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FROM THE EDITOR ///

October brings a wide-range of heat-treat topics

Part of what I enjoy about being editor of *Thermal Processing* is bringing you information about the heat-treating industry, and it's always an extra pleasure to bring you such a wide scope of topics, especially in a season that is synonymous with cornucopia.

That's right. Our October issue boasts a cornucopia of articles where I'm sure you'll find at least one that's of interest. (Although, I bet you'll find much more than that.)

The aerospace industry is an important user of the services and products within the heat-treat industry, so our cover story is devoted to that subject.

An article from Wisconsin Oven Corporation Vice President of Sales Mike Grande looks at how the ever-evolving aerospace industry is requiring innovative heat processing solutions that are larger, smarter, better, and faster.

Our second article featuring aerospace applications looks at how 4D quenching can be used by tools manufacturers to address distortion control during heat treatment.

As technology has advanced, the need for more precise and accurate certifications has become a highly sought-after aspect of the heat-treat world.

In that vein, make sure you check out our final Focus article from BASF's Biagio Orlando where he discusses what ISO 17025 certification can mean for the heat-treat industry and how it's a great way to showcase laboratory competence.

Keeping within the certification arena, frequent contributor and columnist Jason Schulze brings his own expertise to the table as he spells out the benefits of the Nadcap merit process and how achieving this merit can be a good thing for suppliers.

As anyone who has to sit back and write a certification report knows, it can be time consuming, to say the least. But there's some help on the way. I had the pleasure of talking with C3 Data founders Nathan and Matt Wright, who have developed a software platform to help ensure furnace compliance to a number of industry requirements such as Nadcap, AMS2750, CQI-9, and more. Check out their story in this issue's company profile.

See what I mean? A lot of interesting articles and much more to exercise your heat-treating brain cells.

Enjoy this month's issue, and, as always, thanks for reading!

KENNETH CARTER, EDITOR
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Antonio Catalano, Tenova executive vice president, left, and David Paterson, chief executive officer at Latrobe Magnesium Limited. (Courtesy: Tenova)

Latrobe Magnesium awards contract to Tenova Technology

Tenova, a leading developer and provider of sustainable solutions for the green transition of the metals industry, was awarded a contract by Latrobe Magnesium Limited (LMG), a company based in Australia. The scope of work is the engineering, supply, and supervision of the Magnesium Oxide (MgO) production plant at Latrobe Valley, Victoria, Australia, a demonstration plant using a world-first process of combined hydromet/thermal reduction.

As part of the first phase of the project, Tenova's scope of supply will include a magnesium oxide (MgO) plant, with spray roaster technology, with a production capacity of 300 kg/h.

The demonstration plant will initially have capacity of 1,000 metric tons of magnesium (Mg) metal per year, and in the second stage, LMG intends to develop a commercial scale operation with an envisaged production capacity in the range of 10,000 to 40,000 metric tons per annum of magnesium metal.

Thanks to its world-first patented hydrometallurgical extraction and thermal reduction process, the plant will harvest magnesium metal from a fly ash resource—a waste stream from brown coal power generation. The project is at the forefront of environmental sustainability as it converts nearly 100 percent of the resource into valuable commodities. The released CO2 emissions are approximately 50 percent less than comparable magnesium production plants.

"Demand for magnesium worldwide is strong," said David Paterson, chief executive officer at LMG. "It has the best strength-to-weight ratio of all common structural metals and is increasingly used in the manufacture of car parts, laptop computers, mobile phones, and power tools. Currently, the Latrobe Valley contains 25 million tons inventory of fly ash, that is why it so important for us to have a reliable partner in this project."

"Through many years of experience and continuous improvement of pyro hydrolysis process, Tenova is able to meet specific customer requirements. The positive and constructive cooperation with Latrobe during the development phase of the magnesium production facility was a decisive factor to now deepen this work in the course of realization," said Gregor Kappacher, branch manager at Tenova Austria, the competence center for spray roaster technology. "The project is of paramount importance for Tenova, because it opens positive future perspectives and is in line with our effort towards achieving a sustainable industry."

The first magnesium is forecast to be produced in 2023.

MORE INFO www.tenova.com

L&L commissions high-temp box furnace for ceramics

L&L Special Furnace Company, Inc. has shipped and commissioned a large high-temperature box furnace to a Midwestern U.S. plant starting production on ceramic matrix parts that will be used in military and aerospace applications.

The L&L GHH3350 has an effective work zone of 32" wide by 30" high by 50" deep. The furnace is capable of reaching temperatures up to 1,700°C/3,100°F under partial atmospheric pressure. There is also a vacuum pump to help remove oxygen prior to beginning the thermal cycle.

The front-loading box furnace is insulated with multi-layer, high-temperature insulation. The floor is reinforced and includes a composite hearth capable of supporting load weights up to 500 pounds.

The GHH3350 is heated with molybdenum disilicide elements on the side walls and back. It is controlled by a Eurotherm program control with overtemperature protection and

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

The GHH series box furnace for ceramic matrix composite. (Courtesy: L&L Special Furnace Company)

includes a multi-pen chart recorder with 36 inputs to record various temperatures, flow rates, and pressures.

The case is sealed for use with inert atmosphere. It includes an automated flow panel, type B thermocouples, and a stack light audible visual annunciator system. The furnace has an afterburner or scrubber to remove any contaminants prior to evacuation from the furnace.

All L&L furnaces can be configured with various options and be specifically tailored to meet customers' thermal needs. L&L also offers furnaces equipped with pyrometry packages to meet ASM2750.

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

MORE INFO www.llfurnace.com

Delta H commissions DCAHT compliant to SAE AMS 2750G

Delta H® Technologies, LLC recently commissioned a state-of-the-art DCAHT® (dual chamber aerospace heat treating) system for heat treating aviation grade aluminum. The new system was a modern replacement of an original Delta H DCAHT furnace installed and in service since 2011 at PEMCO at Tampa International Airport.

