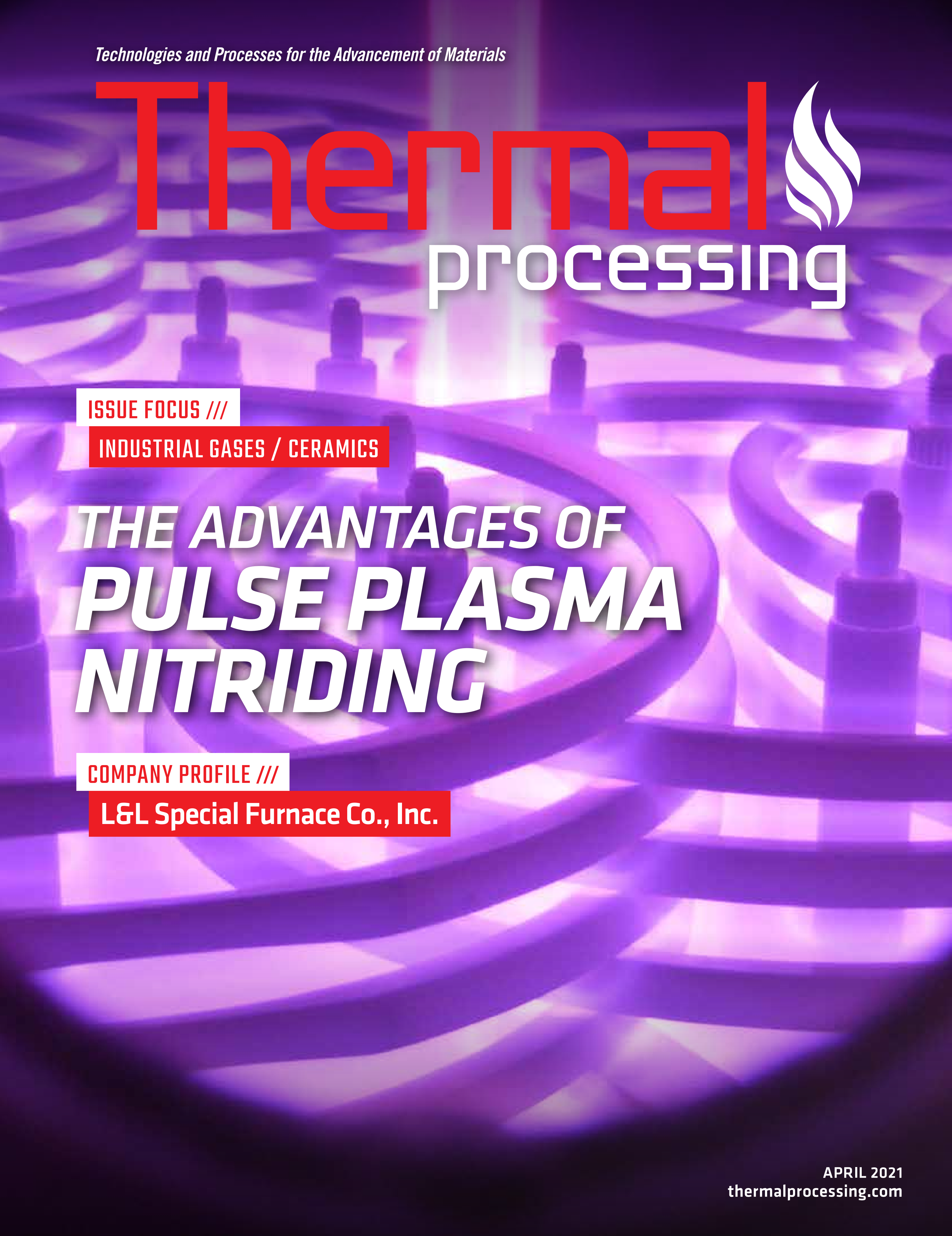

Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

INDUSTRIAL GASES / CERAMICS

THE ADVANTAGES OF PULSE PLASMA NITRIDING

COMPANY PROFILE ///

L&L Special Furnace Co., Inc.

APRIL 2021
thermalprocessing.com


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CONTENTS ///

COVER PHOTO: PVA INDUSTRY VACUUM SYSTEMS

DEPARTMENTS ///

APRIL 2021 VOLUME 10 / NUMBER 4

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FROM THE EDITOR ///

Industry inching back to normalcy

As the world continues to slowly move toward a bit of normalcy, thanks for checking out the current issue of *Thermal Processing*, where we're always keeping that window open on the world of heat treating.

Judging from some of the news releases we've received from various companies, it would appear that, at least as far as heat-treating is concerned, business continues to grow at a steady pace.

That being said, April's Focus section takes a look at a variety of subjects important to heat treating that are as essential as they are innovative.

With part of this month's focus spotlighting industrial gases, our lead article takes a deep dive into pulse plasma nitriding and how the process can improve surface hardness, wear resistance, fatigue strength, and heat resistance.

We are also looking at ceramics this month as well. In an article from Axiom, the company's experts discuss the properties of oxide-oxide ceramic matrix composites and how their fiber and fabric architectures can enable significant component-level cost reductions.

April's final article is the second part in frequent contributor Jason Schulze's multi-part series on the AC7102 checklist review. Part 2 tackles specific sections that can often challenge suppliers.

In this issue's company profile, I had the pleasure to talk to L&L Special Furnace President Greg Lewicki as he shared his company's rich history that spans back to WWII.

And be sure you check out the latest from some of our expert columnists:

In Metal Urgency, Justin Sims looks at predicting plastic strains during hardening of carburized components and how it is key to evaluating steel components' response to heat treatment.

In Hot Seat, D. Scott MacKenzie continues his multi-part series on the heat treatment of aluminum.

Keep in mind that *Thermal Processing* is here to get your message out to your customers, whether that be with news releases that we happily share with our readers or advertising that can drive home what your company can offer. There are options available, and *Thermal Processing's* primary goal is to help you with your company's mission in any way we can.

In the meantime, keep wearing that mask, practice social distancing, get vaccinated when you can, and, as always, thanks for reading!

Kenneth Carter

KENNETH CARTER, EDITOR
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(800) 366-2185 x204

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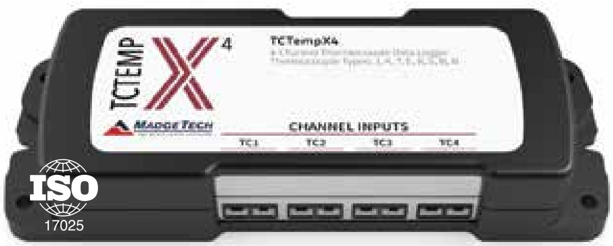

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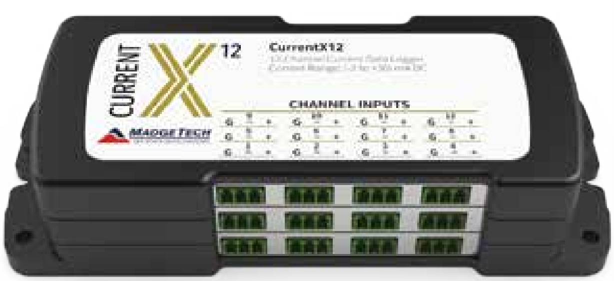

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Six zones of temperature control and 900 KW will be used to heat large parts up to a maximum temperature of 1,400°F. (Courtesy: Premier Furnace Specialists)

Premier Furnace ships large car bottom furnace

Premier Furnace Specialists/BeaverMatic shipped a large electrically-heated car bottom furnace to be installed at a customer's location in the midwestern United States. The system was designed, built, and tested at Premier's spacious new 40,000-square-foot facility in Farmington Hills, Michigan.

The furnace is capable of processing 16-foot x 16-foot parts that weigh up to 80 tons each. Six zones of temperature control and 900 KW will be used to heat these large parts up to a maximum temperature of 1,400°F. In keeping with current industry trends, the car bottom system has been designed to include all the necessary features required for strict compliance to current AMS 2750 standards.

The furnace includes a fully-insulated movable car bottom complete with oversized cast steel wheels that will roll over rails embedded in the customer's floor. When the car bottom extends into the furnace, it will be securely sealed in place with a series of pneumatic clamps and high-temperature tadpole gaskets arranged to prevent air infiltration into the heating chamber. This pneumatic sealing mechanism is a standard and proven BeaverMatic design that has been successfully employed on many previous car bottom installations.

During processing, the customer's product will rest on removable ceramic piers that can be specifically configured according to the size and weight of the individual part. Optimum thermal uniformity will be achieved by using large high-capacity fans and stainless-steel ductwork to aggressively direct and circulate either heated air or an inert gas atmosphere over and around the work piece. After heating, the furnace could selectively use a rapid cooling feature whereby products may be quickly and evenly cooled using an ambient air blower and a series of modulating valves controlled by the PLC.

The furnace includes an Allen Bradley PLC control system that will be used for process control and will also be capable of recording input from up to 40 part-contact thermocouples during a typical cycle. The datalogging features are very flexible and the recording parameters may be easily selected by the operator from the system's color touchscreen HMI. Additionally, part-contact thermocouples could be used for process control. This would allow for either heat or ambient air to be selectively applied or removed depending on whether the control system called for heating or cooling. Ethernet communication will allow for the car bottom furnace system to be fully integrated into the customer's plantwide data network.

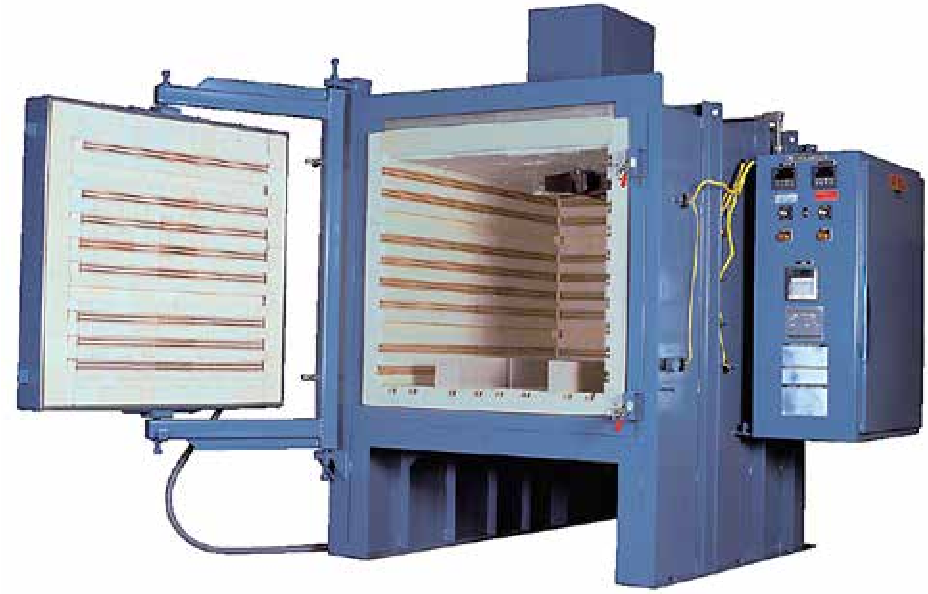
MORE INFO www.premierfurnace.com

L&L gets box furnace order for annealing firearm barrels

L&L Special Furnace Company has received a second order for a medium-sized floor-standing box furnace that will be used for annealing gun barrels for rifles. This is the second furnace supplied to a leading Midwest manufacturer of custom firearms and rifles. A marked increase in production and reliable operation of the existing L&L furnace preceded the sale.

The L&L Model XLE 3636 has an effective work zone of 34" wide by 30" high by 32" deep. It is designed for use with inert blanketing gas for atmosphere control to minimize surface de-carb. A programmable flow panel with regulator and two flow meters for high and nominal flow rates along with a visual flow indicator light are included. There is a high-temperature air-cooled fan with packing gland to maintain the case seal integrity. A cast alloy hearth provides a flat work platform for the fixturing of parts.

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.



L&L Special Furnace Company has supplied its second furnace to a Midwest manufacturer of custom firearms and rifles. (Courtesy: L&L Special Furnace Company)

Honeywell controls and a Yokogawa recorder enable precise temperature control and accurate chart representation of the furnace cycle. The power control is a series of solid-state relays and the furnace is constructed in accordance with NFPA86 compliance for safety.

All L&L furnaces can be configured with various options and be specifically tailored to meet your thermal needs. The company also offers furnaces equipped with pyrometry packages to meet ASM2750F and soon-to-be-certified MedAccred guidelines.

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

MORE INFO www.llfurnace.com

Busch Vacuum Solutions USA acquires sales partner

Busch Vacuum Solutions USA, one of the largest manufacturers of vacuum pumps, blowers, compressors and systems, acquired Jennings Associates Inc. (dba Jennings Alberts Inc), a distributor for new equipment, maintenance, and repair for vacuum pumps blowers and heat exchangers. The acquisition of Jennings Alberts' vacuum pump, blower and service portion of the business furthers Busch's long-term goal of providing even better technical and service support for customers in the Eastern Central Region.

Busch partnered with Jennings Associates to represent them in eastern Pennsylvania, southern New Jersey, and Delaware in 1977. Together, they have become industry leaders supplying vacuum solutions for many applications including meat processing, food packaging, chemical, pharmaceutical, metallurgy, and plastics.

"The Busch-Jennings family business relationship has continued to grow over the last 44 years. We are all very excited that the Jennings vacuum pump and blower, sales and service, business officially becomes part of the larger Busch company which is also a family-owned business," said Bill Altier, part owner of Jennings Alberts. Altier joins Busch as a regional manager and will continue to serve customers in this market.

Also joining Busch as a regional sales manager is Lisa (Jennings) Dugery, part owner of Jennings Alberts. "We are excited to join the Busch team because of the success and mutual trust our companies have built over the years," she said. "And because of their long track record of innovation and great success, I know our family's legacy is in good hands."

Turgay Ozan, president of Busch USA, said, "As a vacuum industry leader, we are acquiring one of the foremost distributors and service organizations in the market. Joining with the Jennings team, after such a long partnership, is a logical step. For this region, we are becoming a direct resource for customers with access to Busch product managers, engineers and service specialists, nationally and globally."

Busch Vacuum Solutions manufactures products and designs systems in the USA and offers a wide national service network. The transition of the Jennings vacuum and blower business takes place immediately.

MORE INFO www.buschusa.com

ECM USA hires senior project manager in Mexico

Juan Cruz will be leading the Mexican market, projects, and support for customers for ECM USA. (Courtesy: ECM USA)

Juan Cruz, of Saltillo Coahuila Mexico, has joined the ECM USA team. With a mechatronics engineering degree from the Technologic Institute of Saltillo ITS and an MBA from the Northeast Autonomous University UANE, Cruz has more than 10 years of experience in the heat-treat industry. His industry experience includes previous leading roles in maintenance, sales, and service in the United

Thermal Care's Accuchiller line of water-cooled portable, packaged, and central chillers is AHRI certified. (Courtesy: Thermal Care)

States, and senior management in Mexico.

With international vacuum furnace experience in supporting many projects for the heat-treat industry, his focus is on continuous improvement. In his role as ECM USA's senior project manager to Mexico, Cruz will be leading the Mexican market, projects, and support for customers. He will be located in Saltillo Coahuila, which is in the north of Mexico.

ECM Technologies is an innovative low-pressure vacuum furnace manufacturer with headquarters in Grenoble, France. With subsidiaries and ventures around the world, ECM's global presence is well known in the automotive, aerospace, nuclear, energy, electronic, induction, and 3D additive industries. ECM is a furnace system supplier for heat-treatment processes ranging from rapid thermal processing (RTP) to low pressure vacuum carburizing (LPC). Service capabilities include advanced automation, robotics, after sales, spare parts, on-site training, and more.

MORE INFO www.ecm-usa.com
www.ecm-furnaces.com

Thermal Care earns AHRI certification for line of chillers

Thermal Care was recently AHRI certified for its Accuchiller line of water-cooled portable, packaged, and central chillers by the Air Conditioning, Heating and Refrigeration Institute (AHRI). AHRI certified is a globally recognized, industry-respected program that assures equipment will achieve the highest performance rating standards.

To become AHRI certified, equipment is subject to rigorous annual evaluation from a third-party laboratory under contract to AHRI to ensure that it performs according to the participant's published claims. Only products certified by AHRI are listed in AHRI's Directory of Certified Product Performance, a real-time database at https://www.ahrinet.org/certification/directory. Certificates can be downloaded from the AHRI directory on certified chillers to conduct energy performance comparisons between manufacturers and to provide accredited data for programs such as energy rebate incentive programs.

