to thank the staffs at Rapid Prototyping Center at the University of Louisville, Kentucky, for conducting the laser sintering and Linda McCorkle and Daniel Scheiman of Ohio Aerospace Institute for performing the rheology, thermal analysis, and thermal conductivity. Furthermore, the team effort from the University of Dayton Research Institute (UDRI), including Thao Gibson's contribution in cure characterization, Andrew Abbott and Ron Trejo's help in mechanical testing and Marlene Houtz's X-ray CT, are greatly appreciated.

REFERENCES

[1] David K. Leigh: "A Comparison of Polyamide 11 Mechanical Properties between Laser Sintering and Traditional Molding", Proceedings of Solid Freeform Fabrication Symp. 574-605 (2012).

[2] R. D. Goodridge, C. J. Tuck, R. J. M. Hague: "Laser Sintering of Polyamides and Other Polymers", Progress in Materials Science, 57(2), 229-267 (2012).

[3] S. Berretta, K. E. Evans, O. Ghita: Processability of PEEK, "A New Polymer for High Temperature Sintering", European Polymer Journal, 68, 243-266 (2015).

[4] S. Brretta, Y. Wang, R. Davies, O. R. Ghita: "Polymer Viscosity, Particle Coalescence and Mechanical Performance in High Temperature Laser Sintering", Journal of Materials Science, 51(10), 4778-4794 (2016).

[5] WO2017046132, Le-Huong, Nguyen: "Use of thermosetting Polymeric Powder Composition."

[6] WO2016127521, Chune Yan, Wei Zu, Yusheng Shi, Jie Liu: "3D Printing Manufacturing Method of Short fiber Reinforced Thermosetting Resin Composite Product."

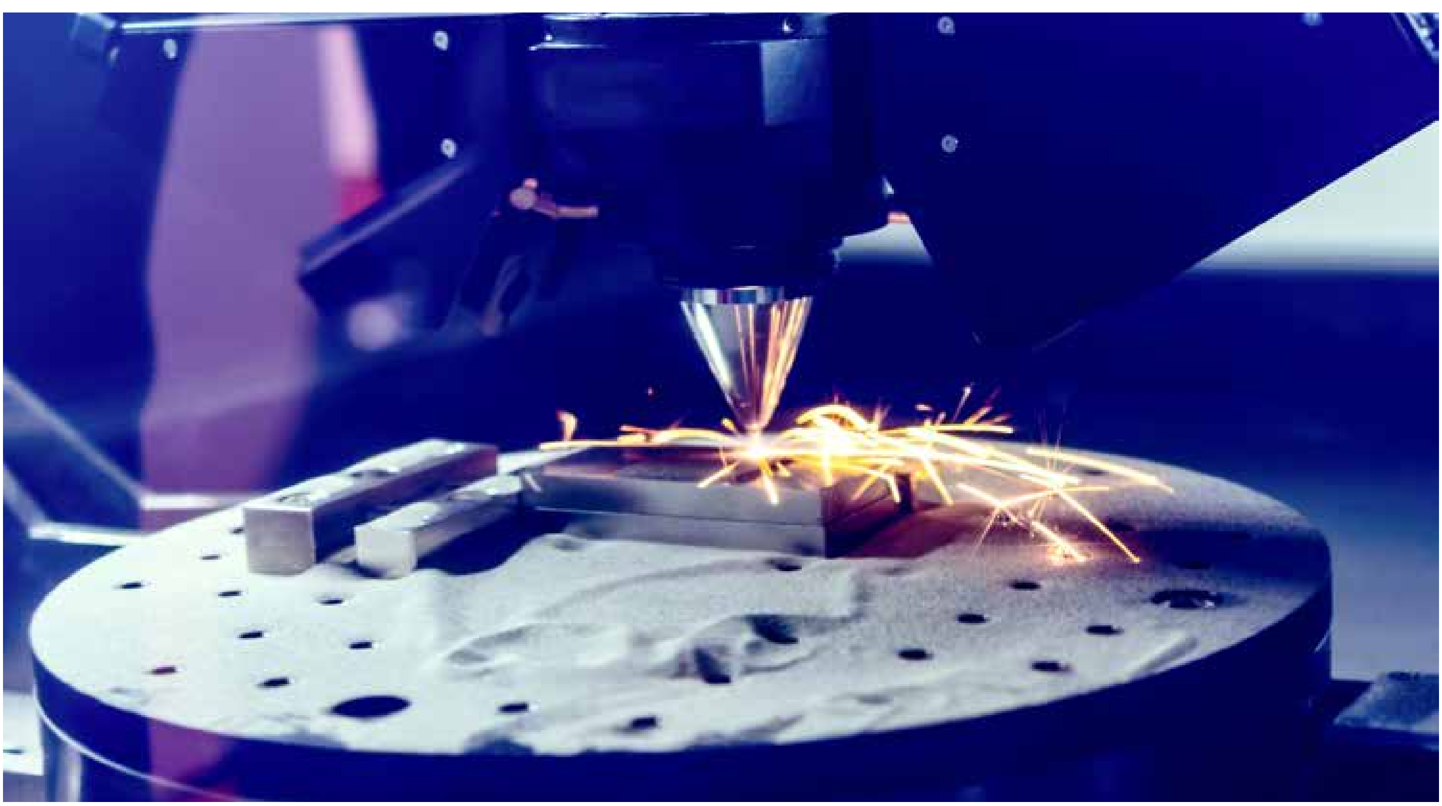
[7] Kathy C. Chuang, Timothy Gornet, Hilmar Koerner: "Challenges in Laser Sintering of Melt-Processable Thermoset Imide Resins", Proc. of CAMX Conference, September 26-29, Anaheim, CA (2016).