The system features secure and tamper-proof batch records, soak time, and quench delay recorded to within 1/10 of a second, as well as full documentation of work order/tail number, before/after condition, part name and quantity, and other information. Extensive training was involved to not only more than a dozen operators but also many QC personnel and two "trainers" qualified to train other operators. Additional training was provided to personnel responsible

The installed system from Delta H Technologies features a certified TUS volume of 30 inches wide, 16 inches high, 72 inches deep, with an upper chamber convection oven operable to 500°F, and a lower chamber convection furnace capable of 1,200°F. (Courtesy: Delta H Technologies)

for maintaining pyrometry records to assure compliance to AMS2750G.

The installed system features a certified TUS volume of 30 inches wide, 16 inches high, 72 inches deep, with an upper chamber convection oven operable to 500°F, and a lower chamber convection furnace capable of 1,200°F. In addition to aluminum, the system can be used for PH stainless steel aging, as well as titanium and ferrous alloy processes. Both chambers qualified as Class 1, but were certified as Class 2 for aluminum applications. Honeywell controls and recorders are featured and include remote computer control, data entry, and process monitoring.

Given the accuracy of the quench delay system, part of the training included how to manually quench aircraft parts in less than five seconds from the time the door opens until fully submerged. Delta H calls this section of training a "Quench Off," with the goal being to make the "Three Second Club." Delta H says not only did most operators make the Three Second Club, two operators broke records and made the newly formed "Two Second Club."

"We look forward to sharing about our continued success with [Delta H's] great product," said Cruz Hernández, airborne maintenance and engineering services back-shop supervisor. "I am certain we will be using Delta H for future heat-treat and furnace endeavors."

MORE INFO www.delta-h.com

ASM offers course on using analytical tools to heat-treat steel

ASM International is offering an "Analytical Tools for the Steel Heat Treater" course at ASM International World Headquarters-Materials Park on October 31-November 2.

The material and coursework for the class were developed by a team from Dante Solutions. The three-day course offers a fundamental understanding of metallurgy and materials of heat-treat processes from an analytical perspective. Learn about process design and analysis using analytical tools; how to characterize equipment and part interactions; and gain an understanding of how process and material selection affects

ASM's "Analytical Tools for the Steel Heat Treater" course is for anyone looking to learn more about modeling a wide variety of heat-treatment processes. (Courtesy: Dante Solutions)

heat-treat results by using computer modeling. The course will benefit anyone looking to learn more about modeling a wide variety of heat-treatment processes while earning 2.25 CEU credits.

MORE INFO www.asminternational.org

Parts2clean offers innovations, trends for parts cleaning

Parts2clean recently presented the appropriate solutions, trends and know-how on parts cleaning at the Stuttgart Exhibition Center (Germany). Parts cleaning is an essential component of quality-oriented and stable production in all sectors of industry. Future industrial competitiveness will depend on the ability to meet new and ever-changing parts cleaning challenges in a process-safe, efficient, and resource-saving way.

Parts cleaning is an essential component of quality-oriented and stable production in all sectors of industry. (Courtesy: Deutsche Messe)

As a quality criterion and competitive factor, industrial parts and surface cleaning makes an essential contribution to value creation in manufacturing, remanufacturing, and recycling. Due to current product and manufacturing trends as well as the need to make parts cleaning more energy and resource efficient, companies are facing an array of challenges. In order to remain competitive in the future, it is important not only to know the current and future requirements for the surface quality of workpieces in all the different industrial sectors, but also to develop methods of improving sustainability and cost-effectiveness.

"Featuring the most comprehensive set of international offerings for all stages of the industrial parts and surface cleaning process, parts2clean is the world's best information and procurement platform for this purpose," said Hendrik Engelking, global director at Deutsche Messe.

The event unveiled their new and refined products and services to an international specialist audience, including new and optimized system concepts for precision and high-purity applications in areas such as the optics and supplier industry for semiconductor technology, electromobility, and medical, measurement and analysis technology. In addition, suppliers of cleaning technology are responding to the increasing requirements for particulate and filmic cleanliness, which can be seen in a number of industrial

sectors, with new and optimized process and drying technologies for wet- chemical cleaning. Various new and further developments for dry individual part cleaning, which can be easily integrated into manufacturing steps such as coating, sealing, bonding, and assembly processes — including in cleanrooms — were on display at parts2clean. Exhibitors also provided information on innovative approaches for integrating Industry 4.0 and artificial intelligence (AI) with industrial cleaning processes.

MORE INFO www.parts2clean.de/en

Seco/Warwick, GreenIron team for green future

The Seco/Warwick Group, a global manufacturer of metal treatment equipment, has signed an agreement with the Swedish company GreenIron H2 AB for the delivery of a series of furnaces for fossil-free metal production from ore, residuals, and waste recycling.

The new line of reduction furnaces, based on the technology provided by GreenIron, is in response to climate change and the urgent need to reduce CO_2 emissions and create energy and resource-efficient business models.

"The long-term agreement provides for the delivery of a series of equipment. Cooperation in this technology area will provide us with development and cooperation in the area of pro-ecological solutions, which is in line with the company's mission. With this new technology, together with GreenIron, we are contributing to global ecosystem protection," said Sławomir Woźniak, CEO of Seco/Warwick Group.

The furnaces ordered by GreenIron will be used to recycle oxidized metals without emissions. They will therefore directly contribute to CO_2 emission reduction on an unprecedented scale. Each furnace has the capacity to reduce emissions by 56,000 metric tons/yr. The technology, whose originator and patent rights owner is GreenIron, is a unique solution that will help many enterprises implement "green" solutions and function with the natural environment.

"We are happy to work with Seco/Warwick on this exciting journey toward a more energy and resource-efficient industry with zero emissions," said Edward Murray, CEO of GreenIron. "We feel that our partnership is a great foundation for rapid growth and a positive impact on emissions and climate change. GreenIron has high ambitions in regard to CO_2 reduction, starting with the first furnace, delivered from Seco/Warwick, and the subsequent first shipment of commercial fossil-free iron in 2023."

"It is also an opportunity for Seco/Warwick, because together with GreenIron we are creating a production line of completely new furnaces," said Woźniak. "For the first time, we are working closely with an external partner with technology that

comes from outside of our organization. Our task in the project is to build effective solutions and deliver them on time."