Bob Smith, director of engineering at Thermal Care, said, "This is a huge step for Thermal Care. We have worked diligently through the certification process to ensure our water-cooled chillers consistently meet our published performance standards. In other words, we deliver as promised. As an additional benefit, it allows our customers to have an unbiased method of comparing the performance of our water-cooled chillers to any other certified water-cooled chiller. It reinforces customer confidence that our chillers meet the highest specification and perform with accuracy and consistency as documented. This can be critical to a company as they develop energy efficiency strategies, without the need to purchase a larger chiller than necessary or to perform expensive independent testing."

MORE INFO www.thermalcare.com

Defense contractor orders from Signature Vacuum

Signature Vacuum received another order from a United States defense contractor for a custom ceramic sintering vacuum furnace.

The Model VBS-12 ordered will increase production capacity and is the fifth Signature furnace to be manufactured and installed in this contractor's facility. The furnace will be provided with a 36" diameter x 48" high work zone in a graphite hot zone rated for 1,850°C.

"Our strength at Signature is solving problems and delivering solutions. We have enjoyed the progression of this relationship over the years and we are committed to providing quality products and dependable services," said Signature President Greg Kimble. Kimble also indicates the defense contractor cites efficient design, consistent performance, and quality support from Signature as critical components to its decision to continue the relationship.

MORE INFO www.signaturevacuum.com

The Signature Model VBS-12 ordered by a defense contractor will increase production capacity. (Courtesy: Signature Vacuum)

Linde launches low-carbon gases product line

Linde announced the launch of Linde Green, a new product line of atmospheric gases produced with 100 percent renewable energy.

The Linde Green portfolio includes low-carbon liquified oxygen, nitrogen, and argon. Instead of using conventional power during the energy-intensive air separation process, Linde will be solely using certified carbon-free sources, such as wind, hydroelectric, and solar, at select locations in Europe and in the United States.

"Linde is proud to offer an atmospheric product line of industrial gases produced with zero-carbon electricity that will help our customers improve the environmental footprint of their supply chains," said Andrew Sarantapoulas, anagement. "Furthermore, finding new opportunities to integrate renewable energy into our production processes accelerates Linde's efforts to lower its greenhouse gas emissions significantly by 2028."

Linde has recently signed an agreement with Plug Power to supply industrial gases produced with carbon free electricity.

"Plug Power is excited to be one of Linde's first customers for low-carbon nitrogen produced with carbon-free energy," said Sanjay Shrestha, CSO at Plug Power. "Linde's nitrogen produced with carbon-free energy complements our efforts to support the clean hydrogen economy and its availability was a major factor in choosing a supplier."

Over a third of all electrical energy procured by Linde, on a global basis, is sourced from low-carbon and renewable power.

MORE INFO www.linde.com

Lucifer Furnaces builds dual chamber Red Devil

Lucifer Furnaces, manufacturer of industrial heat-treating furnaces and ovens, shipped a dual chamber Red Devil furnace to a customer in the Midwest.

The Red Devil offered the end user a cost-effective means to heat treat their small tool steel parts in-house in a timely manner. The Model RD8-KHE18 is a space-saving dual chamber unit with working dimensions of 12" H x 14" W x 18" L in both upper and lower chambers. The upper hardening chamber is rated up to 2,200°F while the lower convection oven tempers up to 1,200°F. This unit was customized with a programmable controller with an overtemp safety system for the upper chamber as well as a 7-day timer with alarm for audible event notification. Both chambers are lined with a multilayered 4.5" combination of lightweight firebrick hotface insulation and mineral wool backup insulation for energy efficient operation. The firebrick is precision dry fit inside the chamber with staggered seams for reduced heat loss while allowing for thermal expansion. Heating elements are coiled with heavy gauge wire of low watt density mounted in easy-to-replace side wall panels. The lower chamber has a rear-mounted fan for uniform circulation of heat. Ceramic hearth plates in both chambers support the workload and protect floor brick and can be replaced without removing heating elements.

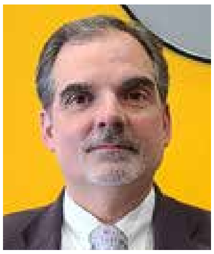
MORE INFO www.luciferfurnaces.com

Solar Atmospheres hires sales director in California

Solar Atmospheres hired Frank Trujillo as director of sales at Solar Atmospheres of California (SCA).

As a seasoned sales professional with more than 30 years of experience in the metals industry, Trujillo has established successful, career-building relationships through clear and honest communication, responsiveness, and consistent reliability. Trujillo brings a wealth of knowledge from the aerospace (military and commercial), medical, power generation, and commercial programs/markets.

Derek Dennis, president of SCA, said, "We're delighted to add Frank Trujillo to the SCA Team. Frank's vast experience in the aerospace industry aligns well with Solar's expertise and capabilities. Solar and Frank share a common core value in our approach to servicing customers with an unwavering commitment to honesty and integrity in all relationships. Frank's professionalism and motivation will help open doors to opportunities where SCA can partner alongside new customers with a goal of adding significant value to our customer's operation. I am confident that Frank will provide our valued customers with the same level of professionalism and unsurpassed customer service that they are accustomed to receiving."



Frank Trujillo

MORE INFO www.solaratm.com

ECM continues to have orders for Flex system

ECM's drive to provide captive and commercial heat treaters with quality vacuum furnace solutions continues into 2021 with two multi-chamber system orders for low-pressure carburizing.

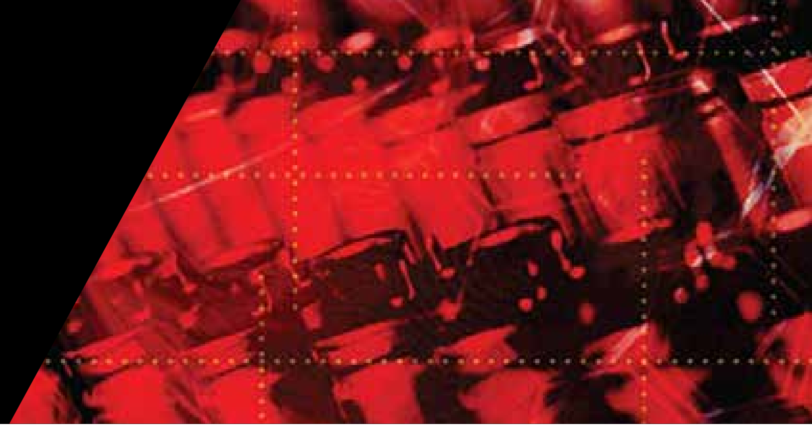
After shipping more than 60 vacuum heating chambers in 2020 for existing and new heat-treat applications, ECM continues to be commitment to customer satisfaction and application solutions. Advanced automation technology, including robotics, and decades of experience are also proving to be a driving force behind this surge in activity including those applications outside the LPC-HPGQ sector, including, but not limited to multiple tool steel processing systems, brazing applications, and Rapid Thermal Processing (RTP) systems.

With the automotive industry embracing revolutionary environmental policy and process changes, an automotive supplier of innovative driveline solutions recently invested in an ECM Flex system for vacuum carburizing. This system is estimated to reduce CO2 emissions significantly for vacuum carburizing vs. an existing atmosphere carburizing furnace.

A second Flex vacuum furnace was purchased by a hydraulic pump manufacturer. For this customer, the modular flexibility of the Flex furnace was the most important advantage, especially since the furnace is built as a standard system with the possibility to further expand its capacity and/or to upgrade to a high level of automation (robots, AGVs, vision systems, or other 4.0 elements).

In addition to modularity, several processes can be handled in the Flex furnace, such as low-pressure carburizing (LPC), vacuum tempering, and a combination of vacuum sintering followed by hardening.

MORE INFO www.ecm-usa.com
www.ecm-furnaces.com



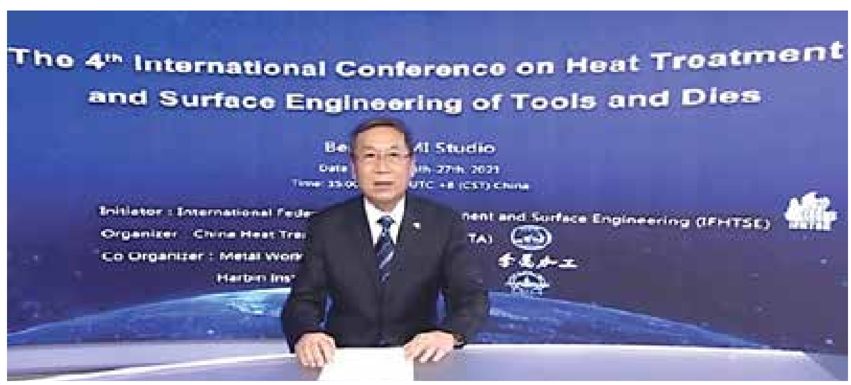
4th International Conference on HTSE of Tools and Dies successfully held online

This first online global IFHTSE conference was hosted by member China Heat Treatment Industry Association (CHTA) and co-organized by Harbin Institute of Technology and Metalworking Dept. CHTA President Li Xinya opened the conference mentioning that the conference was originally planned to be held in Hangzhou in October 2020 but was rescheduled and moved online due to the pandemic.

This event had flawless video and audio quality, as well as a chat function that was available so comments and questions could be posed. The number of registered participants was more than 370, but in the virtual conference room, the number of registered and non-registered participants rose to an astounding 16,300 by the end of the conference.

The conference was novel not only in presentation and participation but also in documentation: The recorded talks were collected as a kind of video proceedings volume and are available on the IFHTSE website for further reference and still wider attention.

Here is the link: www.ifhtse.org/events/conference-proceedings/Recorded-Talks-4th-HTSE_TD.php



The Heat Treatment and Surface Engineering of Tools and Dies conference was a virtual event.

IFHTSE EMBARKS ON VISION 2040

After the extensive work done on VISION 2020, examining the trends and technologies for 2020, a new examination of the upcoming trends and technologies in surface technology and heat treatment has begun.

The current topics include:

›› **ECO-HTSE:** Heat treatment and surface engineering using safer and cleaner practices, better energy efficiency and limited environmental impact processes. Patrick Jacquot, Bodycote FR.

›› **HTSE 4.0:** HTSE and the 4th Industrial Revolution; Artificial Intelligence in HT operations; IoT (Internet of Things) and Big Data assisted Heat Treatment. Rafael Colas, Autonomous University of Nuevo León, Mexico; Imre Felde, University of Obuda, Budapest, Hungary.

›› **Quenching:** Liquid and Gas Quenching, Aqueous based quenchants. Environmental aspects of Quenching. Distortion and residual stress control. Eva Troell, RISE/ivf, Sweden; D. Scott MacKenzie, Quaker Houghton, Inc., USA.

›› **HTSE for Additive Manufacturing:** Additive manufacturing heat treatment and surface engineering. Massimo Pellizari, Università degli Studi di Trento, Italy; Rafael Colas, Autonomous University of Nuevo León, Mexico; Marcel Somers, Technical University of Denmark.

›› **HTSE for Tools and Dies:** Heat Treatment and Surface Engineering of tools and Dies for improved properties, reduced wear and lower residual stresses. Reinhold Schneider, University of Applied Sciences, Wels, Austria; Massimo Pellizzari, Università degli Studi di Trento, Italy.

›› **Education in HTSE:** Future needs of industry in HTSE; Metallurgy v. Materials Science; Selling HTSE; industrial v. academic; generalist v. specialist. Marcel Somers, Technical University of Denmark; D. Scott MacKenzie, Quaker Houghton, Inc., USA.

›› **Surface Engineering – Higher surface functionality:** Surface heat treatment, thermochemical treatment of steels and alloys, surface engineering and related remanufacturing. Masahiro Okumiya, Toyota Technological Institute, Japan; Larisa Petrova, Moscow Automobile and Road Construction State Technical University (MADI), Russia; Kewei Xu, Xi'an University, PRC.

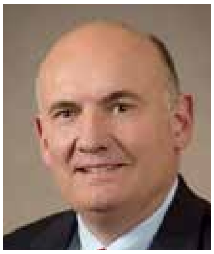
MEMBERS IN THE NEWS

IFHTSE Medal for Prof. John G. Speer

The Executive Committee awarded the IFHTSE Medal to Professor John G. Speer of the Colorado School of Mines in Golden, Colorado. His citation reads:

"For his life-time achievement in physical metallurgy, development, and heat treatment of advanced steel concepts from theory to practical application, with particular focus on his leading role in the development of the quenching and portioning process."

Speer is the John Henry Moore Distinguished Professor of Physical Metallurgy at Colorado School of Mines, and Director of the Advanced Steel Processing and Products Research Center (ASPPRC). He received



John G. Speer

Imre Felde

Rob Goldstein

a B.S. degree from Lehigh University in Metallurgy and Materials Engineering in 1980 and a D.Phil. in Physical Metallurgy from the University of Oxford, U.K., in 1983. He served in various positions at the Homer Research Laboratories of Bethlehem Steel Corporation from 1983 to 1997, where he was involved in product research, customer and operations support, and research management. He became a Professor in the Department of Metallurgical and Materials Engineering at Colorado School of Mines in 1997 and has also served as Mines' Associate Vice President for Research from 2008 until he became Director of ASPPRC in 2013.

With the medal for Speer, IFHTSE follows the tradition to honor excellent work in the field of physical metallurgy for heat treatment. Previous awardees of the IFHTSE in the physical metallurgy of heat treatment were Prof. G. Krauss (2007), Prof. T. Maki (2008), and Prof. H. K. Bhadeshia (2015).

Imre Felde

A recent interview was conducted by Sigma Technology regarding the relationship between Obuda University and Sigma Technology Hungary. Dr. Felde is the Vice Rector for Industrial Relations at Obuda University, Budapest. The focus of the interview was digital training and online learning. Read the entire interview at https://sigmatechnology.se/news/obuda-university-elevates-online-learning-together-with-sigma-technology/

Rob Goldstein

Goldstein is Executive Director of Product Development and Strategic Planning of IFHTSE's member company Fluxtrol. Recently, a survey by the magazine "The Monty" counts him among "The 30 Most Influential People in The North American Heat Treating Industry." He also was awarded ASM Fellow in September 2020.

IFHTSE 2021 EVENTS

Due to the pandemic, many conferences planned for 2021 have either been delayed or canceled. Please watch this space for updates on current conference planning.

APRIL 27–28
European Conference on Heat Treatment and 2nd QDE – International Conference on Quenching and Distortion Engineering
Online event I Germany I www.echt-qde-2021.de

SEPTEMBER 5–9
6th International Conference on Steels in Cars and Trucks
Milan, Italy I www.sct2020.com

SEPTEMBER 8–10
4th Mediterranean Conference on HTSE
Istanbul, Turkey I mchtse2020.com

SEPTEMBER 13–16
International Materials Applications & Technologies
St. Louis, MO, USA I www.asminternational.org/web/imat

SEPTEMBER 29–OCTOBER 1
14th HTS International Exhibition and Conference
Mumbai, India I www.htsindiaexpo.com

OCTOBER 26–28
HK 2021
HK is the largest materials technology industry meeting in Europe
Cologne, Germany I www.hk-awt.de

APRIL 2022
12th Tooling Conference
Sweden

SEPTEMBER 2022
27th IFHTSE Congress / European Conference on Heat Treatment
Salzburg, Austria

NOVEMBER 13-16, 2022
28th IFHTSE Congress
Yokohama, Japan

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

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INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

IHEA announces its 2021 annual meeting

The Don CeSar in St. Pete Beach, Florida, site of the 2021 IHEA Annual Meeting.

After a year of virtual events, heat treaters will finally gather in person

The Industrial Heating Equipment Association (IHEA) is ready to deliver a safe and healthy environment for its 2021 Annual Meeting, scheduled for July 26-28, at the beautiful Don CeSar in St. Pete Beach, Florida. Situated on the west coast of Florida just west of Tampa, the Don CeSar is a historic hotel on a stretch of beach recently named the top beach in the United States by TripAdvisor.

"Beyond the majestic and recently renovated art deco hotel, IHEA will once again deliver outstanding presentations that impact business today," said IHEA Executive Vice President Anne Goyer. "It's been far too long since our membership has had the opportunity to see each other in person. The connections people make during in-person events is so important and after more than a year, our members are looking forward to getting together at an IHEA meeting."

To ensure we can hold a safe meeting, IHEA staff members have been working closely with the hotel staff regarding health and safety protocols. While some are continuously evolving, we encourage anyone planning to attend the event to become familiar with the required procedures in place. You can read the current hotel protocols by visiting their website: www.doncesar.com/health-and-safety. IHEA will remind attendees of these about two weeks prior to the event, and IHEA will also abide by the state and local health and safety protocols in place at the time if they are over and above the hotel procedures.