[8] K. C. Chuang, D. M. Revilock, J. M. Pereira, J. M. Criss, Jr., E.A. Mintz: "High Temperature RTM370 Polyimide Composites Fabricated by RTM: Characterization and Impact Testing", SAMPE Journal, 40(5), 48-57 (2013).

[9] Kathy C. Chuang, Thomas A. Yip, Ronald B. Kollmansberger, Thomas K. Tsotsis: "Evaluation of RTM370 Polyimide Composites by Resin Film Infusion", SAMPE Technical Conference, June 2-5, Seattle, WA (2014).

ABOUT THE AUTHORS

Kathy C. Chuang is with the NASA Glenn Research Cenrter in Cleveland, Ohio. Timothy J. Gornet and Kate Schneidau are with the Rapid Prototyping Center at the University of Louisville in Kentucky. Hilmar Koerner is with the Wright Patterson Air Force Base in Dayton, Ohio. This paper is declared a work of the U.S. Government and is not subject to copyright protection in the United States. It was presented at the Composites and Advanced Materials Expo; September 23-26, 2019, in Anaheim, California.



OFFERING A WORLD OF STRENGTH

Modernization of vacuum furnace controls pushes the limits in equipment performance and extends the furnace's useful life. In this photo, the new UPC control system based on the Protherm 710 controller includes chart recording and recipe control with specific programming for automatic leak test cycles and guaranteed soak for medical industry requirements. (Courtesy: Nitrex)

Having recently ushered in a comprehensive rebranding strategy, Nitrex continues to be a global partner offering modern nitriding/nitrocarburizing and vacuum heat-treat solutions, technologies, equipment, and services.

By KENNETH CARTER, THERMAL PROCESSING EDITOR

Nitrex, a leading global provider of fully integrated heat-treating solutions and technologies, has experienced rapid growth and expansion in its 35 years in the industry, and with that growth, the company has been able to offer a substantial range of services.

With all that it has to offer, Nitrex CEO Jean-Francois Cloutier essentially defines the company as a "solutions provider."

It might be a simple phrase, but what Nitrex has accomplished is anything but as it rolls out efforts designed to present itself under one brand.

"It was mainly to support the growth, and where we want to go," Cloutier said. "Because we want to keep growing."

THREE DIVISIONS, ONE COMPANY

Now, the company's various brands will operate under one umbrella company. Along with Nitrex, the new brand will include UPC-Marathon, but legally operating as United Process Controls, and G-M Enterprises, which is the newest addition to the Nitrex Turnkey Systems portfolio.

"The company operates with three divisions," Cloutier said. "One is called Nitrex Turnkey Systems, which designs and manufactures nitriding and vacuum heat-treating systems. Another division is Heat Treating Services, composed of multiple commercial services centers located in the U.S., Mexico, Poland, Italy, Canada, and China. Finally, United Process Controls, branded as UPC-Marathon from now on, is a controls and solutions provider — process controllers, oxygen probes, analyzers, automation software, electronic flow meters and controllers, atmosphere mixing panels, but also furnace upgrades and heat-treating plants' modernization projects."

Cloutier stressed that these three divisions help the company stand out among others in the heat-treating industry.

"It allows us and our people to go beyond selling the product," he said. "Because most of the time, when customers come to us, sometimes it's to buy a component or buy a furnace. But usually they come to us because they're looking for a solution. They're looking to solve a problem. And solving a problem or providing a solution requires some knowledge of the application, of the industry, even where the part will be installed and what it will do in the environment in which it's going to operate. It's broader than just selling a product."

PROVIDING SOLUTIONS

To that end, Nitrex is able to offer its customers services and products that run the gamut of heat treating, which include a wide variety of applications, heat-treatment processes, and industries. The company's potential-controlled gas nitriding and potential-controlled gas nitrocarburizing (ferritic nitrocarburizing-FNC) heat-treatment technologies are applied in the precision parts, automotive, aerospace, aluminum extrusion tooling, defense, gears, tool and die, machinery, and more.