Seco/Warwick supports ecological solutions making the heavy industry environmentally friendly. The new furnaces in the production line, manufactured in cooperation with GreenIron, are units that have not been available on the market so far. Their great value is the fact that they contribute to carbon dioxide reduction, as well as significantly reducing the costs of recycling post-production residuals and waste.

The metals are extracted from ore or recycled without the release of fossil gases. Iron oxide (magnetite, hematite, wustite) is converted to pure iron by the hydrogen reduction process. In traditional technology, this process takes place in coke furnaces, which results in CO_2 emissions. In the GreenIron furnaces, CO_2 emissions are zero.

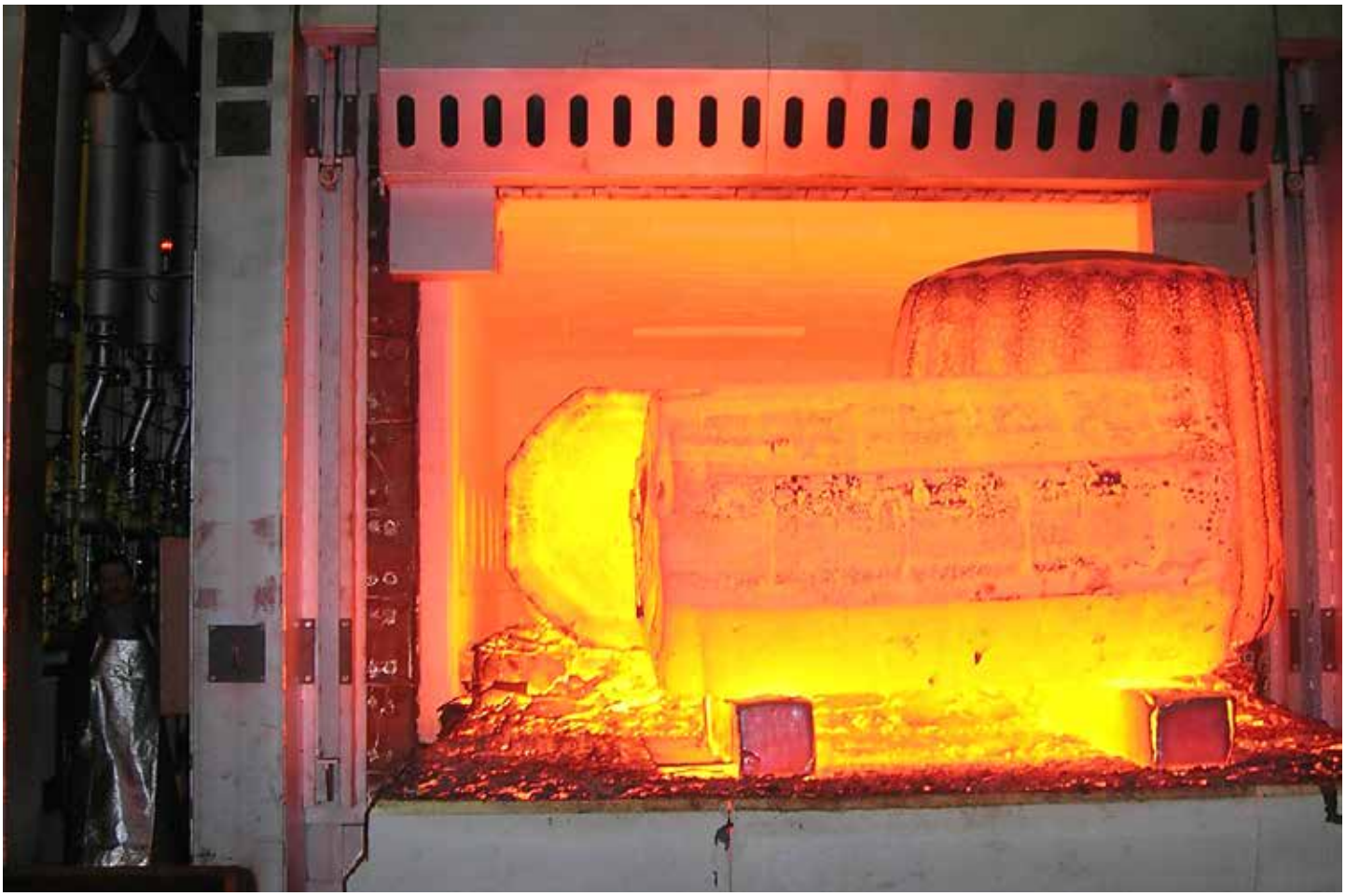
Reduction furnaces will be available to companies throughout the entire lifespan of iron and other metals — including mining, steelmaking, milling stations, foundries, metal workshops, and heavy ashes from incinerators. With GreenIron and Seco/Warwick, this waste will be given a second life and can be reused as pure steel or iron.

These will not be the first solutions from the Seco/Warwick brand that support "green technologies." Another example is ZeroFlow® gas nitriding technology allowing users to reduce technological costs by up to several dozen percent. Another solution — Vortex® (aluminum coil annealing furnace) reduces the component processing time by up to 30 percent compared to other available technologies. This reduces both energy consumption and emissions. On the other hand, Pit-LPC (pit furnace) technology shortens process time thus reducing energy and gas consumption. This directly decreases production costs, while improving the quality of results compared to traditional technology. But in the case of Seco/Warwick, taking care of the environment does not apply only to its products. Sustainable production and ecological innovation are part of a long-term strategy.

GreenIron H2 AB is a privately held company with patented and proven energy-efficient technology to reduce metalloxides to pure metal. The process is suitable for the creation of metals from ore, residuals, and waste. The technology is hydrogen based with only water as the process emission. When using the GreenIrons process in conjunction with a steel mill users can, without any CO_2 emissions, create prime iron-based metals for reintroduction to the steelmaking process from the waste and residuals formed in the steelmaking process. GreenIron enables a fully circular resource usage on site. GreenIron has a strong focus on minimizing CO_2 emissions and strives to create circular business models with minimized CO_2 emissions and high resource efficiency.