That said, we want to provide a highlight of the programming that will be a part of IHEA's 2021 Annual Meeting. Our featured presentations include:

THE POWER OF SUPERVISION

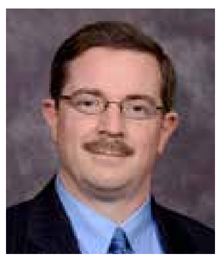
Chief Master Sgt. (Ret.) Bob Vasquez, United States Air Force

One of IHEA's most popular speakers, Chief Master Sgt. Bob Vasquez returns with a new presentation based on his recently published book: *The Power of SUPERvision!* Every supervisor who aspires to become a SUPERvisor needs SUPERvision. SUPERvision starts with how you see yourself. What you see is what you'll be. How do you see those people entrusted to you? How you see them is how they'll be. How do they see you? They're watching. You can count on that. Vision is important. SUPERvision is critical.

Bob Vasquez

Doug Glenn

Chris Kuehl



Tim Lee

LETTERS TO OUR CHILDREN: THINGS WE WISH THEY'D REMEMBER

Doug Glenn, Heat Treat Today

They are the next generation to follow in our footsteps and keep our beliefs, industries, and businesses going. Glenn's presentation promises to provide plenty of thoughts for serious consideration.

ECONOMIC UPDATE: DOES THE ROLLER COASTER CONTINUE?

Chris Kuehl, Armada Corporate Intelligence

An annual favorite, IHEA's economist Chris Kuehl will join us to give an economic update with his take on what lies ahead in these still uncertain times. His message is honest, informative, and always a highlight of IHEA's Annual Meeting.

SURVIVING THE UNEXPECTED

Tim Lee, Honeywell Thermal Solutions

Did any company truly anticipate what happened in 2020? Sure, there are companies that have crisis management plans, but did anyone really expect the severe challenges everyone faced last year? The questions are: How did companies handle the crisis, and what changes have been implemented to ensure survival moving forward? IHEA member and past president Tim Lee will share insights from his experiences over the past year in dealing with the crisis at hand and moving forward. This discussion will also allow for other members to share their experiences in dealing with the crisis.

ADDITIONAL ANNUAL MEETING HIGHLIGHTS

In addition to our featured presentations, traditional IHEA activities will be offered including our committee meetings, welcome reception, a golf tournament, beach activities, and IHEA's annual gala dinner.

Finally, yes, we know it will be hot in Florida in July, but IHEA has worked hard to minimize outdoor activities in the middle of the day when it is the hottest, and we are sure that our outstanding program will attract many members to this year's event — again, in a safe environment.

"We are anxious to welcome members and spouses and family members to our 2021 Annual Meeting in July," said IHEA President Scott Bishop of Alabama Power. "We realize how challenging the past year has been for our industry and membership, but we are looking forward to bringing everyone together again to help all of our businesses move forward. I hope I will see you at the Don CeSar this summer."

For complete program information and to register, go to: www.ihea.org/event/21AM

IHEA 2021 CALENDAR OF EVENTS

APRIL 14–16

Virtual Safety Standards and Codes Seminar

3-day online course

This seminar covers critical safety information for those involved with a wide range of industrial thermprocess applications. Attendees will receive a printed copy of the current NFPA 86 Standard for Ovens and Furnaces. Registrations that are received after April 2 may not get the printed NFPA 86 book prior to the seminar.

JULY 26–28

IHEA 2021 Annual Meeting

Don CeSar Hotel I St. Pete Beach, Florida

AUGUST 10–11

Powder Coating & Curing Processes Seminar

Alabama Power Technology Applications Center I Calera, Alabama

This day and a half Introduction to Powder Coating & Curing Processes Seminar will include classroom instruction and hands-on lab demonstrations. Registration is $325 for IHEA members, $425 for non-members. Fee Includes: Seminar materials, Powder Coating Manual, Infrared Manual, breakfast and breaks both days, lunch Day 1, Networking Reception, Certificate of Completion.

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

JUSTIN SIMS
MECHANICAL ENGINEER /// DANTE SOLUTIONS

Plastic strain during hardening of carburized steel components: How significant are phase transformations?

Predicting strains key to evaluating heat-treat response

Quench hardening of steel components requires the components to be heated to a temperature such that the solid-state crystal structure of the material changes from a body-centered cubic structure, generally containing some form of carbides, to a face-centered cubic structure with the carbides dissolved within the crystal structure. The heated steel component is then rapidly cooled, with the face-centered cubic structure transforming to either a body-centered cubic structure with carbides or to a body-centered tetragonal with supersaturated carbon locked in the crystal lattice. The final structure obtained after cooling to room temperature is determined by the steel's alloy content and cooling rate. During this process, there exists the possibility to generate plastic strain, resulting in a final shape which differs, sometimes significantly, from the shape it began with.

For a quench hardening process of a steel component, the high cooling rate, and possibly a high heating rate, can generate strains from the steep temperature gradients near the surface of the part. These thermal strains are due to a material's natural response to a change in internal energy. As thermal energy is added to the material, its internal energy is raised, and its volume increases as the crystal lattice expands ever so slightly. The opposite then occurs as thermal energy is removed during quenching. If the stresses induced on surrounding material of a different temperature reach a certain value, plastic strain is generated. The other phenomenon that can lead to plastic strain during a quench hardening process is the transformation from one solid-state phase to another. The generation of plastic strains from phase transformations is also related to volume differences between adjacent material in the part. Generally, plastic strains generated from phase transformations are greater than those generated from thermal gradients.

This article will explore, using the heat treatment simulation software DANTE, thermal and transformation strains of a carburized, AISI 4120 steel ring at several locations. The process modeled consists of gas carburization, transfer from the carburization furnace to the oil tank, quenching in oil, and cooling to room temperature. Figure 1(A) shows the meshed, axisymmetric finite-element model. Fine elements near the surface are required to properly describe the carbon and thermal gradients, and their subsequent effect on phase transformations and stress. The ring has an inner diameter of 80 mm, an outer diameter of 120 mm, and a height of 60 mm. Figure 1(B) shows the locations that will be evaluated in the model and the nomenclature used. The locations consist of two surface points, one at mid-height and the other at the corner; two points at the effective case depth of 1.0 mm, one at mid-height and the other at the corner; and one point in the core.

Figure 2 compares the predicted effective plastic strain generated from thermal gradients only to the effective plastic strain generated from a combination of thermal and phase transformation gradients.

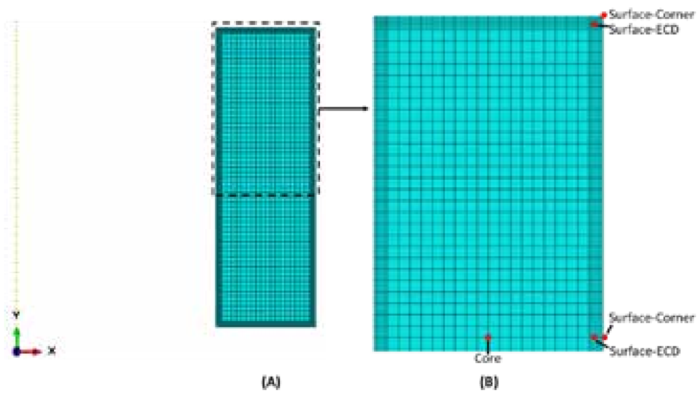


Figure 1: (A) Axisymmetric model of ring used for study, and (B) locations of nodes in the model used to report results.

Figure 2: Plastic strain generated from thermal strains only (dashed lines) and a combination of thermal and phase transformation strains (solid lines).

The effective plastic strain is a magnitude only value and is calculated in the same manner as the von Mises stress. Being independent of tensile or compressive strain, the effective plastic strain is cumulative and is a good measure of the total strain experienced by a component. The results reported as "with Phase Change," the solid lines, are a combination of plastic strains and used DANTE's material database data for AISI 4100 series steel, including thermal, mechanical, and phase transformation parameters. The results reported as "No Phase Change," the dashed lines, used the same DANTE material database data, though the phase transformation parameters were ignored, resulting in no phase change from the initial microstructure of ferrite/pearlite to austenite.

Figure 3: Plot from Figure 2 showing only the heating portion of the process.

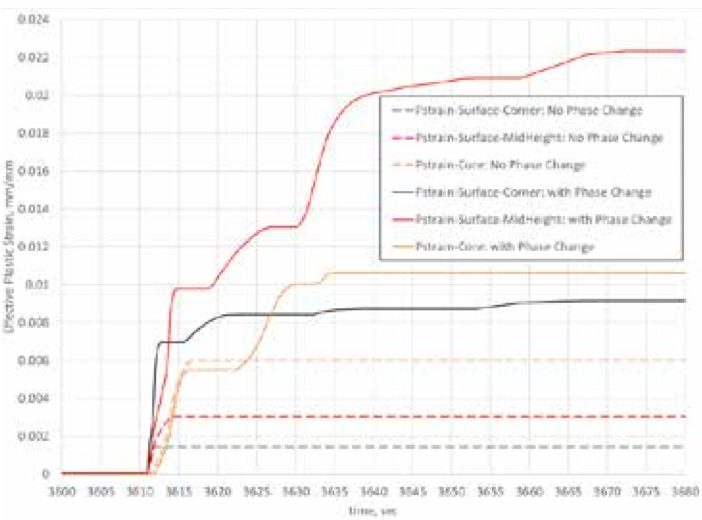


Figure 4: Plot from Figure 2 showing only the cooling portion of the process, including transfer and quench.

> ***The large amount of plastic strain on the surface at mid-height can be attributed to the influence of carbon on the phase transformation timing.***

From Figure 2, it is clear that the phase transformations are responsible for most of the plastic strain experienced by this component. Generally, the plastic strain in this example is approximately a full magnitude greater when considering the phase transformations. The exception is the core, where the material does not undergo the stress reversals, and is not subjected to the steep gradients, experienced near the surface. In order to see the effects of heating and cooling on the plastic strain, Figure 2 is divided into these two processing steps.

Figure 3 shows the heating step of the process from Figure 2. The heating step for the model assumed the room temperature part was placed in a preheated radiant tube batch furnace. Even without any attempt to control the heating rate, the thermal gradients from heating in this case were not enough to cause any plastic strain in the initial microstructure. No plastic strain from heating is not always the case, as part geometry can create stress concentrators which can significantly affect the strains witnessed by the part. For simple shapes, however, thermal gradients from heating rarely result in plastic strain. The transformation from a ferritic/pearlitic microstructure to an austenitic microstructure, on the other hand, does create plastic strain on and near the surface, as shown in Figure 3. The core does not undergo any plastic strain from the austenite transformation and was removed from the plot to better illustrate the "No Phase Change" condition.

Figure 4 shows the cooling portion of the process from Figure 2, including the transfer step and quenching. The first noticeable difference between heating and cooling, with respect to plastic strain, is that quenching can generate plastic strain from the thermal stresses alone. Even the core undergoes plastic strain from the thermal gradients, and actually has the most strain when phase transformations are not considered. However, the phase transformation from austenite generates a significant amount of strain. The core has the smallest difference between the two cases, due to the lack of stress reversals experienced by material closer to the surface as the part undergoes phase transformations, but phase transformations still account for a 75 percent increase in the core effective plastic strain. The largest strain is witnessed by the surface of the ring at mid-height and is seven times greater when phase transformations are considered.

The large amount of plastic strain on the surface at mid-height can be attributed to the influence of carbon on the phase transformation timing. Since the surface has the highest carbon concentration, it will transform to martensite last. This means the strain from the austenite to martensite transformation on the surface changed the strain from 0.021 mm/mm to the final value of 0.0225 mm/mm. All prior plastic strain is due to the influence of material volume change in locations below the surface.

One thing to note is that the plastic strain from cooling will be greater for the case considering phase transformations since the strength of austenite is less than that of ferrite/pearlite. This behavior is clearly visible in Figure 4. Referencing the "Surface-MidHeight" values, without considering phase changes, the ferrite/pearlite strains 0.003 mm/mm due to thermal strains only. Whereas, by considering phase transformations, the austenite strains 0.01 mm/mm due to thermal strains only. Following the "Pstrain-Surface-MidHeight: with Phase Change" data, the jump from 0.01 mm/mm to 0.013 mm/mm is due to the transformation of the base carbon material below the carbon case, the gradual increase from 0.013 mm/mm to 0.021 mm/mm is due to the transformation in the carbon case, and the final increase is from the transformation at the surface. Since DANTE uses rate-based transformation models, results can be viewed throughout the entire process, and the causes of strains are easily discernible.

In summary, quench hardening of steel alloys is a dynamic phenomenon that involves multiple local stress reversals due to thermal expansion differences and phase volumetric differences, and both must be considered to accurately predict part distortion and residual stress in the final part. DANTE has been shown to accurately predict these strains and can be a powerful tool when evaluating the response of a steel component to a particular heat-treatment process.

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.

HOT SEAT ///

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

Processes determine, verify condition of heat-treated alloy.

Heat treatment of aluminum Part VII – Hardness and conductivity

In the previous article, we discussed the artificial aging of aluminum. Once we have heat treated the parts, we need to verify the properties. While a tensile test can be used, the most frequent method of verifying mechanical properties of heat-treated aluminum is by hardness and conductivity.

HARDNESS AND CONDUCTIVITY OF ALUMINUM

Conductivity measurements in aluminum are commonly designated as a percentage of IACS (International Annealed Copper Standard) where the conductivity of the measured alloy is compared to the conductivity of unalloyed annealed coper at 20°C (68°F). Pure annealed copper has a conductivity of 100 percent IACS. Alloying elements in solution in aluminum reduce the conductivity. If the alloying elements precipitate or are not in solution in the aluminum, the conductivity will tend to increase. The conductivity of aluminum is determined by the percentage of alloying elements in solid solution and the amount and nature of the precipitates.

In the as-quenched condition, all alloying elements are in solid-solution. As the alloy is naturally aged, the conductivity will decrease. This is the result of the formation and growth of GP zones. These fine precipitates lead to an increase in the hardness of the alloy. As more fine precipitates form, the hardness increases. This increase is due to strains around the coherent GP zones and precipitates, which hinder dislocation movement [1]. As aging increases, particularly in the peak aged condition, the hardness is at a maximum and conductivity has increased. As the precipitates become incoherent with the matrix, the strains dissipate, and the hardness decreases. Conductivity will increase, as less of the alloying elements is present in solid solution [2]. When a fully annealed condition is obtained, the final equilibrium precipitates are obtained, and most of the alloying elements are present as precipitates. At this point, the conductivity is at a maximum, and the hardness is at a minimum. This results in a hardness and conductivity loop as shown in Figure 1. Therefore, it is important to measure both hardness and conductivity to determine the heat-treated condition of a part. This is illustrated further with actual data from different alloys (Figure 2) [3].

Hardness of a part is measured using a typical Rockwell "B" hardness tester. The surface conductivity of aluminum alloys is typically measured using an eddy-current conductivity meter. Eddy current is a non-destructive testing technique that uses a probe to induce small alternating current within the part that is being examined. Eddy current testing produces a rapid and easily used method of determining the conductivity of a part. A typical eddy current conductivity tester is shown in Figure 3. Reference standards are required to properly calibrate the eddy current meter.

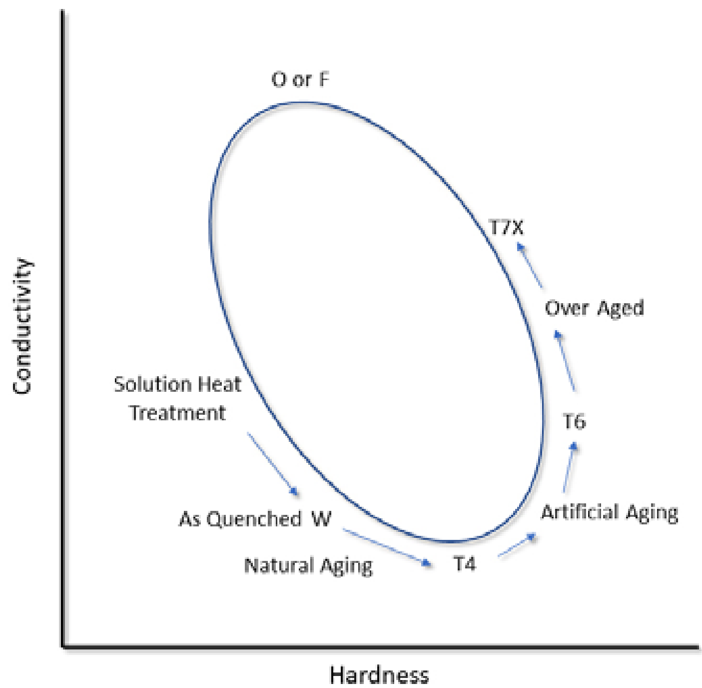


Figure 1: Schematic hardness and conductivity loop showing the relationship of hardness and conductivity to the heat-treated condition of an aluminum alloy.