"Our goal is to stay in the field of providing solutions — meaning that we see that our product portfolio as complementary, and we'll keep evolving it; we will keep investing in that complementary theme of products," Cloutier said. "We are in a big niche; we are investing only in high-end processes. We're in gas nitriding; we're in vacuum. We do have some other processes in our company. But we stick to high-quality complexity and work with companies that require more than providing a product."

Nitrex is a solutions provider that goes beyond traditional heat-treating services. While world-renowned for its nitriding expertise, Nitrex also provides a full suite of state-of-the-art vacuum, atmosphere, and LPC solutions to its many OEMs, Tier 1s and end-users from its nine service locations in the U.S., China, Canada, Mexico, and Europe. (Courtesy: Nitrex)

APPROACHING CUSTOMERS' CHALLENGES

And that means genuine attempts at understanding any challenge a customer brings to Cloutier and his experts.

"First, we try to understand the problem that they're trying to

G-M Enterprises vacuum heat treat furnaces are designed with ease of maintenance and a lower cost of ownership in mind. These furnaces are real workhorses, capable of meeting exacting standards with consistent accuracy and repeatable quality. (Courtesy: Nitrex)

solve," he said. "And by understanding the problem and the application and which component or part is being used, we can better understand the context. And because we have this internal library of knowledge and people with experience, we can rapidly find a path to what the solutions could be."

That internal library of knowledge and experts spans the globe, which enables Nitrex to quickly assign the necessary personnel to any problem the company may face, according to Cloutier.

"We have facilities in different countries, so we're able to respond quite fast to a request, depending on where it's coming from," he said. "We have a lot of people with a lot of experience not only in heat treating but also in material science and metallurgy, chemistry, mechanical design, and physics. We can pull on different people in different places to join. And we're starting to use some different tools to communicate. So, pretty soon we'll announce a new line of products to respond even better and faster to the customer, using technology and knowledge together."

With its multiple acquisitions, Nitrex has been able to expand globally in the U.S., Asia, and in Europe, and with the addition of G-M Enterprises, Nitrex has been able to grow stronger in the aerospace sector, as well as MIM, 3D printing, and defense.

HUMBLE BEGINNINGS

Nitrex began as a small service center back in 1984 offering its proprietary Nitreg® gas nitriding technology, before evolving into a company that designs and manufactures turnkey heat-treating installations, while its subsidiary, Nitrex Inc., offered commercial metal-treating services throughout the world.

The company started installing nitriding systems in the '90s. Soon after, the company began to grow through acquisitions, which continued onward through 2015, when it was acquired by Novacap, a Montreal, Canada-based private equity firm, according to Cloutier. Several more acquisitions sparked the need for the current rebranding campaign.

"Basically, we grew from a company controlling gas nitriding through computer and software, which at the time was quite innovative," he said. "But it kept innovating throughout the years and investing in that process, building a knowledge and different recipes or formulas for heat-treat."

As the company grew and flourished, a library of formulas and recipes and knowledge was created that became the heart of Nitrex, according to Cloutier, which spurred more growth until it was present in 16 sites around the world and selling in more than 60 countries.

But with that rapid growth under different brands acquired through the years, it was becoming difficult to truly express how large the company had become.

"Before the acquisition of G-M Enterprises, we had put a strategic plan together for a different orientation for the company," Cloutier

A Nitrex pit-type turnkey nitriding installation for treating stainless steel turbine components. Through the process of improving the durability and reliability of components, Nitrex also helped this customer meet their sustainability goals, reducing energy and gas consumption with a shorter cycle time. (Courtesy: Nitrex)

said. "We thought that it was the right time to start integrating our brands to support the growth strategy and make it clear to the market how we want to show ourselves. When that materialized, it was good timing to start integrating the brand under one umbrella."

EYE ON THE FUTURE

As Nitrex continues under its newly branded portfolio, the CEO said he sees the need to continue to keep a close eye on what the OEMs are doing since heat-treating is a larger part of the supply chain.

That will more than likely involve more digital implementation and the Internet of Things, according to Cloutier.

"When it comes to supply chain improvements and increased velocity in the supply chain, companies are connecting their assets and trying to make their equipment more intelligent so they can better predict maintenance, avoiding disruptions, and improving efficiency of those assets," he said. "What the OEMs are doing in the industrial segment or automotive spaces is something that the heat-treating industry will need to adjust to as well, and probably quicker than what people originally thought. They are probably pressed by what's happening right now in the industry with COVID-19. I think connectivity and the digitalization of products is definitely in the future."

In that vein, Cloutier feels that Nitrex's business model will continue to work toward that goal.