MORE INFO www.secowarwick.com
www.greeniron.se

IHEA's Fundamentals of Industrial Process Heating starts October 24



The curriculum includes the basics of heat transfer, fuels and combustion, energy use, furnace design, refractories, automatic control, and atmospheres as applied to industrial process heating.

IHEA's Fundamentals of Industrial Process Heating Online Learning Course has been a successful source of high-level learning for those in the industrial heat-processing industry for more than 10 years. Registration is now open for the next course beginning October 24 and runs for six weeks through December 11. The flexible online format and interactive forums are just some of the benefits of this class.

This affordable course is ideal for students to learn through a virtual format while at home or in the office, allowing them to go at their own pace. It offers indispensable tools to industrial process heating operators and users of all types of industrial heating equipment. Throughout the in-depth online course, students learn safe, efficient operation of industrial heating equipment, how to reduce energy consumption and ways to improve the bottom line. The content provides an excellent overview of the essential information used throughout the industry.

The curriculum includes the basics of heat transfer, fuels and combustion, energy use, furnace design, refractories, automatic control, and atmospheres as applied to industrial process heating. Weekly

course work, quizzes, and a final exam project are administered to guide students on their progress and evaluate their knowledge of the material. For a complete listing of the topics covered visit www.ihea.org/event/OnlineFall22.

Glen Bradley

Glen Bradley joins the IHEA team as the moderator of the course. Bradley is a professional engineer and has more than 30 years of experience in the industry with companies such as Maxon, Coen Burner, and Honeywell Thermal Solutions where he retired in 2019. His knowledge and experience offer invaluable resources online students can access throughout the course.

Registration for the Fundamentals course is open now through October 21, 2022, at www.ihea.org/event/OnlineFall22. Cost for IHEA members is $775 or two-member vouchers, and cost for non-members is $950. Registration fee includes an electronic course handbook, course instruction, quizzes and projects, class forums, and the opportunity to contact the instructor throughout the course. Students who successfully complete the course will receive 18 PDHs. Printed materials are available for an additional fee.

CALLOUT: VISIT IHEA VIDEO TIP LIBRARY

Have you visited the video tips library? Two new videos have recently been added:

- Cooling System Tips for Induction Heating.
- The Importance of Frequency and Field Orientation.

The tips are made available at no charge on the IHEA website. These short videos are designed to provide important tips and information relevant to the industrial thermal-processing industry. IHEA will add new video tips periodically. More information at www.ihea.org/page/videoTips.

IHEA CALENDAR OF EVENTS

OCTOBER 24

Fundamentals of Industrial Process Heating Online Course

Six-week online distance learning course is designed to give the student a fundamental understanding of the mechanisms of heat transfer within an industrial furnace and the associated losses and the operation of a heating source either as fuel combustion or electricity.

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

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

Distortion caused during heat treatment of aluminum alloys is a complex subject, and many papers have been written to address this expensive problem.

Control of distortion in heat-treated aluminum

In this column, we will discuss controlling the distortion of aluminum heat-treated components.

The heat treatment of aluminum (solution heat treatment, quenching and aging) are critical processes to ensure that the desired mechanical and corrosion properties are achieved. Of these steps, quenching is perhaps the most critical of all the operations. If quenching is too fast, properties are met, but the part may have excessive distortion or residual stresses. This can result in shortened life due to residual stresses or result in additional non-value-added straightening of the component.

The typical heat treatment for aluminum consists of solution heat treatment to approximately 525°C to ensure that all solute is in solution. Parts are then typically quenched into water or polymer quenchants [1] [2]. Following quenching, parts are then straightened. If parts are unable to be straightened immediately after quenching, the parts are placed into a sub-zero freezer (typically at −28°C) to prevent hardening due to natural aging [3]. Once time is available, the parts are removed from the freezer and allowed to warm to room temperature. Straightening of the parts is then performed [3]. Parts are naturally aged, depending on the alloy and the desired temper. Parts are then artificially aged at an elevated temperature (121°C to 176°C) to the desired final properties and temper.

Quenching is the most critical step in aluminum heat treating. The objective of quenching is to preserve the solid solution formed at the solution heat-treating temperature by rapidly cooling to room temperature. Quenching is a balance of supersaturation and diffusion rate [4]. If quenching is too fast, then properties are achieved, but distortion or warpage of the parts may occur. If quenching is too slow, then excessive grain boundary precipitation can occur [5]. This removes the solute from aging and has detrimental effects on corrosion properties. Generally, the highest strengths and corrosion resistance attainable are those associated with the fastest quenching rates. However, the amount of warpage or distortion that occurs during quenching tends to increase with the rate of cooling. In general, the best quench rate is the slowest quench rate that achieves properties.