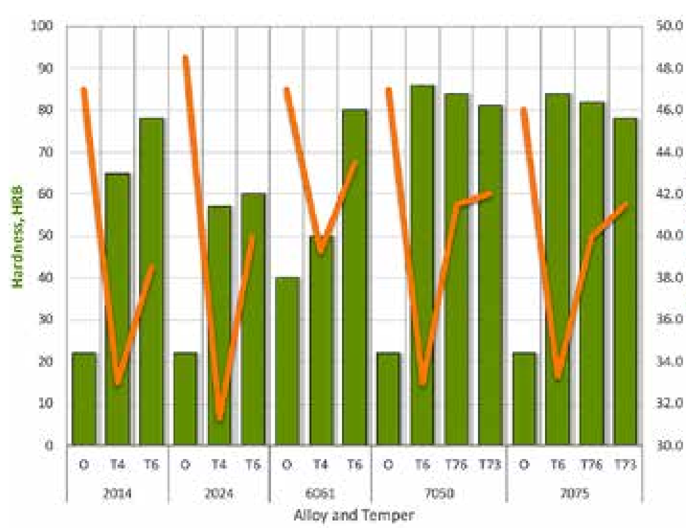


Figure 2: Hardness and conductivity relationships for several different heat treatable aluminum alloys.

Hardness of a part is measured using a typical Rockwell "B" hardness tester. The surface conductivity of aluminum alloys is typically measured using an eddy-current conductivity meter. Eddy current is a non-destructive testing technique that uses a probe to induce small alternating current within the part that is being examined.

Figure 3: Typical conductivity meter used for measuring the conductivity of aluminum.

Alloy	Temper	Hardness (HRB) Minimum	Conductivity %IACS
2024	**O**	**22 max.**	**46.0 - 51.0**
	T3	**63**	**27.5 - 32.5**
	T4	**63**	**27.5 -34.0**
	T6	**72**	**34.0 - 44.0**
	T72	**72**	**38.0 - 45.0**
	T8	**74**	**35.0 - 42.5**
	T86	**83**	**37.0 - 41.0**
7075	**O**	**22 max.**	**44.0 - 48.0**
	T6	**84**	**30.5 - 36.0**
	T73	**78**	**40.0 - 43.0**
	T76	**82**	**38.0 - 42.0**

Table 1: Typical values of different aluminum alloys per AMS 2658D [4].

REQUIREMENTS

In many instances, the values for the hardness and conductivity of a heat-treated aluminum part are fixed as part of the specification. This is especially true in the aerospace industry where the hardness and conductivity of heat-treated aluminum parts are specified by AMS 2658D "Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts" [1]. This specification establishes hardness and electrical conductivity acceptance criteria of finished or semi-finished parts of wrought aluminum alloys. Many other industries, such as automotive, are also adopting this standard. Typical values of those required in AMS 2658D are shown in Table 1.

CONCLUSION

In this short article, the use of hardness and conductivity was discussed to determine the heat-treated condition of an aluminum alloy, or to verify the condition of the alloy after heat treatment. The changes in hardness and conductivity were described as a function of the amount of solid solution present and the strain fields present around the coherent and incoherent precipitates.

It is hoped that you enjoyed this series on the heat treatment of aluminum. I would welcome suggestions for either a new series or suggestions for new columns. If you have any questions or comments about this or any other column, please contact the editor or myself.

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ABOUT THE AUTHOR

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SHAUN KIM
DIRECTOR OF QUALITY /// BYINGTON STEEL TREATING, INC.

Thorough contract review is as crucial as knowing the correct times and temperatures needed for the heat-treating process.

Good habits, a solid system can help avoid mistakes

The contract is the first piece of paper you receive with incoming parts prior to processing. This is the purchase order (PO) that details what type of processing the incoming parts require. Besides heat treatment, the PO will detail any additional instructions such as straightening, cryogenic treatment, and company-specific processes.

From my previous articles, it's known that aerospace (AMS/NADCAP) and commercial heat treating are vastly different regarding processing controls and requirements. Commercial heat treating is very loose on PO requirements, whereas AMS processing has specific language that must be documented on the PO for the contract to be accepted as an AMS job.

However, not all AMS processes are created equal, and each AMS process has its own requirements on what must be documented on the PO. This is usually located at the beginning of the specification under "ORDERING INFORMATION" and will list all the information needed. When performing contract review of AMS jobs, you must make certain that your customers have accurately listed every AMS requirement on the PO before you begin the process of heat treating. This is where things can get sticky. Often customers will not know these important requirements and leave the details out. This article will point out the pains of those occurrences, what you can do as a quality representative to help mitigate those pains, and how to train your staff to be efficient in locating missing information during contract review.

One of the most common problems I see when performing contract review is missing information. Before any heat treating can begin, the PO must be in conformance with the requirements of the AMS spec being referenced. A common occurrence I run into at my facility is customers who know what AMS process they want, but do not know what information needs to be on the PO. An example would be a customer who wants to heat treat 6061 aluminum to a T6 condition in accordance with AMS 2770R, but they will not list the heat-treat condition as delivered, which is a requirement of AMS 2770R.

If your quality system is working as intended, you will catch this missing information on contract review. In this case, a simple fix would be to contact your customer and notify them that they are missing information, and a revised PO is necessary. Simple, right? Well, what should be a simple remedy is not always so simple. I have run into situations in which the customer questioned why it was needed, as well as customers not knowing how to read a material certification to determine that condition. You would be surprised at how common both these scenarios are.

These are a few specific circumstances among many, but the common theme here is that your customers need guidance. You cannot assume your customers are as well versed in the AMS heat-treating world as you are. You must remember that most customers are flowing down heat-treating requirements without knowing the specifics. Have patience. Be patient in your discussions with the customer and

How can you mitigate the risk of a PO missing information and slipping through the cracks of your quality system? This might surprise some but this is perhaps the easiest part of contract review. You must train your staff to review AMS contracts accurately. As always, find what works best for your company when you train.

explain your reasoning behind the request. I've noticed that if you simply tell them you cannot certify to that specification without the required information on the PO, they will follow. Some may need more explaining than others, but in my experience the result is usually the same. In the end, all they want is their job to be certified to the requirements of the AMS process and will do what is required to accomplish that.

How can you mitigate the risk of a PO missing information and slipping through the cracks of your quality system? This might surprise some readers but, in my experience, this is perhaps the easiest part of contract review. You must train your staff to review AMS contracts accurately. As always, find what works best for your company when you train. My staff has access to the AMS specifications Byington Steel processes and has been trained to locate the ordering information based on what AMS process is needed. Even though your staff is trained, you must still check the work. As I like to say, "trust but verify." In my opinion, there is no such thing as checking your work too much.

Constantly checking your work is a good habit that can save you in many cases. Therefore, I like to use a robust check and double-check system when performing contract review. At Byington, contracts are reviewed multiple times by different individuals to make certain that contracts are correct, processing parameters are accurate and clearly defined, and in conformance with the AMS specification. The process of contract reviews I'm most proud of is our final contract review. The final contract review comes with a checklist that the final reviewer must fill out. This checklist was created by my engineers, and every checklist is specific to what AMS process is being used.

The checklist asks a series of questions that the final reviewer must fill out. The checklist uses an Excel worksheet, and areas will turn red if any information is missing and turn green when all information is accounted for. Any red boxes will alert the reviewer of missing information, and the process of communicating with the customer is initiated. This checklist is attached to every single AMS job processed at Byington. It gives us traceability that the review process was conducted in the manner it was intended. Ideally, all checklists attached will be green.

Contract review is performed for every job that comes in whether it's commercial or aerospace. The monotony of performing this task is not lost on me, but it's as crucial to heat treating as processing at the correct times and temperatures.

It's important to point out that missing information on the AMS PO won't prevent you from processing parts correctly, but it will certainly open you up for audit findings when an auditor looks into your contract review process. Why leave that door cracked open when you can bolster your review process and slam the door shut? Believe me when I say that this review has gotten me out of a potentially bad situation more than a few times. I won't say that I know why AMS has these requirements, but the people who vote on these specifications have good reasons for them to be there. As quality representatives, we don't set or question the requirements — we just follow them.

ABOUT THE AUTHOR

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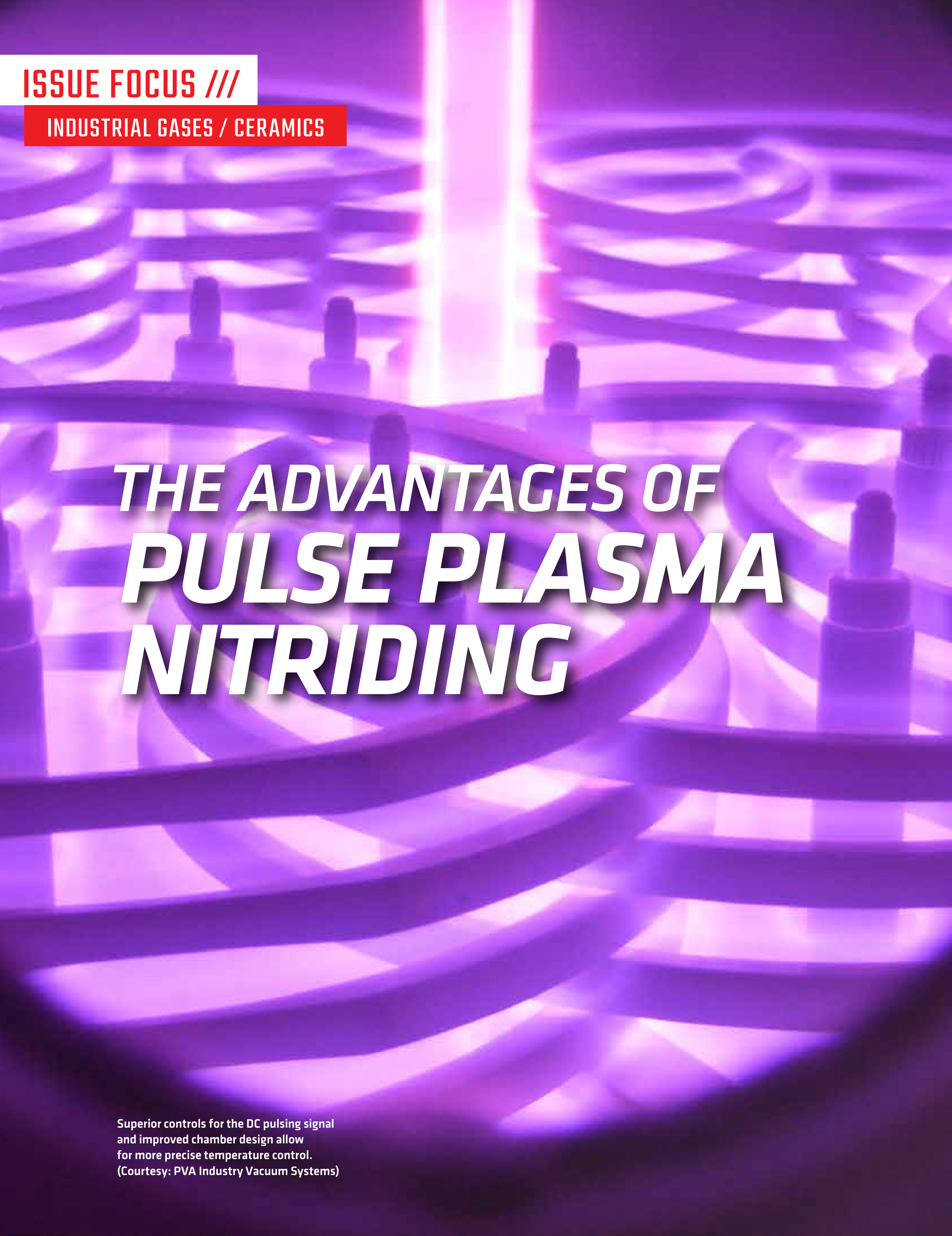
ISSUE FOCUS ///

INDUSTRIAL GASES / CERAMICS

THE ADVANTAGES OF PULSE PLASMA NITRIDING



Superior controls for the DC pulsing signal and improved chamber design allow for more precise temperature control. (Courtesy: PVA Industry Vacuum Systems)

Pulse plasma nitriding systems can deliver more uniform case-hardening and increased speed of processing when treating high-wear parts.

By JEFF ELLIOTT

In the gear manufacturing industry, when case-hardening, tempering, or nitriding the surface of steel, whether for gears or gearboxes, the options have traditionally included one of three processes: carburizing, salt-bath nitrocarburizing, or gas nitriding.

Each process has advantages and disadvantages. However, those seeking more precise control of the diffusion layer formation, depth of case hardening, and preservation of component dimensions are increasingly turning to advanced pulse plasma nitriding. The advanced process enhances not only surface hardness, wear resistance, and fatigue strength, but also reduces friction and surface adhesion.

Although pulse plasma has been used for decades, superior controls for the DC pulsing signal, along with improved chamber design and construction allow for more precise temperature control and uniform distribution of the heat zone throughout the hot-wall chamber. The result is extremely consistent and uniform nitriding batch-to-batch, with less gas consumption.

"The benefits are more precise control of the diffusion layers, and its broader appeal to heat treat more diverse materials, beyond steel, that include titanium, stainless steel, and even aluminum," said Thomas Palamides, senior product and sales manager at PVA TePla America.

In addition, high-volume cutting part producers can now select from multiple system configurations that offer flexibility, efficiency, repeatability, and throughput optimization. As a result, global manufacturers in the industry are now leveraging these systems to run a cleaner, more efficient operation.

PULSE PLASMA NITRIDING ADVANTAGES

For steel and steel alloys, case-hardening can be achieved by carburizing, nitriding, cyaniding, or carbonitriding. Although carburizing, and nitrocarburizing of steel is a traditional approach, the part has to be raised above the A1 temperature (727°C) on the iron-carbon diagram, usually in the temperature range of 900°C to 930°C. Since the solubility of carbon is higher in the austenitic state than the ferritic state, a fully austenitic state is required for carburizing.

Along with the high temperatures and time-at-temperature associated with carburizing, parts can be distorted. Therefore, a post-carburizing heat treatment is required, at a minimum, to reduce internal part stresses. Depending on the part and its geometric tolerances, limited machining may also be required.

An alternative to carburizing is nitriding, a lower-temperature, time-dependent, thermo-chemical process used to diffuse nitrogen into the surface of metal.

One method is salt bath nitriding. In this process, liquid immersion is required and is typically conducted at 550°C to 570°C. The nitrogen-donating medium is a nitrogen-containing salt, such as sodium cyanide, often greater than 50 percent in concentration. However, with post salt bath nitriding, there is a high washing effort required to remove the residual cyanide-based treatment. In addition, there are disposal costs for salt and washing lye, environmental handling costs, as well as safety and operational liabilities.

Extremely consistent and uniform nitriding batch-to-batch, with less gas consumption are achieved with new chamber design. (Courtesy: PVA Industry Vacuum Systems)

Gas nitriding (500°C) and gas nitrocarburizing (540°C to 580°C) are universally accepted procedures and typically require a high concentration of ammonia (NH_3), and a high amount of carrier gas flow (normal pressure process) compared with pulse plasma nitriding. The elemental nitrogen gas constituent diffuses into iron and forms hard nitrides. Because of the reduced temperature compared to carburizing, no quenching is necessary, and, therefore, the chance

Multiple system configurations can offer flexibility, efficiency, repeatability, and throughput optimization. (Courtesy: PVA Industry Vacuum Systems)

for distortion and cracking is lower. Disadvantages of gas nitriding are that it requires the use of flammable gases such as ammonia, high gas consumption, and it is not able to treat nitride rust- and acid-resistant steels.

PRECISION AND CONTROL

With recent advancements in pulse plasma nitriding, however, a new level of precision and control is possible, which results in uniform and consistent case hardening. Together with the advantages of using environmentally friendly gases only — in contrast to the use of ammonia in gas nitriding — plasma-based nitriding has become a focal point for additional innovations and a requirement for those that seek a more environmentally and safe solution.