"I'm CEO of the company, but I've been in the supply chain for many years in large corporations, and supply chains are becoming more and more complex," he said. "As time goes by, especially right now under the circumstances we're operating in, this challenging economic context and the global supply chains will be pressured to be more efficient. So, I think our business model fits well with this new challenge coming. We are capable of serving different industries and different customers at different stages of their manufacturing phase, from the design on out. I think Nitrex is well adapted for what's coming."

SOLUTIONS PROVIDER

And that circles back to Nitrex, above all else, being a solutions provider.

"It's more than the manufacturing or designing of furnaces," Cloutier said. "The combination of those three divisions, plus the knowledge I was describing earlier, puts us in a unique position in the market. Actually, there's nobody else in the market that is vertically-integrated like that."

To that end, Nitrex's vision is to be a worldwide partner in offering metal heat treating solutions, always ahead of its customers' expectations by delivering innovative technology.

MORE INFO nitrex.com

MARKETPLACE ///

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

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

ADVERTISER INDEX ///

COMPANY NAME | **PAGE NO.**

ROBERT ANTOLIK /// VP OF SALES /// APPLIED TEST SYSTEMS

"If it has something to do with heat, let us look at it."

What's a typical day like for you at Applied Test Systems (ATS)?

Things have changed quite a bit lately due to COVID-19. But, in general, a typical day involves me checking all the incoming website emails and distributing them out. I'll run a lot of reports from backlog to quoting, and I'll have a daily conference with all the sales personnel to see if anyone needs any help, I'll also make sure everybody has followed up on their quotes.

I also do a lot of interfacing with production and the engineering team in order to make sure our customers are well taken care of. Quite often, I assist customers with operating their furnaces and control systems. New systems are great, but we don't neglect customers who have older ones. If a customer has an issue with an older system, I will go above and beyond to troubleshoot the problem. Basically, I do a little bit of everything.

What does ATS offer the heat-treat industry?

We're a manufacturer of custom furnaces with ranges up to 1,800°C as well as ones capable of negative temperatures using liquid nitrogen. We make large car-bottom-type furnaces running 40,000 pounds worth of metal to ones that are only a few inches in size.

And the furnaces we make are not just used in heat treating — it's anything to do with heat. And that's what I tend to tell people: If it has something to do with heat, let us look at it.

Have there been any recent developments that you're excited about?

SAE has a specification AMS2750E, where everything has to be a certain uniform temperature within a specific area of the furnace. It is the user's responsibility to make sure their furnace is within those specifications.

This particular aerospace specification says that anything heat-treated in a class 1 furnace has to be ±5 degrees Fahrenheit and you have to be able to verify this. Depending on your control system, you may have to prove monthly — or even weekly — that the furnace still meets those specifications.

ATS has recently developed a smaller unit that meets the specifications, and we are working on additional sizes that meet the AMS2750E specifications as well. We have also developed a furnace that has a class 2 uniformity range. This is what 90 percent of users require. In that same furnace, we can reach a class 1, but it's in a reduced size.

ATS has manufactured a furnace that makes it easy for customers to install their survey sample with its required thermocouples. Typically, a customer will just run the thermocouples out of the door, causing the seal to go bad. The ATS design allows the customer to run the thermocouple through their own special port, which eliminates damage to the seal.

ATS has made these furnaces customer friendly; you don't need to be a trained technician or have any special tool for maintenance. If they want to replace the heating elements, it's very simple: just undo a couple of wires and then pull it straight out. Even though we installed a special port in the back where customers can run all the thermocouples for their temperature surveys, we still redesigned the door seal so that it can be replaced with only a screwdriver.

The customer was first and foremost in our minds when we designed the 3150 series furnace. It's simple to maintain, and it allows customers to continuously do calibrations and surveys in order to keep their furnaces within specifications. And we designed it so it has an excellent uniform temperature.

What else can your customers expect from this?

We are able to supply the documentation and the certifications that meet the AMS 2750. And if the customer desires, we also can do the onsite commissioning and the inspection through our service department. Our service department is a certified calibration laboratory, and we operate under an ISO standard 17025. So, not only do we supply the equipment, but we can fully service it.

A lot of our customers are working under the National Aerospace and Defense Contractors Accreditation Program guidelines, which require the AMS 2750 uniformity.

And now, along with aerospace and defense, the automotive industry and other similar industries have picked up on this standard — not because they are aerospace-related, but because it's a standard that they can all work off of.

The bottom line is that the materials our customers need will be in compliance.

Where do you see the heat-treat industry in the next 10 years and ATS's place in that future?

As far as this specification at least, we do seem to think there's going to be a lot more people needing to comply to these standards. This is going to nudge many in the heat-treat industry to be more precise and have tighter quality control. With Applied Test Systems, that is now possible and within reach.

MORE INFO www.atspa.com