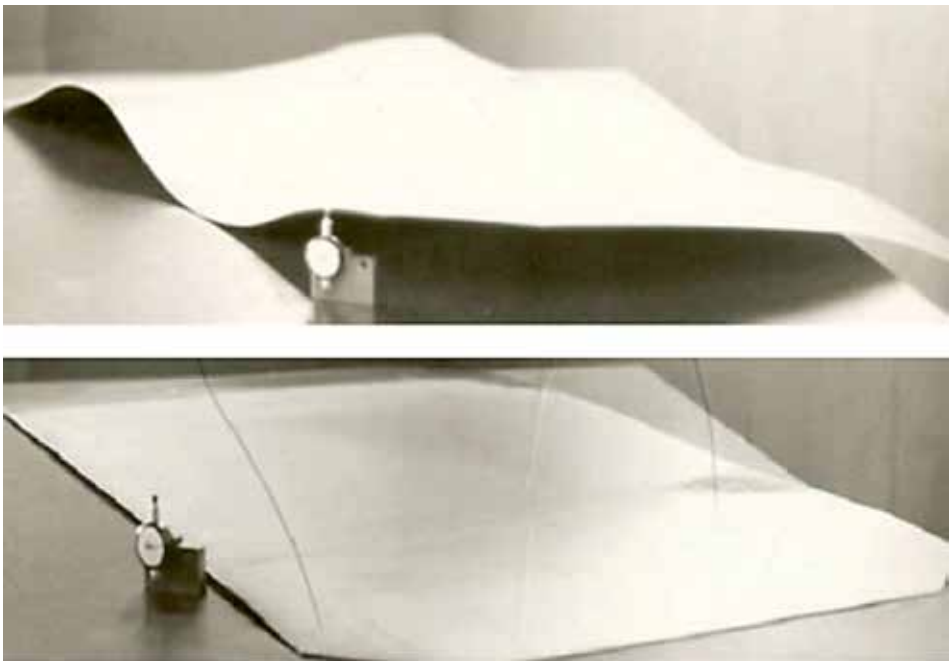

Figure 1: Comparison of immersion rate on the distortion of thin gauge 7075 sheet. In the top photograph, a slow immersion rate was used, quenched into 32% PAG. In the lower photograph, a fast immersion rate was used into 32% PAG. The quench delay time was identical in both. Sheets are 500 x 500 mm x 1.0 mm thick.

CONTROLLING DISTORTION

Aluminum is extremely prone to distortion. During solution heat treatment, temperatures are used that are very close to the liquidus temperature [6]. This results in very high plasticity and low strength at typical solution heat treating temperatures [7].

In addition to the poor strength at elevated temperatures, aluminum also has a large coefficient of linear expansion. This results in large growth of aluminum during solution heat treatment and contraction during quenching. If the part is constrained, then high strains and stresses are developed in the part. If these stresses exceed the yield strength at temperature, then permanent set of the part could occur, resulting in distortion of the part. This indicates that racking and constraint of the parts are important to control the distortion of the part.

RESIDUAL STRESSES PRIOR TO HEAT TREATMENT

Aluminum parts are typically forged, cast, or formed prior to heat treatment. Each of these processes produces significant tensile or residual stresses [8] [9] [10]. Machining of these forgings or castings can also produce significant residual stresses [11] [12]. The use of a stress relief process after major manufacturing steps will also reduce distortion in heat treatment.

Figure 2: Distortion of an F/A-18 wing spar due to improper quenching and racking technique. Wing spar is 3,050 mm long.

SOLUTION HEAT TREATMENT

With excessive heat-up rates, thermal gradients can be developed in the part that can exceed the yield stress at temperature [13]. This is especially true when there are very thick and very thin portions of the part. The thin sections will heat rapidly, while the larger sections will lag in temperature behind the thin sections. If the thermal gradient is high enough, distortion of the part can occur. If residual stresses are present in the part from prior operations, then distortion can occur from relief of those stresses.

IMMERSION RATE

The rate of immersion during quenching plays an important role in reducing the distortion of quenched aluminum. Aluminum parts should be immersed into the quench rapidly. This immersion rate is often confused with the quench delay; however, the immersion rate is the velocity at which the parts enter the quenchant. While it is sometimes not possible to adjust this rate due to furnace design, it is often a variable that is overlooked. The immersion rate should be on the order of 0.15 m/s to 3 m/s [14]. This is shown in Figure 1.

QUENCHANT

Of all the possible "defects" occurring during the heat treatment of aluminum, distortion during quenching is the most common. It is probably responsible for most of the non-value-added work (straightening) and costs associated with aluminum heat treating. An extreme case of distortion is shown in Figure 2 [6].

Water is the most common quenchant for all aluminum alloys. It is easy and inexpensive to obtain, and it is readily disposed unless severely contaminated. Water is used as a quenchant from ambient temperatures for sheet metal, to 90°C for castings and thick forgings to reduce quenching thermal stresses.

As the temperature of water is raised, the stability of the vapor phase increases, and the onset of nucleate boiling in a stagnant fluid is suppressed. The maximum rate of cooling is decreased, and the overall rate of cooling is also decreased. This can result in non-uni-

Aluminum parts are typically forged, cast, or formed prior to heat treatment. Each of these processes produce significant tensile or residual stresses. (Courtesy: Shutterstock)

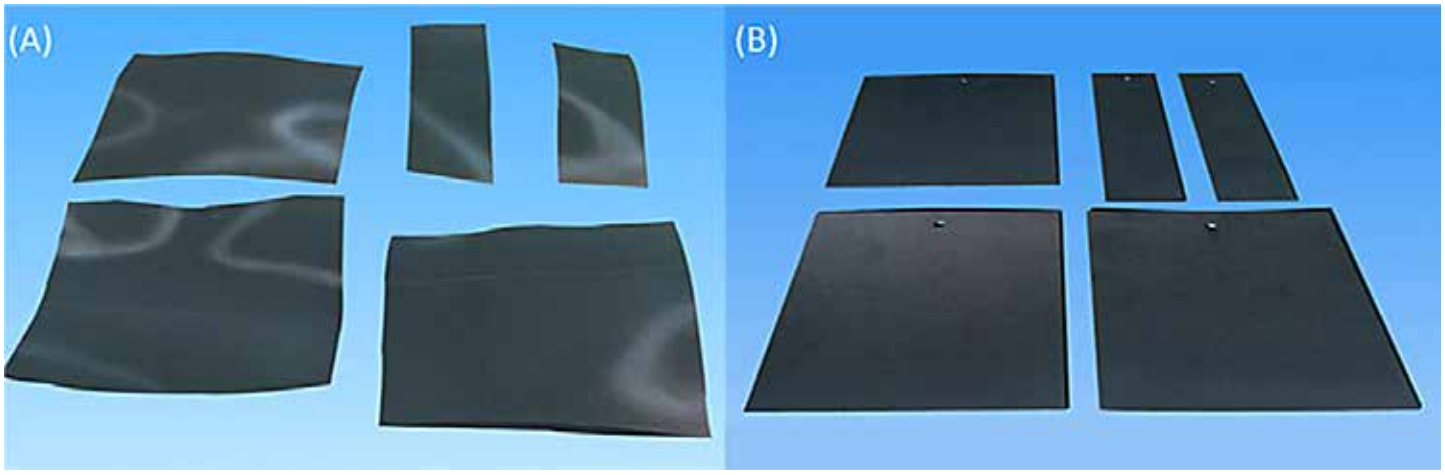

Figure 3: Comparison of water and PAG quenching results for different size 1.5 mm thick panels: (A) water quenched; (B) PAG quenched at 20%. Upper left panel is 300 x 250mm; Upper right panel is 100mm x 300 mm; lower left and right panels are 300 x 300 mm.

form quenching of part, with resultant distortion and high residual stresses.