In pulse plasma nitriding, parts are loaded into a heated vacuum chamber. After evacuating the chamber to a working pressure of 50 to 400 Pa on a supporting fixture, it can be covered by a bell chamber. The chamber is evacuated to below 10 Pascals prior to heating and a pulsating DC voltage of several hundred volts is applied between the charge (cathode) and the chamber wall (anode). The process gas in the chamber is then ionized and becomes electrically conducting. For this type of process, nitrogen and hydrogen gas mixtures and gases with carbon additions, like methane are often used.

Depending on treatment time and temperature, nitrogen atoms diffuse into the outer zone of components and form a diffusion zone. This can be atomic nitrogen dissolved in the iron lattice, as well as in the form of nitrate deposition.

Adding further precision, innovators in pulse plasma have discovered methods to optimize the process through better control of the pulses. In the PulsPlasma® process developed by PVA TePla AG Industrial Vacuum Systems, for example, a precision regulated gas mixture of nitrogen, hydrogen, and carbon-based methane is used. A pulsating DC voltage signal of several hundred volts is delivered in less than 10 microseconds per pulse to ionize the gas. This serves to maximize the time between pulses for superior temperature control throughout the chamber.

"If you have a temperature variance of ±10 degrees within a batch, you will get completely different treatment results," said Dietmar Voigtländer, sales manager at PlaTeG – Product Group with PVA Industry Vacuum Systems (IVS), Wettenberg, Germany, the manufacturer of PulsPlasma nitriding systems. "However, by controlling the pulse current by means of an exact pulse on and off time management, the overall temperature can be precisely managed with a uniform distribution, from top to bottom, throughout the hot wall chamber."

STABLE GLOW DISCHARGE

A unique feature with this approach is that the system can be switched on to a stable glow discharge at room temperature. Most systems cannot do this because the generators do not supply stable plasma. To compensate, those systems must first be heated to 300°C to 3,500°C before plasma can be applied, adding time to the process. With PulsPlasma, that time can instead be used to prepare the surface by giving it a fine cleaning.

Even the materials of construction used to manufacture the nitriding systems furnace itself have been optimized. In all systems, PlaTeG uses insulative materials developed in the aerospace industry to create a furnace wall as thin as 40 millimeters, compared to the industry standard of 150 millimeters. With less wall mass, the furnace requires less energy and time to heat, while still protecting workers that may accidentally touch the outside of the chamber.

With better overall control, the PulsPlasma nitriding furnaces offer multiple heating and cooling zones with each controlled by its own thermocouple.

"This will create a very uniform temperature distribution within ±5 degrees Celsius from the bottom to the top of the furnace," Voigtländer said.

Uniformity of temperature within a chamber pays a dividend beyond the consistency of nitriding results. With an even temperature throughout the chamber, the entire space is available for loading components, which effectively increases the chamber's capacity.

More precise control of the diffusion layers and its broader appeal to heat treat more diverse materials are achieved with the new technology. (Courtesy: PVA Industry Vacuum Systems)

INCREASED PRODUCTION THROUGHPUT

Nitriding is a batch process. Innovation in furnace design, through an optimized mechanical operation, can increase efficiency and increase production capacity. While the actual time for nitriding does not change, efficient loading and unloading scenarios play an important part. The PlaTeG plant design can use any one of a mono, shuttle, or tandem footprint to manage throughput, resources, and operations costs.

As a batch process, nitriding typically requires waiting for the prior batch to be treated, cooled, and unloaded before a new batch can be started. Shuttle and tandem extensions are now available to streamline the batch process.

With a shuttle extension, an additional vacuum chamber bottom may be added to a furnace. During a running nitriding process, the unloading of an earlier batch and the loading/preparing of a subsequent batch on the second vacuum chamber is possible. The cycle time therefore for two consecutive batches is reduced because of the overlapping of the time for unloading/loading of a vacuum chamber with the treatment time of the running process.

With a tandem extension, there are two complete vacuum chambers that are operated alternately by the vacuum pumps, the process gas supply, the plasma generator, and the control unit of the system. In situations such as unmanned weekend operations, an automatic process can be started and controlled for both batches in succession.

With this type of operational structure it is possible to increase overall nitriding capacity by 30 to 60 percent annually, according to Voigtländer.

Because plasma nitriding uses environmentally friendly nitrogen and hydrogen, the furnaces can be co-located with the machining of components without requiring a separate room. Moreover, the pulse plasma nitriding systems produce no polluting gases. This makes nitriding more efficient as part of an overall manufacturing process as an operator can locate the furnaces next to their drilling machines.

Pulse plasma offers significantly more precision in nitriding through the control of the mixture of gases, the controllability of glow discharge intervals, the design of the pulsed signal, and the use of a highly insulated hot wall nitride furnace. Together with innovations in the design of the furnaces to streamline batch management in nitriding operations, manufacturers who depend on nitriding components can benefit from greater uniformity of results, better-protected materials, and increased throughput.

For more information on pulse plasma nitriding, go to PVA Industry Vacuum Systems at www.pvatepla-ivs.com.

ABOUT THE AUTHOR

Jeff Elliott is a Torrance, California-based technical writer. He has researched and written about industrial technologies and issues for the past 15 years.

OXIDE-OXIDE CERAMIC MATRIX COMPOSITES

ENABLING WIDESPREAD INDUSTRY ADOPTION

Fiber and fabric architectures can enable significant component-level cost reductions for OxOx CMC; while primary cost savings are achieved at the fiber level, secondary benefits may also be realized at other points in the OxOx CMC supply chain.

By JOHN LINCOLN, BARRETT JACKSON, AMY BARNES, AARON BEABER, and LARRY VISSER

Oxide-oxide ceramic matrix composites are gaining increasing attention as a mainstream material option for high-temperature components in the aerospace and advanced energy sectors. As the material moves from bench to production, cost reductions are required to ensure the solutions are market-competitive with titanium and other high temperature alloys. In parallel, a more comprehensive portfolio of fabric geometries and data is desirable to enable flexibility in both engineering and design. 3M, maker of Nextel™ ceramic fibers, joins CMC pre-preg developer and manufacturer, Axiom Materials, Inc., and CMC parts designer and fabricator, Composites Horizons, in developing data for the present work. The team jointly compares the properties of Oxide-Oxide CMCs fabricated from conventional Nextel fabric architectures with those of new, lower-cost fabric designs.

INTRODUCTION

Oxide-oxide ceramic matrix composites (OxOx CMCs) now have significant application momentum in oxidation-sensitive component applications, yet both the transition to OxOx CMC, as well as the engineering of new OxOx CMC hardware, has been gradual as a result of its high cost relative to conventional materials or as an element of any new component design. The global market for OxOx CMC components is positioned for near-term growth and on the cusp of mainstream adoption provided that reasonable cost profiles can be achieved. Particularly in the case of the aerospace sector, cost reduction initiatives have become especially high-priority as the OxOx CMC cost/value proposition crosses that of machined titanium components for turbine engine and other high-temperature hardware. The present work seeks to provide engineering solutions for cost-conscious OxOx CMC design through (a) the development of lower cost fiber and fabric architectures and (b) characterization of their physical and mechanical properties.

Indeed, there is precedent in using higher denier fibers and fabrics to achieve reduced costs. Similar trends have been observed for carbon-fiber composites, which has progressed from 1k and 3k fibers initially, to upward beyond 50k fibers to reduce the cost of finished components [1]. Like carbon components, costs associated with the manufacturing process for OxOx CMC components are weighted heavily toward the cost of the fiber and/or fabric. Insofar

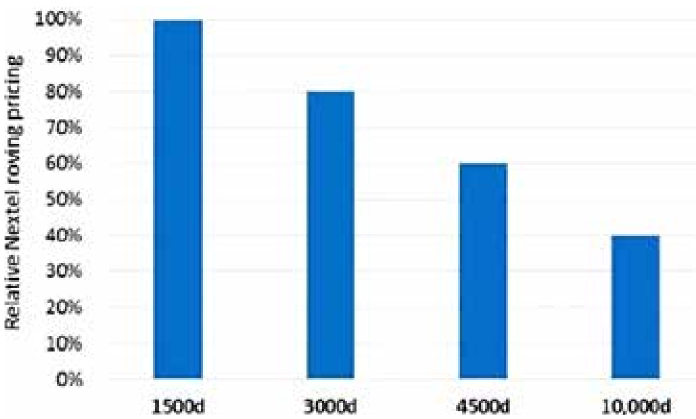


Figure 1: Current (6/2016) relative price per pound for structural ceramic fibers at various deniers (3M).

as these costs can be reduced, component level costs can likewise be reduced. To date, most OxOx CMC technical property data and research has been based on the use of NextelTM 610 and 720 fibers [2-7], and most notably styles DF-11 and EF-11 (1,500 denier). The 1,500 denier yarns are the finest produced commercially and are the most expensive fibers from a manufacturing standpoint due to small fiber bundle size and high demand placed on fiber manufacturing lines. 3M has demonstrated that higher denier yarns may be made by increasing the number of filaments in the tow bundle and keeping the individual filament diameters similar [8], which results in a significant cost advantage in fiber production. As the cost savings available from higher deniers of the Nextel fibers are of primary interest, relative costs of various fiber deniers are presented in Figure 2. The fiber types used in the present study for both grades Nextel 610 and 720 are 1,500, 3,000, 4,500, and 10,000 denier.

Figure 1 expresses the 1,500 denier fibers as 100 percent, and each higher denier is reported as a lower percentage of the 1,500 denier price. The comparative pricing shows that fiber costs can be significantly reduced in transitioning to higher denier fiber tows. Further, it is worth noting that changes at the fiber level also have the potential to affect cost and other points in the supply chain. Figure 2 expresses the typical flow of large-volume OxOx CMC sup-

Figure 2: Typical OxOx CMC supply chain from fiber to component.

ply chain from fiber manufacturing to finished component.

Weaving costs, for example, can be reduced through the use of higher denier yarn configurations, simpler weaving patterning and setup, or reduced total yardages in the case of heavier fabric architectures. Pre-pregging costs can likewise be reduced with heavier fabrics (lower overall yardage), as would part fabrication costs (reduced layup and yardage). Therefore, from a holistic supply chain standpoint, additional cost savings are expected through the use of modified fibers and fabrics.

Fiber	Denier	Filament Count	Single Filament Break Load Typical (g)	Strand Strength Break Load Typical (lbs)	Theoretical Strand Break Load (lbs)
610	1500	400	33	12	29
610	3000	750	34	20	56
610	4500	1140	35	24	88
610	10,000	2,560	32	33	182
720	1500	400	24	7	21
720	3000	750	27	12	44
720	10,000	2,560	27	24	151

Table 1: Single Strand and Tow Break Loads.

In preparation for the present study, a variety of woven fabrics was designed from various deniers of both 3M™ Nextel™ 610 and 720 fiber. Nextel 610 is >99% alpha alumina, which is the higher strength fiber, and 720 is an 85% alpha alumina and 15% silica, which as fired is a mix of alpha alumina and mullite, making it the more refractory fiber [8]. A presentation of mechanical properties of base fiber tows at various deniers is of value in order to interpret the greater implication of their use in the fabrics. Table 1 expresses the fibers used in the present study, alongside their reported breaking strengths. Typical single filament and strand strengths are listed from historical process data.

Fabric Type	Input Yarn	Weave	Thread Count (ppi) (warp / fill)	Weight (oz/yd2)		Thickness (inch)		Thickness (mm)	
				Sized	Heat Cleaned	Sized	Heat Cleaned	Sized	Heat Cleaned
Nextel 610 Fabrics									
DF-6	1500 d	4HS	18.5 / 18.5	7.5	7.3	0.008	0.006	0.20	0.15
DF-11	1500 d	8HS	27.5 / 27.5	11	11	0.011	0.01	0.28	0.25
DF-11-10-4500	4500 d	5HS	10 / 9	~12	~10	0.014	0.011	0.36	0.28
DF-11-14-3000	3000 d	5HS	15 / 14	~11	~11	0.013	0.01	0.33	0.25
DF-19-16-4500	4500 d	5HS	15 / 16	~19	~15	0.019	0.015	0.48	0.38
DF-11-17-3000	3000 d	5HS	16.5 / 17	~14	~13	0.013	0.012	0.33	0.30
DF-19	3000 d	8HS	23.5 / 23.5	19	18	0.019	0.017	0.48	0.43
DF-24-8-10000	10,000 d	4HS	8 / 8	~ 22	~ 21	0.024	0.019	0.61	0.48
Nextel 720 Fabrics									
EF-11	1500 d	8HS	27.5/ 27.5	11	11	0.013	0.012	0.30	0.30
EF-11-13-3000	3000d	4HS	13 / 13	~10	~10	0.013	0.012	0.33	0.30
EF-11-14-3000	3000d	5HS	14/15	~11	~11	0.017	0.012	0.43	0.30
EF-11-16-3000	3000d	5HS	16 / 16	~12	~12	0.016	0.015	0.41	0.38
EF-11-17-3000	3000d	5HS	17 / 17	~13	~13	0.016	0.015	0.41	0.38
EF-19	3000 d	8HS	23.5 / 23.5	19	18	0.022	0.021	0.56	0.53
EF-20	10,000d w /1500d f	Plain (UD)	16 / 5	22	22	0.03	0.026	0.76	0.66

Table 2: 3M™ Nextel™ 610 and 720 fabrics evaluated.

By keeping the nominal diameter of each filament the same, the breaking load of the filament is independent of denier from 1,500 to 10,000 denier. However, with the number of filaments increasing in each tow, measuring the strength of each tow becomes more problematic. Test method ASTM 2256 is followed where pneumatic grips are used to clamp the tow. With 1,500 and 3,000 denier a typical brittle ceramic break can be observed. As the filament count increases beyond 3,000 denier, the test curves indicate that not all the filaments are breaking at the same time. Because of the strand break load testing characteristics as shown in Table 1, fiber properties are based on the single filament break loads, crystal size, and crystal phase. A comparison of the single filament test results show the fundamental fiber quality is comparable for low and high denier.

Figure 3: Images of select woven Nextel sized fabrics.

As single filament breaking strength is relatively unaffected by higher denier yarn production, higher denier tows are in turn expected to be usable in the woven fabrics of OxOx CMCs to achieve similar performance to lower denier tows. Since much of the early research activity started from 1,500 denier fabric (DF-11 and EF-11), new fabric architectures were largely based around the approximate fiber volume and thickness of DF-11 and EF-11, with some exceptions to explore boundaries. Nascent near-property offsets to DF-11 and EF-11 include DF-11-10,14,17 and EF-11-13,14,16,17, which were prepared from 3,000 and 4,500 denier yarns. In addition to offsets for the 1,500 denier fabric, other fabrics in the test matrix explore an increased amount of fiber in each direction of the weave, in turn helping to determine the effect on composite properties using thicker and/or fewer plies. Lastly, for 3M™ Nextel™ 720 a unidirectional-type fabric (EF-20) was prepared, where the bulk of the fiber is 10,000 denier in the warp direction. For EF-20, 1,500 denier is used at a much lower pick count in the fill direction to give the fabric enough stability to be handled and pre-pregged.

Fabric Style	Matrix	# of Plies	Volume % Fiber	Volume % Matrix	Volume % Porosity	Density g/cc	Laminate Thickness (mm)	Per Ply Thickness (mm)
DF6	Aluminum Silicate	18	45.4	32.9	21.7	2.88	2.56	0.14
DF11		12	45.2	32.8	22.0	2.87	2.56	0.21
DF11-10-4.5K		12	44.5	35.6	19.9	2.94	2.68	0.22
DF11-14-3K		12	42.3	35.7	22.0	2.85	2.71	0.23
DF11-17-3K		12	43.5	34.7	21.8	2.87	3.14	0.26
DF19-16-4.5K		10	44.1	32.0	24.0	2.80	3.68	0.37
DF19		10	41.8	34.3	23.8	2.79	3.82	0.38
DF24-8-10K		8	43.1	33.4	23.5	2.79	3.37	0.42

Table 3: Physical properties for Nextel 610 laminates in the present study.

Table 2 presents a summary of the properties of the uncoated ceramic fabrics used in the present study. Photos of select fabrics, presented in Figure 3, show the visual differences observed when changing deniers and pick counts (tows/in). Fabric EF-11 (identical to DF-11 in construction) is the fabric to which others should be compared. In the 3,000 denier and DF-24-8-10,000 fabrics, the expectation is the tows will spread after the sizing is burned away to make a more uniform fabric without open spaces between tows.