Polyalkylene glycol quenchants (PAG) were developed to provide a quench rate in between that of water and oil. By control of agitation, temperature, and concentration, quench rates like water can be achieved. PAG quenchants are described by AMS 3025 [15], and the concentration is governed by AMS 2770 [16] for aerospace alloys. The benefits of quenching in a PAG are shown in Figure 3.

PART ORIENTATION AND RACKING

Racking of the parts is critical [17]. The parts should be fully supported, with the loads spread out over a large area, since the creep strength of aluminum is poor. Parts, particularly sheet metal parts, are often fixed into place with steel or stainless wire to hold the parts. This practice can increase distortion or cause damage to the part. Aluminum has a very high coefficient of thermal expansion, while steel has a coefficient of thermal expansion that is approximately half that of aluminum (13 x 10-6 mm/mm-°C for aluminum and 8 x 10-6 mm/mm-°C for carbon steel). This means that the aluminum parts will grow twice as much as the steel constraining wires. Aluminum parts should be wired loosely and allowed to freely expand without constraint.

CONCLUSIONS

In this very brief article, the causes of distortion when heat treating aluminum alloys are discussed. This is a very complex subject, and many papers have been written to cure the very expensive problem of aluminum distortion during heat treatment.

Should you have any questions or comments on this column, or suggestions for further articles, please contact the author or editor.

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JASON SCHULZE
METALLURGICAL ENGINEER /// CONRAD KACSIK

Achieving merit can be a good thing for suppliers, but it's important not to get complacent and let quality system requirements slide.

The benefits of the Nadcap merit process

According to PRI/Nadcap Operating Procedure NOP-1111, suppliers are able to receive something called "Merit." If your suppliers meet certain criteria, they are able to secure a merit status, which enables suppliers to have a longer period between audits; this can be 18 months to two years. This may be a cost savings source, although, while you may not have a choice from PRI standpoint, having merit may not always be a benefit, depending on how your organization is structured and supported.

WHAT IS "MERIT"?

Merit allows Nadcap-accredited suppliers to reduce their audit frequency to every 18 months or, if you meet certain criteria, every 24 months. This merit process may not be good for every supplier. It really depends on your management system and support. Your company may have a management system that is very involved and is able to support the two-year merit process. Other companies may not have the support needed. Below are the separate requirements needed to achieve merit.

18-Month Merit

Be at least the second reaccreditation audit in the commodity.

» No Non-Sustaining Corrective Actions identified on current or previous accreditation audit or on any additional scope audit between the current and previous accreditation audit.

» No verification of corrective action (VCA) audits as a result of current or previous accreditation audit.

» No Type C Auditee Advisories (reference OP 1109 Auditee Advisories) issued by that Task Group since the start of the previous accreditation audit.

» No more than 14 days of cumulative delinquency.

» No more than 50 percent of major and 60 percent of total NCRs allowed for mode B reaccreditation audit failure criteria in OP 1110 Audit Failure and Risk Mitigation.

» Any other reason not addressed above and defined by the Task Group in their OP 1114 Task Group Operation Appendix or documented in the audit merit screen and approved by quorum during Task Group Review.

24-Month Merit

Previous two consecutive accreditations in the commodity must have been a minimum of 18 months each.

» No major NCRs.

» No more than seven days of cumulative delinquency.

» Any other reason not addressed above and defined by the Task Group in their OP 1114 Task Group Operation Appendix or documented in the audit merit screen and approved by quorum during Task Group Review.

Once the merit status is achieved, the challenge typically lies in maintaining the existing quality system to ensure conformance.

MAINTAINING MERIT

Once the merit status is achieved, the challenge typically lies in maintaining the existing quality system to ensure conformance. I have seen suppliers get too relaxed with their daily quality assignments, which are typically discovered in the next Nadcap audit. This is especially true for suppliers who are on the two-year merit process.

I would recommend that anyone who has achieved any level of the merit process treat their quality system as though they will be audited every 12 months. Actually, performing internal audits every 12 months will also be helpful, depending on what the internal procedure for audits states. This would mean that constant review of documentation is required along with consistent testing and verification of production cycles.

SUMMARY

Merit can be seen as a good thing to some suppliers due to what is required to achieve it. To others, it may not be conducive to the quality systems. Each supplier is different and it is important to keep up with quality system requirements regardless of the merit status.

ABOUT THE AUTHOR

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ISSUE FOCUS ///

AEROSPACE APPLICATIONS / CERTIFICATIONS

THE LATEST INNOVATIONS IN COMPOSITE HEAT-PROCESSING TECHNOLOGY

The aerospace industry is evolving quickly and creating new challenges every day, requiring innovative heat processing solutions that are larger, smarter, better, and faster.

By MIKE GRANDE

Composite cure ovens are becoming larger than ever to accommodate enormous composite parts that require vacuum bag curing and post cure.

When a leading private space exploration company decided to manufacture its rocket fairings out of composite material, instead of the aluminum alloys used in the past, it would be breaking new ground. These would be the largest composite fairings ever made. Composite materials must be cured in a high-performance oven capable of heating and cooling at a strictly controlled rate and maintaining very tight temperature uniformity throughout the heating chamber.