Fabric Style	Matrix	# of Plies	Volume % Fiber	Volume % Matrix	Volume % Porosity	Density g/cc	Laminate Thickness (mm)	Per Ply Thickness (mm)
EF11	Alumina	12	51.1	27.9	21.0	2.83	2.54	0.21
EF11-13-3K		12	52.6	25.5	21.9	2.78	2.42	0.20
EF11-14-3K		12	50.8	26.8	22.4	2.77	2.57	0.21
EF11-16-3K		10	51.4	26.5	22.1	2.78	2.43	0.24
EF11-17-3K		10	52.9	25.8	21.4	2.80	2.65	0.26
EF19		8	50.8	28.5	20.7	2.84	2.95	0.37
EF20		6	47.3	28.4	24.3	2.72	2.79	0.47

Table 4: Physical properties for 3M™ Nextel™ 720 laminates in the present study.

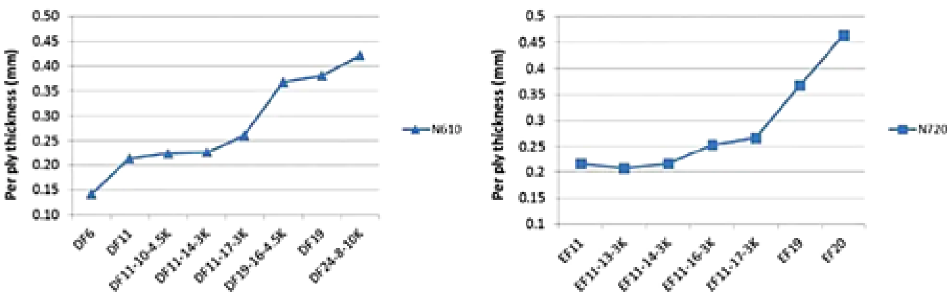


Figure 4: Per ply thicknesses of prepreg laminates from various Nextel 610 and 720 fabrics.

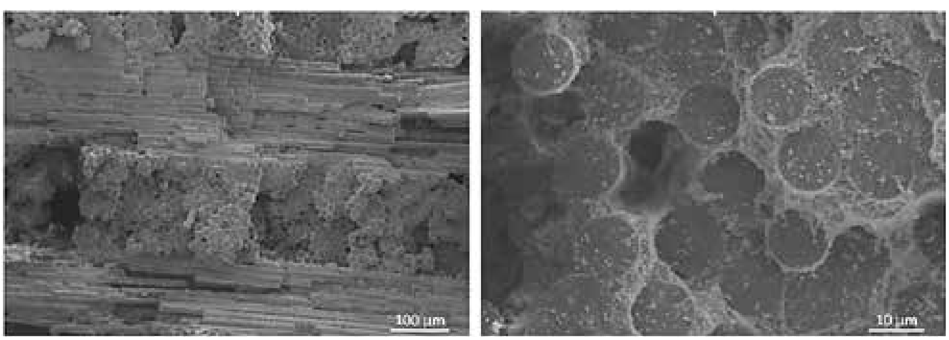


Figure 5: SEM Images of EF-11 OxOx CMC (1,500 Denier).

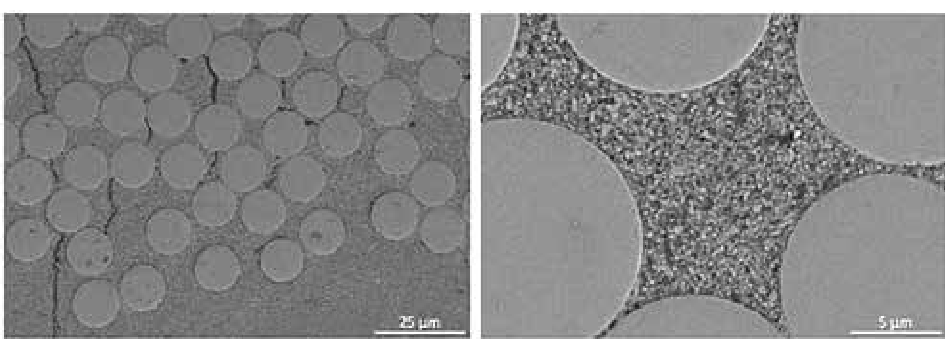


Figure 6: SEM Images of DF-11 OxOx CMC (1,500 Denier).

Composite thicknesses provide a framework for establishing cost per unit thickness of components using various prepregs.

Fabrics have balanced 4 to 8 harness satin (HS) weaves except for EF-20, which is the semi-unidirectional (UD) fabric.

With consideration toward the cost benefits of increased fiber denier, and on supply chain savings through modified fabric architectures, this study explores the effects of higher denier fibers and fabric architectures on the resultant composite properties.

EXPERIMENTAL

Fabrics of Nextel 610 and Nextel 720 described in Table 2 were woven and heat cleaned. Fabrics were coated to a known matrix content with proprietary ceramic slurries formulated and blended at Axiom Materials, Inc. and Composites Horizons using laboratory-based coating techniques. For Nextel 610 fabrics, an aluminum-silicate slurry was used. For Nextel 720 fabrics, an alumina slurry was used. Matrix absorption and fabric handling characteristics were observed and recorded. Pre-pregged fabrics were laid up at Composites Horizons into multi-ply 0°/90° laminates with a target thickness of 0.100-0.130 inches (2.5-3.3 mm). EF-20 was laid up into a 0° laminate because of its unidirectional weave pattern. Automated coating behavior for DF-11, DF-19, EF-11, EF-19, and EF-20 were independently explored using a single pass solution pre-preg treater at Axiom Materials, Inc. Laboratory-coated laminates were processed via autoclave cure and sintered at Composites Horizons. Physical properties were evaluated including fiber volume, matrix volume, porosity, density, and per-ply thickness. Laminates were cut into specimens for testing of flexural properties per ASTM C1341, interlaminar shear properties per ASTM D2344 and tension properties per ASTM C1275. In order to evaluate the thermal effects, tension properties of Nextel 610 composites were tested after aging at 900°C, 1,050°C, and 1,150°C (each at 10hr, 100hr, and 500hr exposures), and tension properties of Nextel 720 composites were tested after aging at 1,100°C, 1,200°C, and 1,275°C (each at 10hr, 100hr, and 200hr). Mechanical tests were conducted at 3M, Axiom Materials Inc., and Exova laboratories. Round-robin testing was also conducted to assess laboratory biases for interlaminar shear and tension.

RESULTS AND DISCUSSION

Upon initial weaving, sized fabrics of heavier deniers appeared to have more fiber gapping than weave patterns of 1,500 denier. However, it was observed that the heat-cleaning (desizing) operation had a significant impact on relaxing the fabric tows and spreading them out into a more even plane with greater coverage. This was an important discovery because the presence of rounder, unspread tow bundles of higher denier have the potential to affect the properties of the resultant composite due to inconsistent microstructure and/or increased thicknesses. This is similarly observed in comparing heat-cleaned thicknesses with sized thicknesses in Table 2. The extent to which the heavier denier and weave pattern fabrics accept ceramic matrix impregnation was also evaluated. It was observed that all fabrics identified in Table 2 were readily impregnable in the laboratory with relative ease. Further, automated pre-pregging operations using ceramic slurries were conducted on DF-19 (3,000 denier 3M™ Nextel™ 610), and EF-19 (3,000 denier Nextel 720), and EF-20 (10,000 denier Nextel 720), all of which demonstrated good impregnation performance and handling through the treating equipment, and little difficulty in roll winding or packaging. The expectation is that fabrics having as high as 20,000 denier could be pre-pregged using automated methods with relative ease. Evaluating pre-preg drape characteristics is likewise central in determining if modified fabric architectures are suitable for largescale production. Base assessment of pre-preg drape characteristics indicated that all fabrics of 3,000 denier or lower were not of concern during layup for radii of 1" (25mm) or greater, including fabric styles DF-19 and EF-19. DF-19-16-4500 exhibited fiber resistance and breaking and is suggested for components with gentler radii. Lastly, it was determined that 10,000 denier semi-unidirectional fabric EF-20 was able to be contoured in the 90° direction (perpendicular to dominant fibers) for tubular structures of about 1" (25mm) or greater.

Composite laminate properties are presented in Tables 3 and 4. The characterization of laminate properties provides insight into finished composite laminate quality and microstructure, as well as standard properties such as density, ply count, and dimension.

To the degree that properties are outside of general expectations, physical properties can also indicate the presence of any improperly prepared or processed laminates. No unusual characteristics were observed for any of the fiber deniers or fabric geometries evaluated. Even at relatively thicker fabrics and higher fiber deniers, similarity was observed in porosity content, matrix content, and density. Volumetric properties were within normal ranges of experimental and measurement variance error.

Per ply thicknesses (PPT), of value from a design perspective, are plotted in Figure 4. Comparisons may been be drawn between heat-cleaned fabric thickness (refer to Table 2), and postprocessed, composite PPTs. The data indicates that a reduction in PPT between heat-cleaned fabrics and finished part component readings can be expected, although variation in the change is significant and deemed to be largely geometry-dependent and affected by the behavior of both (a) the fibers laying down during composite processing, and (b) the flow and behavior of the matrix around the fiber. The composite thicknesses are useful to the part designer in determining the number of plies of a particular fabric style to use in costing and/or engineering OxOx CMC components. Composite thicknesses also provide framework for establishing cost per unit thickness of components using various prepregs.

In order to provide some understanding of composite microstructure, SEM images were taken of various composite laminates in the present study, and are presented in Figures 5-8.

The images are polished cross sections that show both the matrix and the fibers. What is obvious is the shape of the fiber changing from round to more of an oval to dog-bone shape as the denier increases. This is the result of a drying phenomenon that occurs when the fibers are spun during initial manufacturing. As is shown in Table 1, the single filament strength is not affected by the shape change of the fibers at higher deniers.

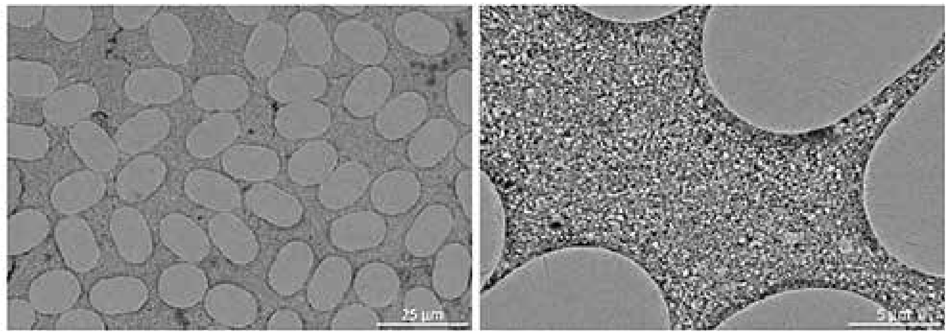


Figure 7: SEM Images of DF-11-10-4500 OxOx CMC (4,500 Denier).

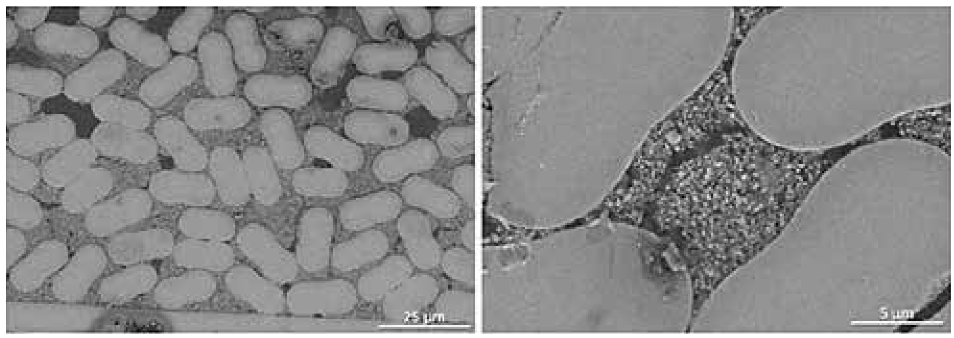


Figure 8: SEM Images of DF-24-8-10k OxOx CMC (10,000 Denier).

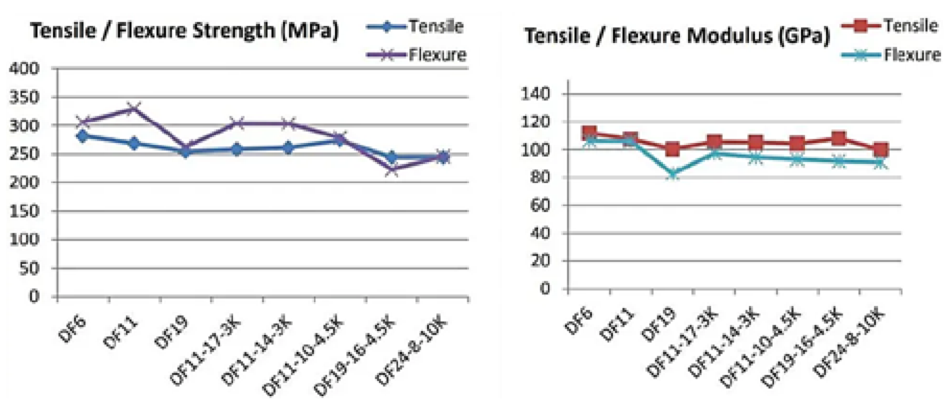


Figure 9: Tensile and flexural properties for Nextel 610™ composite laminates.

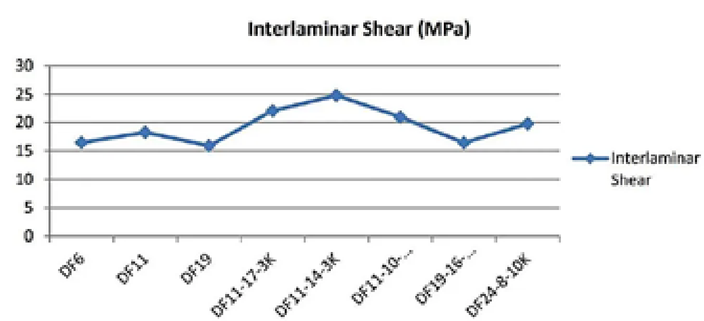


Figure 10: Interlaminar shear properties for 3M™ Nextel™ 610 composite laminates.

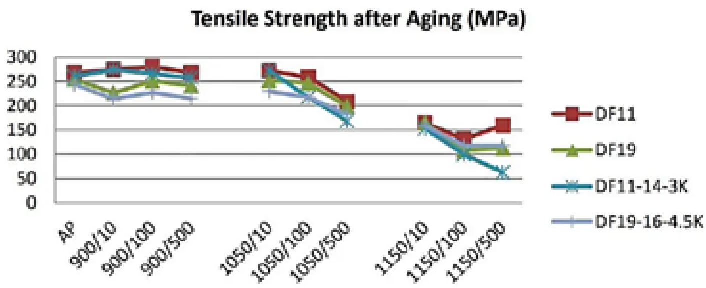


Figure 11: Tensile strengths of 3M™ Nextel™ 610 OxOx CMC laminates as processed (AP), 10/100/500 hrs at 900°C, 10/100/500 hrs at 1,050°C, and 10/100/500 hrs at 1,150°C.

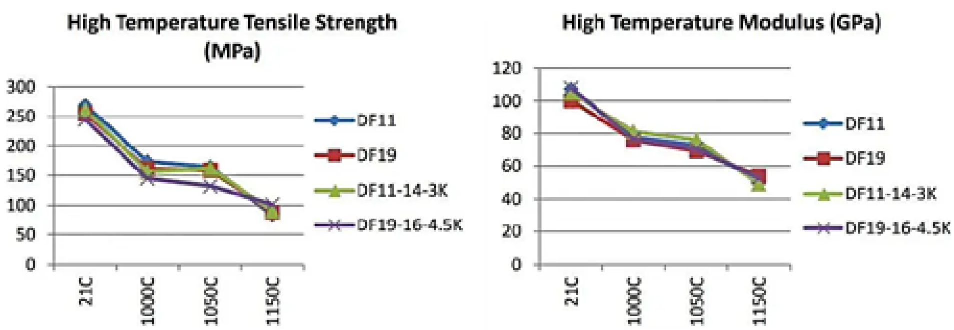


Figure 12: Tensile properties of Nextel 610 OxOx CMC laminates as processed (21°C), at 1,000°C, 1,050°C, and 1,150°C.