In order to cure these fairings, the company purchased the largest composite cure oven ever manufactured. The oven had a heating chamber that was 34 feet wide x 90 feet long x 32 feet high and a load capacity of more than 100,000 pounds with a maximum temperature rating of 500°F. In order to ensure the temperature inside the oven was within tolerance, the oven had to pass a uniformity test using test thermocouples to measure the air temperature at 210 locations within the heating chamber. After the equipment was installed and final adjustments were made, the thermocouples all measured within ±10°F of the oven set point at three different temperatures. To achieve this feat, the oven featured a 272,000 CFM (cubic feet per minute) blower system, which recirculated 1.2 million pounds of air per hour across the parts. (Figures 1 and 2)

The oven also had an extensive vacuum system required for vacuum bagging the parts. It used 100 individual vacuum ports, each capable of operating at a different separate vacuum level and maintaining each of them using closed loop control.

The oven airflow system was designed using computational fluid dynamics (CFD) software, which simulated the air circulating throughout the heating chamber and around the parts in three-dimensional space. Through this airflow modeling, it was determined the best airflow pattern was bottom-up, in lieu of the more conventional combination airflow using supply ducts on the side walls of the heating chamber. In order to provide the bottom-up airflow pattern, a large supply duct was buried in the floor under the load and had air supply louvers on the top to direct air vertically upward and through the heating chamber. The duct was the same width and length as the heating chamber. This thoroughly bathed the load in heated air, and left no areas where it could bypass around the parts.

Figure 1: Large batch oven.

Figure 2: Interior view large batch oven.

AEROSPACE OVENS BECOME MORE INTELLIGENT WITH INDUSTRIAL IOT

Over time, all industrial equipment will experience wear and become vulnerable to breakdown, and this includes industrial ovens. In the aerospace industry, a single load being processed in an oven can have a value of well over $100,000. It is critical, therefore, that unexpected shutdowns be minimized to avoid the loss of a load. The latest technology to ensure maximum oven uptime and avoid shutdowns is an industrial IoT (Internet of Things) performance monitoring system.

The IoT system tracks the performance and health of a variety of oven components and operating conditions such as motor vibration, controller output percentage, chamber pressure, motor speed, current draw, burner operation, and many others. The system features an IoT gateway, which collects information from predictive maintenance sensors that gather performance data from the oven. The gateway wirelessly transmits the data to a cloud platform where it is displayed in dashboards designed for viewing and analytical monitoring. Thresholds can be set around warning or alarm conditions, and when exceeded, the system alerts the oven manufacturer or the end user of the anomaly. This allows time to schedule preventative maintenance and minimize unplanned downtime. Since the system uses cellular data transmission and does not connect to the factory network, it does not create a security vulnerability. Industrial IoT also provides the

ability to monitor the energy consumption of the oven, allowing the owner to achieve optimum efficiency by adjusting the temperature and other curing parameters.

In addition to predictive maintenance, an IoT system can diagnose problems arising from improper oven adjustment or operation. If the oven has suddenly started consuming more energy or producing improperly cured parts, the IoT system can often determine the cause (an incorrectly adjusted exhaust damper or a burner that needs cleaning, for example). The IoT system can also reveal if the oven is not being operated properly — if an operator is leaving the door open too long during loading/unloading, for example, wasting energy and money. Perhaps the biggest benefit is that all of this is done without a service visit from the oven company, meaning the issue is resolved in hours, instead of days or weeks, at a much lower cost. (Figure 3)

Figure 3: Oven IOT systems installed throughout the U.S.

ADVANCED CONTROL AND DATA ACQUISITION FOR OUT OF AUTOCLAVE PROCESSING

With the increasing use of vacuum bag composite processing for aerospace components, there is a need for more sophisticated control and recording systems to optimize the curing process and track the data collected. The end user must be concerned with both the vacuum level and the temperature of each part and have this information recorded, archived, and time stamped. This is necessary so that, if there is an improper cure leading to failure of a part in the field, it must be trackable to the specific oven load. (Figure 4)

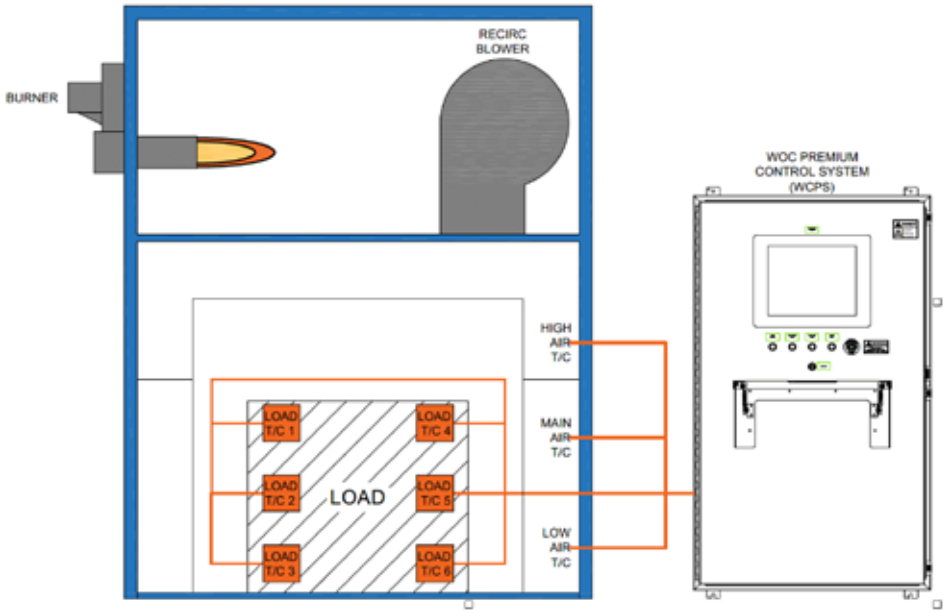

Figure 4: Advanced control systems monitor the load temperature.