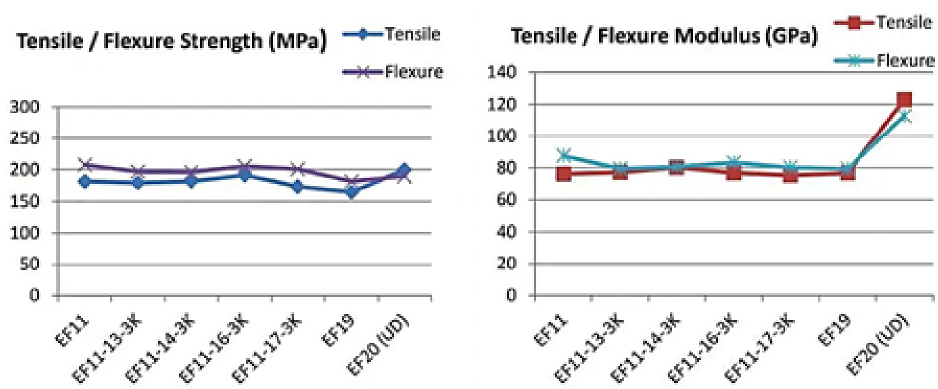


Figure 13: Tensile and flexural properties for 3M™ Nextel™ 720 composite laminates.

Nextel 610 OxOx CMC results: Ambient-temperature mechanical property data collected on OxOx CMC produced from various Nextel 610 fabrics are presented in Figures 9 and 10.

Both tensile data and flexural data indicate a mild downward trend with increasing fabric thickness and/or denier. What is significant about both tensile and flexural properties is that they suffer less degradation for higher denier and/or thicker weaves than was the expectation at the onset of this research. Properties remained relatively constant, despite drastic changes in filament geometry and fabric architecture. Interlaminar shear properties appear generally unaffected in Nextel 610 OxOx CMC laminates of heavier architecture, although there is some scatter in the data. The assumption for interlaminar shear properties was that an increase in the variation in composite microstructure would track with an increase in fiber denier and, in turn, a decline in properties, but this was not observed.

Thermal aging data and high-temperature test data are presented for Nextel 610 OxOx CMC in Figures 11 and 12, respectively. The impact of thermal aging on tension strength after various aging times and temperatures is in alignment with historical data for Nextel 610 fiber performance, which suggest a decline in fiber mechanical performance whose occurrence begins at approximately 900-1,000°C [9]. Tensile data at various temperatures is also in alignment with fiber performance expectation, where a decline in strength can be expected to correspond directly to temperature [9]. Notably, data trends are tight and relatively independent of fiber denier or weave pattern.

Nextel 720 OxOx CMC results: Ambient-temperature mechanical property data collected on OxOx CMC produced from various Nextel 720 fabrics are presented in Figures 13 and 14. Tension and flexural data indicate a stable trend with increasing fabric thickness and/or denier for balanced-weave fabric composites. EF-20, a unidirectional fabric of unbalanced weave, should not be considered in assessing trends. Similar to Nextel 610 composites, Nextel 720 OxOx CMCs do not appear to have significant mechanical property reduction for increased thicknesses or deniers.

Nextel 720 OxOx CMC interlaminar shear properties followed a similar flat trend to Nextel 610 in properties, although slightly upward with weight/fiber denier in this case. In drawing a relative comparison to the industry-standard EF-11 fabric, results presented for tension, flexural, and interlaminar shear properties are similar to those of heavier denier and courser weave fabrics. In the case of EF-20 semi-unidirectional fabric, the results for tensile and flexural modulus and interlaminar shear properties are in alignment with the general expectation of increased values in the 0° direction relative to same-thickness laminates of balanced weave. Tensile and flexural strength properties did not meet the expectation of an increase in strength for the additional fiber aligned with test direction.

The impact of thermal aging on tension and interlaminar shear properties is presented for Nextel 720 OxOx CMC laminates after various aging times and temperatures in Figures 15 and 16. Results

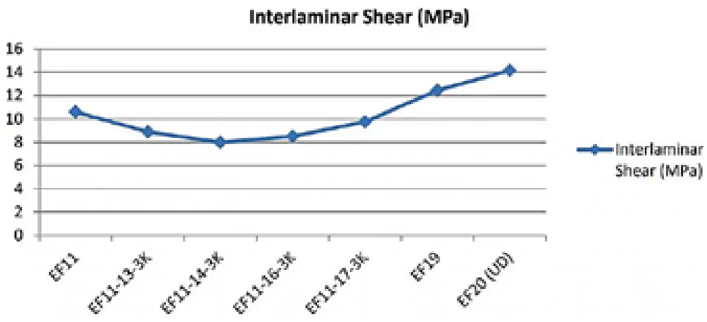


Figure 14: Interlaminar shear properties for Nextel 720 TM composite laminates.

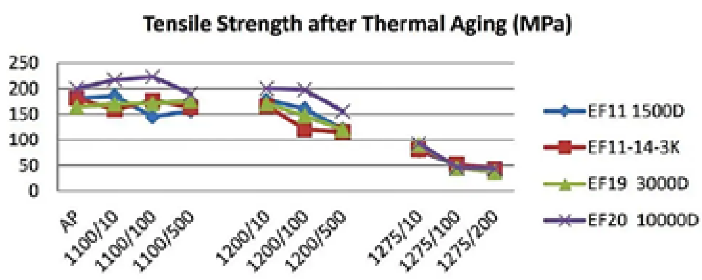


Figure 15: Tensile properties of 3M™ Nextel™ 720 OxOx CMC laminates as processed (AP), 10/100/500 hrs at 1,100°C, 10/100/500 hrs at 1,200°C, and 10/100/200 hrs at 1,275°C.

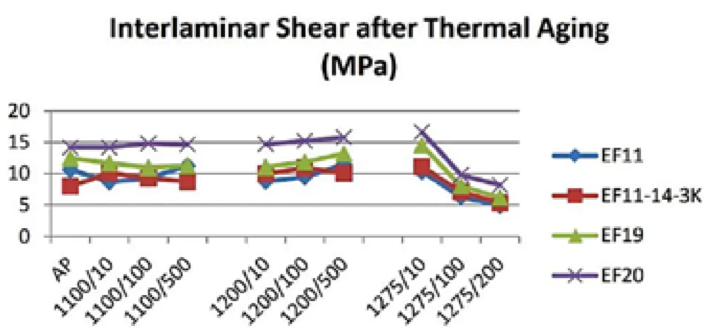


Figure 16: Interlaminar shear properties of Nextel 720 OxOx CMC laminates as processed (AP), 10/100/500 hrs at 1,100°C, 10/100/500 hrs at 1,200°C, and 10/100/200 hrs at 1,275°C.

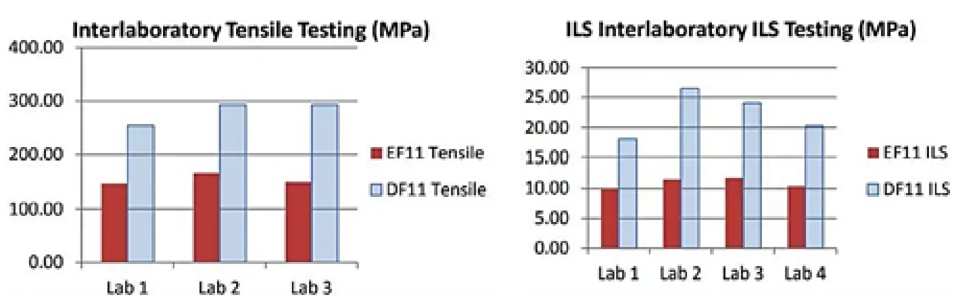


Figure 17: Interlaboratory test data for tensile strength and interlaminar shear strength.

for tension are in alignment with expectations for fiber strength performance, which is reported to decline at or about 1,100 to 1,200°C [9]. Interlaminar shear data at various temperature aging suggests long-term property reduction onset at approximately 1,250°C. Data trends are for both properties are relatively independent of fiber denier or weave pattern.

Interlaboratory testing: Round-robin testing was conducted between various laboratories to identify any expectations of bias for tensile and interlaminar shear data. Data are presented in Figure 17.

Site-to-site comparability for tensile strength was reasonable, while there was significant scatter for interlaminar shear data. Based on the variation in shear data recorded for this study, it is recommended that the data presented for shear are used for comparative purposes rather than engineering or design purposes.

CONCLUSION

Fiber and fabric architectures enabling significant component-level cost reductions for OxOx CMC have been presented. While primary cost savings are achieved at the fiber level, secondary benefits may also be realized at other points in the OxOx CMC supply chain in transitioning to the heavier fabric designs. OxOx CMC pre-pregs of higher-denier fabrics have been produced, evaluated, and converted into composites for mechanical characterization. Pre-preg layups may be completed on tight contours using up to 3,000 denier. Gentler geometries are advised for parts intended to be produced with 4,500 denier or above. Data and observations indicate that the transition to heavier denier yarns and architectures have relatively minimal effect on mechanical properties or on thermal stability of OxOx CMCs. Future research should be directed toward product standardization and design-quality data development for higher-denier fabrics to enable more flexibility in engineering design. It is recommended that part contours and layup characteristics are carefully considered in selecting the lowest cost fabric suitable for the application.

ACKNOWLEDGEMENTS

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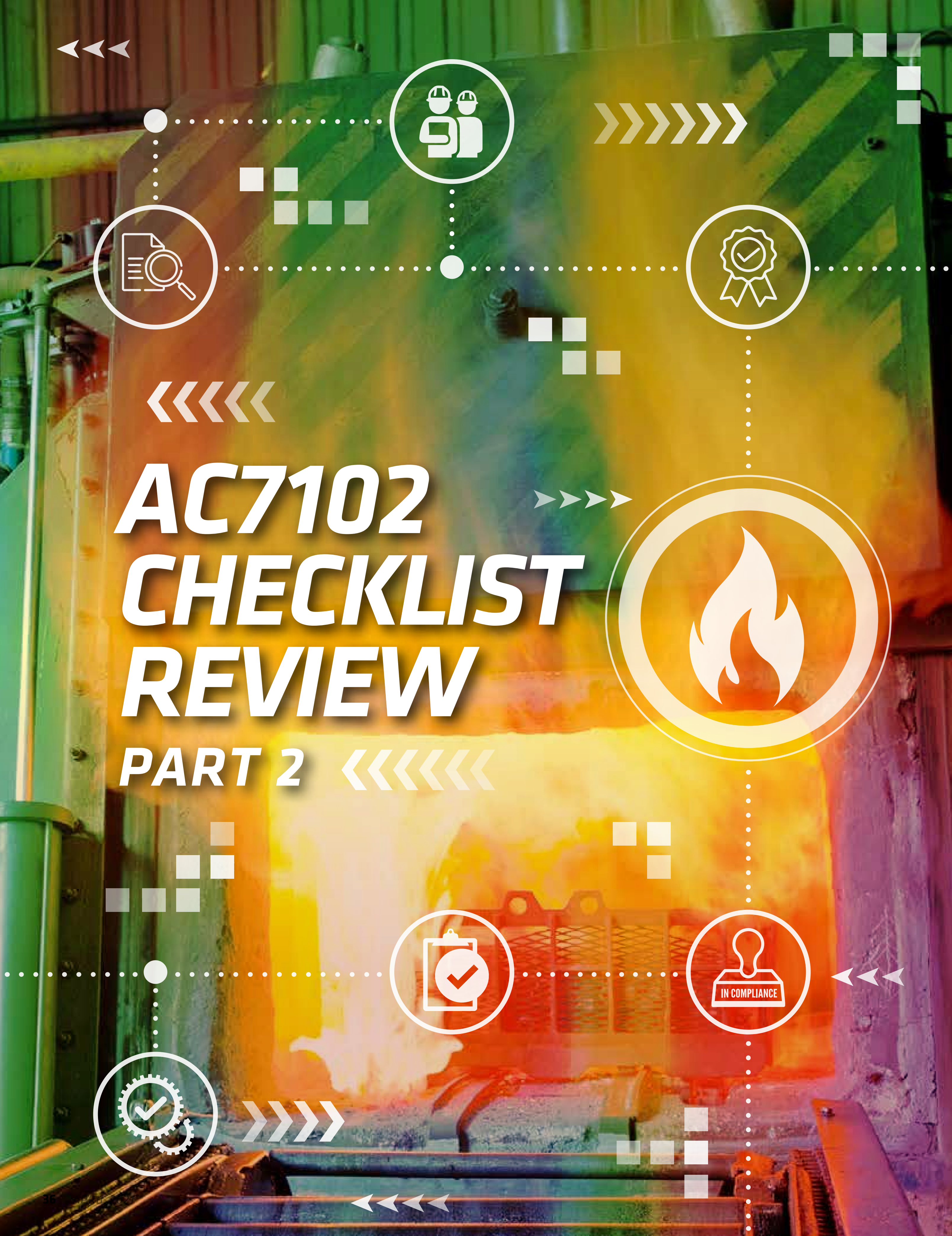
AC7102 CHECKLIST REVIEW

PART 2



AC7102.1 is comprised of 12 sections, and this article will look at the specific sections that tend to challenge suppliers.

By JASON SCHULZE

EDITOR'S NOTE » This is the second of a five-part series of articles that will deconstruct the requirements of AC7102. Each article will appear every other month through 2021. Part 1 was published in February.

It is my hope that suppliers may have, at the very least, gained some insight into some challenges they may face when interpreting and implementing the AC7102 Nadcap general checklist. Both tasks mentioned can be time consuming regardless of how long one has been in the industry. The goal of these five in-depth focused articles is to point out the challenges that, as I see, face suppliers who are both new to Nadcap and are seeking reaccreditation. To interpret the checklist requirements while explaining both intent and what is expected is my goal.

In the following article we will discuss the challenges associated with AC7102/1, less the job audits.

FURNACE BRAZING – HEAT TREAT COMMODITY

The initial challenge I see from suppliers is recognizing that, while furnace brazing is considered joining and not heat treating, because a furnace is used, it is placed within the heat-treat commodity. This is an important fact to recognize, especially when structuring procedures around Nadcap qualification as it pertains to heat treat and furnace brazing. As an example, a supplier may process aluminum, as well as furnace brazing — two very different tasks using different furnaces. A single general heat-treat procedure could, since furnace brazing is included in the heat treat commodity, contain general brazing requirements as well. It is important to keep in mind that the requirements within AC7102 relate to furnace brazing as well as general heat treating. Keeping that frame of mind when writing procedures will help.

THE STRUCTURE OF AC7102.1

AC7102.1 has 12 sections. In this article, we will visit areas of these sections that tend to challenge suppliers.

Throughout these sections, PRI has attempted to capture important variables throughout the furnace braze process. Braze requirements can be flowed down to suppliers in a number of ways: from purchase orders and prints to industry specifications such as AWS C3.6M/C3.6. These types of specifications and/or customer requirements must be considered in conjunction with the checklists, as not all aspects can be expected to be within the AC7102.1 checklist. An example would be the frequency at which temperature uniformity surveys must be performed. AWS C3.6 requires furnaces to be surveyed at a quarterly frequency when operating temperatures in excess of 2,000°F. If a supplier has a Class 3, Type B furnace, they need to stay at a quarterly frequency and would not be able to take advantage of the permitted extended periodic interval of semi-annual. This type of requirement is not reflected in AC7102.1 (nor should it be), although it must be considered when writing internal procedures for furnace brazing and pyrometry.

SECTION 1: VALIDATION

Section one presents questions related to BPS and BQR records. For those new to the brazing, a BPS is a Braze Process Specification and a BQR is a Braze Qualification Record. A BPS outlines the specific braze application and process parameters for specific part numbers. This can take many forms as suppliers typically design and use a BPS that was developed internally. The BQR qualifies general aspects of a braze based on base metal, filler metal, joint type, thermal cycle parameters, etc. This document qualifies the braze with both inspection techniques and metallurgical examination. Question 2.1 in

“Do procedures require periodic evaluation to ensure that approved personnel maintain proficiency in their assigned brazing filler metal application and related tasks?”

AC7102.1 refers to BQRs, as well as any related customer qualification.

SECTION 2: PERSONNEL

The most common challenge within this section that I see when consulting is question 3.2.1: “Do procedures require periodic evaluation to ensure that approved personnel maintain proficiency in their assigned brazing filler metal application and related tasks?” The intent is to ensure that scheduled repeated training occurs to ensure personnel maintain proficiency. Internal procedures should specify reoccurring training at specific frequencies for personnel performing braze application as well as braze furnace operators.

SECTION 4: MATERIAL CONTROL

This section relates to the braze filler metal. Typically, storage as well as filler metal mixing statements are not an issue. What stands out in this section is question 4.4: “Is there objective evidence that the raw materials certifications are reviewed?” Having a statement within internal procedures requiring filler metal certifications to be reviewed is one thing — showing consistent evidence of this seems to be where some suppliers run into issues. It is important to receive and review filler metal certifications to ensure the chemical composition is met as well as any other purchase order requirements.

SECTION 6: BRAZE EQUIPMENT

Section 6 contains requirements for the braze furnace used. This is typically a vacuum furnace, although there are separate requirements for dip salt brazing and atmosphere brazing. Questions 6.1.1 and 6.1.2 are the most commonly missed in this section. The two questions relate directly to each other: “Is the gas dew point monitored?” and “Is the dew point monitored at the required location?” It is important to realize these questions do not have an option to mark NA. They must be answered. Procedures should state how often the dew point is checked, what the limitations are (i.e. < minus-60°F) and the location where the dew point sample is taken (i.e. as it enters the furnace, at the furnace point from supply, etc.).

SECTION 7: BRAZE FILLER METAL APPLICATION AND ASSEMBLY PLANNING

This section contains, among other things, specific items that are required to be within the braze process planning documentation (i.e. router, BPS, procedures, etc.). Question 7.7 states: “Does the braze filler metal application/assembly work instruction/procedure contain the following, if required?” The remaining questions outline the items that should be documented. Question 7.7 is where I notice suppliers have gaps.

SECTION 8: BRAZE PROCESSING

Section 8 relates to what was discussed in section 7: What is required to be within the internal documents? Question 8.1.7 states: "Instructions for determining when to start the brazing time and when to complete the brazing time?" This question may relate to an internal heat-treat procedure as this is also required within AC7102. The determination of start- and end-of-soak may differ depending on the braze cycle. Some braze cycles have a stated time with tolerance, such as "Braze for 6-10 minutes." While other braze cycles, such as aluminum brazing, may simply state that once a thermocouple reaches a specific temperature, the furnace should be cooled.

Another question to pay particular attention to is question 8.1.16: "Instructions when to remove parts from the brazing equipment?" This question, while it does have an NA option, may apply to materials such as titanium or other sensitive materials. It is important to recognize that, when procedures do state a specific temperature that parts may be removed from the brazing furnace, the furnace recording must reflect that and recording should not be stopped until evidence of the specified temperature has been reached. In cases like this, the furnace recording system would also need to be calibrated at the temperature specified.

SECTION 9: POST-BRAZE CLEANING

Post-braze cleaning may not always be performed in the same way, depending on the braze process. For suppliers using stop off, cleaning may differ from suppliers who do not use stop off. Question 9.1.1: "Does the post-brazing cleaning work instruction contain the following, if required: Method and product used for post-cleaning?" does not give an NA option (unless the entire section is marked NA), so some type of cleaning method needs to be documented.

SECTION 13: BRAZING REWORK

Braze rework is often performed to correct nonconforming aspects of a braze joint. Question 13.1: "Where required, are the total rework cycles or the total time tracked and recorded to verify that the maximum time at temperature, or the maximum number of cycles, meet the requirements of the engineering drawing or specification?" addresses braze rework in several ways. In my consulting with suppliers, tracking of braze rework cycles is typically the challenge suppliers face. A practical way of tracking braze rework is putting defective parts through your nonconforming material system that will then go through material review and have the rework assigned.

SUMMARY

Accounting for Nadcap checklists requirements is two-fold; 1) documenting customer and checklist requirements and 2) showing evidence the requirements are met. To do this, suppliers should understand the checklist and interpret the requirements as clearly as possible. Part three will explore Nadcap Checklist AC7102/2.

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L&L SPECIAL FURNACE CO., INC.

PRECISION, UNIFORMITY, VALUE

Model FSC42 hydrogen retort shuttle furnaces.
(Courtesy: L&L Special Furnace Co.)

With a decades-long reputation for designing special industrial furnaces, ovens, kilns, quench tanks, and heat-treating systems, L&L Special Furnace Co., Inc. has manufactured some of the best heat-treating equipment for the industrial and laboratory world for more than 60 years.

By KENNETH CARTER, Thermal Processing editor

Sometimes, big things can be born from a simple act of kindness. Such is the case with L&L Special Furnace Co., Inc.

The company is known for designing and building high temperature furnaces, ovens, kilns, quench tanks, and heat-treating systems, specializing in batch production furnaces and ovens with applications requiring high uniformity and controlled atmosphere.

But L&L's humble origins began during World War II, when L&L's owner and president Greg Lewicki's mother employed about 20 displaced Eastern Europeans in her ceramics factory in Chester, Pennsylvania, where they helped decorate knick-knacks and mementos.

"At some point, she realized she was going to need a better kiln," Lewicki said. "My father was working at the Sun Shipyard in Chester as a welder, and he looked at what was being offered on the market at that time and realized he could probably do a better job than they did. So, he talked to a buddy of his at the shipyard, and the two of them got together and decided they were going to make electric kilns. They started up a little company in 1946, L&L Manufacturing Company, and they made electric kilns for hobbyists. And my mother was the first customer."

Not long after, Lewicki's father became interested in industrial heat-treating furnaces, and he and his business partner started a smaller division inside of L&L Manufacturing Company called L&L Industrial Division. Later on, Lewicki's father took the industrial division solo in the 1960s, where it became L&L Special Furnace Company.

SOLID REPUTATION

In the 60 years since, L&L has earned a reputation for sophisticated engineering, quality workmanship, excellent documentation, and professional service, according to Lewicki.

"We pride ourselves on uniformity and precision and value in our electric and gas-fired heat-treating furnaces," he said. "We manufacture some ovens for tempering. We don't get into really low temperature ovens; it's just not our thing because we're not a sheet-metal house. We also manufacture quench tanks, some with load elevators and cooling systems, and furnace loaders."

L&L offers a huge line of furnaces in all different sizes, according to Lewicki.

"We make commercial grade furnaces for bench top; we make a very nice line of little box furnaces for people who are just getting started in heat treating where they don't have very big parts, and we go all the way up to pretty large chambers," he said. "We make car bottom furnaces, shuttle furnaces, a very nice bottom loading, high-temperature furnace using molybdenum-disilicide elements.

Model XLA3636 Class 2 box furnace for aerospace applications. (Courtesy: L&L Special Furnace Co.)

Our furnaces have temperature ranges from, I would say our sweet spot is about 1,800°F up to 3,000°F."

EVERYTHING IS CUSTOMIZABLE

On top of that range of product offering, L&L is able to customize them as well, according to Lewicki.

"Everything we make is customized to whatever the customer needs," he said. "If the customer needs very high uniformity, we'll provide element bank control. I'm not going to call it zone control

Model FNC536 CMC pyrolysis furnace. (Courtesy: L&L Special Furnace Co.)

"A lot of customers have similar requirements, so we are able to sort of custom fit. It's almost like tailoring – tailoring our offerings to what the customer requires."

because we don't necessarily put thermocouples all over the place. That's where we started, but we stopped doing that, since, with the Nadcap requirements, it would just take too many thermocouples to do what we used to do. Right now, what we do is we'll have one thermocouple, and we'll do a survey and with trim pots controlling the power controls for each element bank and still get a very tight uniformity depending on what the class requirements are."

TECH SAVVY

Because L&L has tried to stay ahead of technology, that has translated in the company's product line being state-of-the-art for decades, according to Lewicki.

"We're early adopters of different technologies," he said. "We started CAD here when CAD first came out for small companies; that was back in the late '70s, early '80s. We actually talked to various control manufacturers. We saw the need for a PLC integrated with a temperature control a long time ago and talked to various manufacturers like Honeywell and Barber Coleman at the time, and we expressed a very strong interest in that kind of controller. When Honeywell came out with its UMC 800, I think we were their first customer."

Lewicki pointed out that the UMC 800 has since evolved into a much more sophisticated controller, which the company still uses.

"We use that; we use an offering by Eurotherm called the E+PLC400," he said. "We use that in certain applications. Our philosophy is to integrate what the control manufacturers have to offer, and we try to integrate all that into a very precise arrangement for a uniform heat-treating machine."

UNIQUE PROJECTS, UNIQUE CHALLENGES

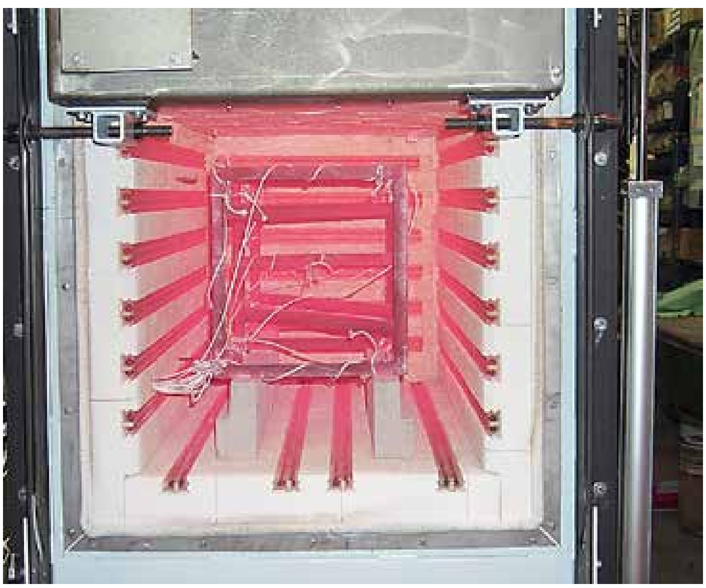
With all that L&L has to offer, Lewicki emphasized that the company has had some interesting requests from customers over the years.

"One of them was a glass manufacturer in the market for a very uniform tube furnace they needed to calibrate their high-tech glass slugs," he said. "The glass slugs needed to be five feet long, and we needed to have, of course, an entrance-end and an exit-end with enough of a margin so that the uniformity inside would be ±3°C. And in consultation with their engineers and our own resources, we got that furnace to ±1°C, and they're still using it after 30 years."

Another L&L customer was manufacturing superconducting wire and submitted a particular design it needed, which boiled down to a series of furnaces with a 2 meter by 2 meter by 2 meter work volume, according to Lewicki.

"It was a fairly large size, even for us; in fact, it was problematic

Setting the tarp on a large box furnace assembly after loading inside L&L building using 10-ton capacity crane. (Courtesy: L&L Special Furnace Co.)



Model XLE248 with special corrosion resistant case under TUS testing. (Courtesy: L&L Special Furnace Co.)

getting the darn things shipped because of the height," he said. "But we needed to get it up in the high-uniformity range because of the material they were processing. It was superconducting material that needed to be at the very same temperature all the way through its heating cycle of heating and cooling. And we developed a system with over 24 zones of control and a 5-horsepower fan and cooling tubes inside the chamber. This would get up to temperature at about 10°C per minute and cooling at ±5°C per minute. And we had ±1.5°C all the way up and down the inside of that six-foot chamber. That was a very proud achievement for us."

SIMILAR REQUIREMENTS

Those are just two examples of how L&L finds unique and successful ways to satisfy its customers, although Lewicki said a majority of the jobs that come to L&L aren't often as challenging. Even though, L&L gives each job 100 percent.

"A lot of customers have similar requirements, so we are able to sort of custom fit," he said. "It's almost like tailoring — tailoring our offerings to what the customer requires. And since we've done so many of these jobs over the years, we have a lot of options, a lot of different things we can do for people. We have inert atmosphere; we have combustible hydrogen atmospheres. Even if somebody needs an oxidizing atmosphere, we will supply a furnace with hydrogen and oxygen in the same device."

Even though L&L does make car bottoms, shuttle furnaces, and larger box furnaces, the company doesn't typically involve itself in heavy automotive projects, according to Lewicki.

"We try to stay on research and development; we've done a lot with aerospace, and recently, we've done a lot with CMC," he said. "In fact, we have developed a series of CMC processing pyrolysis furnaces for an aircraft engine manufacturer."

In addition to the heat-treating needs in the aerospace industry, L&L is involved in magnetic heat treating as well, building furnaces to heat treat magnets used by Fermi Labs for the critical magnets used in the CERN collider, as well as the heat processing of medical devices, precision ceramics, piezo ceramics, and precision glass annealing.

"We made furnaces for NASA to anneal a huge array of mirrors being sent into space," Lewicki said.

LOYAL EMPLOYEE BASE

L&L has about 20 employees for both office and factory, many of whom have been with the company for 10 years or more. Manufacturing and engineering are integrated in the company's 17,000-square-foot facility south of Philadelphia, Pennsylvania.

A typical year's production runs about 80 projects, some of which require more attention than others due to complex customer requirements, according to Lewicki. Some of these are standard products, which are in-stock and ready to ship. All of these jobs, the total now numbering in the thousands, are fully documented and supported by L&L's expert staff.

"We've done these types of jobs for years, and it's not old hat by any means," he said. "Every situation we look at, we look at with fresh eyes."

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TURGAY OZAN /// PRESIDENT /// BUSCH VACUUM SOLUTIONS USA

"With this acquisition, the Jennings team, who have now become Busch employees, can fully concentrate on Busch products and solutions in the heat-treat industry."

Busch Vacuum Solutions USA, one of the largest manufacturers of vacuum pumps, blowers, compressors, and systems, has acquired Jennings Associates Inc., a distributor for new equipment, maintenance, and repair for vacuum pumps, blowers, and heat exchangers. *Thermal Processing* recently sat down with Busch President Turgay Ozan to discuss what the acquisition will mean to its customers and how the company services them going forward.

What types of products does Busch Vacuum Solutions offer?

Busch Vacuum Solutions offers vacuum and pressure solutions to end-user customers, engineering companies, and OEMs in industrial and medium-high vacuum applications and industries. In addition to vacuum technology products, we also have an extensive service network that includes expert field service specialists and service centers across the country.

You recently acquired Jennings Associates. How does that expand and enhance what Busch can do for the heat-treat industry?

With this acquisition, the Jennings team, who have now become Busch employees, can fully concentrate on Busch products and solutions in the heat-treat industry. They bring their manpower, salespeople, service technicians, and market knowledge. With that, together we are better able to focus on the heat-treat industry because Busch has extensive product and system solutions for the various applications in this market. With our more than 50 years of experience in the vacuum industry combined with their 45 years of experience working with us, together, we can apply even more expertise to this industry's demands for higher levels of performance and durability in this changing market. Since vacuum is a key part in many of the heat-treat processes to create atmospheres and necessary component properties, Busch can offer a large range of vacuum generators and customized solutions.

When did you acquire Jennings? And what were the reasons behind the acquisition?

The acquisition was finalized at the end of February 2021 and became effective March 1. The main reason for the acquisition was to extend the boundaries of our core vacuum business in this market by combining dedicated resources and expertise to develop and execute a strategically aligned approach to best support the vacuum customers in the eastern central region. We knew that Jennings was doing a great job, but they also had other products from other companies to represent, so their focus on Busch products and Busch customers was, of course, limited to the resources that they had. The timing was right for both companies to move forward with the acquisition. This year, it became possible for the Jennings team to give their full attention, full focus, and commitment to Busch. It is a mutually beneficial agreement, and their team is quite excited to come on board.

With both Busch and Jennings being family-owned businesses, how did that affect the dynamic of the acquisition?

Because both companies are family-owned, we carry similar values in our approach to joining businesses. Busch Vacuum Solutions in Germany was founded in 1963 by Dr.-Ing. Karl and his wife Ayhan Busch and further expanded together with the second generation, Ayla, Sami, and Kaya Busch. The management of the company is entirely in the hands of the Busch family. They continue to bring their family values to everyday life at Busch. Jennings Alberts was started by William and Kathleen Jennings in 1973 and later turned over operations of their business to the next generation, Pam Altier and her husband Bill Altier and Lisa (Jennings) Dugery. The dynamic of the acquisition was with a sense of appreciation as well as a long-standing partnership and history of successes.

What's been the market response to the acquisition of the distributor?

It has been very positive. The customers are excited about growing their businesses with direct manufacturer resources. Our direct customers, as well as customers that were served by Jennings, know that they will get even better service and quicker response times. In the past, they may have had direct dealings with only a handful of team members from Jennings, now they have access to the entire Busch organization.

Anything else about the acquisition or something else that Busch is involved with that you'd like to mention that our readers might be interested in?

I just want to reemphasize that we are putting a greater focus on our customer service and customer satisfaction now more than ever. We are a significant player in the vacuum industry and one of only a few vacuum solution companies that manufacture in the U.S. We have quite an impressive manufacturing set up in Virginia Beach, where our pumps and systems are designed, manufactured, and serviced for the U.S. market. Furnace manufacturers and plant designers in the U.S. and throughout the world rely on Busch for vacuum technology. And we are excited about the innovations we're able to bring our customers in the heat-treat market, such as leak-detection equipment, new vacuum gauges, Industry 4.0 smart technology, and, of course, the broadest range of dry screw technology and customized solutions.

MORE INFO www.buschusa.com