The core of the system is a PLC using special software designed specifically for vacuum bag composite curing. The temperature is controlled via input from one or more thermocouples (TCs). The TCs can be located in the heated air stream or buried in the part or both. Using leading, lagging, and averaging functions, along with thermal overdrive, the parts are heated evenly as quickly as possible without overshoot. With thermal overdrive, also known as a controlled heat head, the oven temperature is elevated for a period of time during the heatup portion of the cure cycle. This forces the part to heat more quickly than if the oven was set right at the required cure temperature. After the part temperature approaches the cure temperature, the control system automatically reduces the oven temperature to the part cure temperature. Thermal overdrive provides faster heating rates, resulting in shorter oven cycles and increased production through the equipment. (Figure 5)

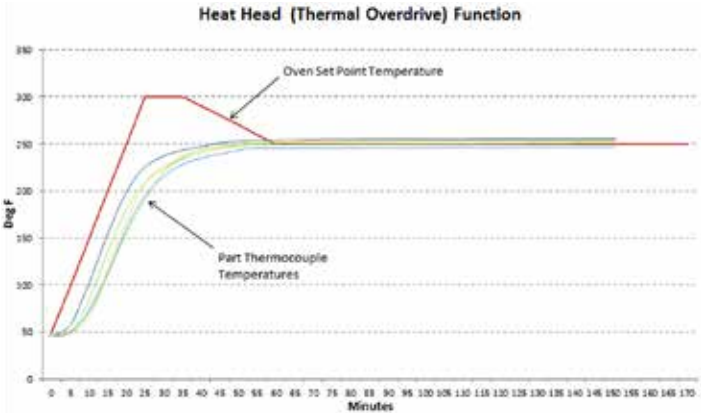

Figure 5: Thermal overdrive temperature graph.

In addition to thermal overdrive, the advanced control system uses the TCs buried in the part to provide a guaranteed soak, where the soak time doesn't start until all the TCs are up to the required cure temperature, ensuring the entire part has been thoroughly cured.

Another feature important to aerospace manufacturers is that, prior to heating, the system checks the vacuum at each port for leaks. Any leaking ports will be displayed, and the operator must then either deselect the bad ports or fix the leaks and run the leak test until successful. This helps ensure no parts are processed under insufficient vacuum, which can cause defects. Monitoring of the vacuum levels continues during the heating cycle, and low- or high-vacuum levels

Maximum Thickness (Note 2)		Maximum Time Seconds (Note 3)
Inch	Millimeters	
Up to 0.016, incl	Up to 0.41, incl	5
Over 0.016 to 0.031, incl	Over 0.41 to 0.79, incl	7
Over 0.031 to 0.090, incl	Over 0.79 to 2.29, incl	10
Over 0.090	Over 2.29	15

Notes:
1. The delay time is measured from the time the furnace door of an air furnace starts to open, or the first portion of the load emerges from a fluidized bed or salt bath or the heating zone of a continuous furnace, to complete immersion of the load in the quenchant.
2. Minimum thickness is the minimum dimension of the thinnest section of any part in the load.
3. The maximum quench delays specified may be exceeded providing tests made within the past year have demonstrated that part temperatures do not fall below 775 °F (413 °C) before immersion except, for 2219 alloy, part temperatures shall not fall below 900 °F (482 °C) before immersion.

Table 1: Maximum allowable quench delay times. (Source: AMS2770)

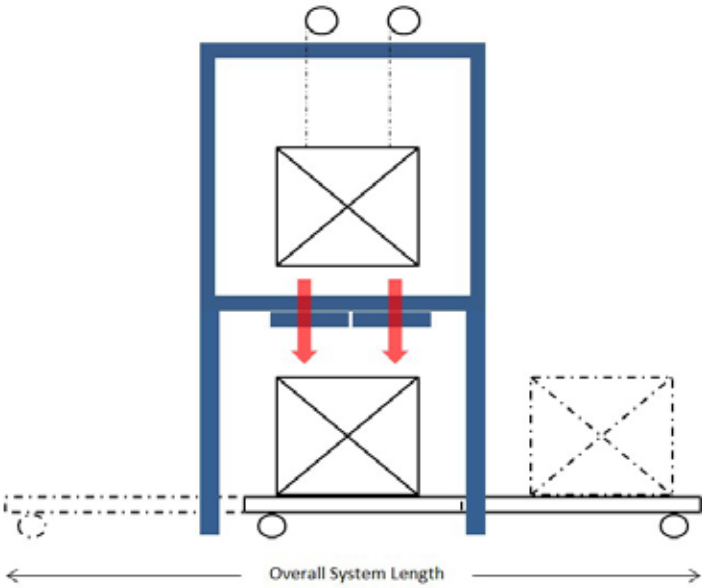

Figure 6: Drop bottom floor space requirement.

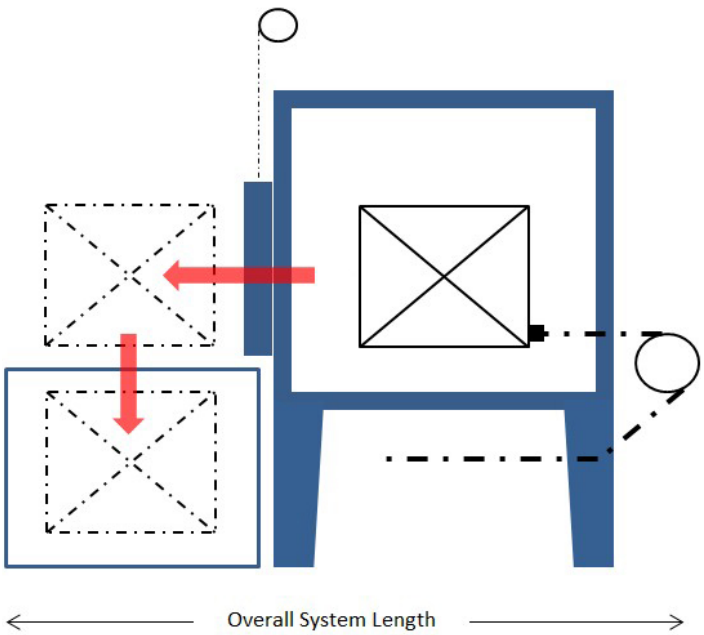

Figure 7: Horizontal quench floor space requirement.

are reported. In the same way, the system can detect a failed control thermocouple and switch control to a backup one to prevent failure of the load.

In order to meet the stringent traceability requirements of the aircraft manufacturers and others, the advanced control system continuously logs data in the background during oven operation and generates a report afterwards. When a batch is completed, the system queries the data for all information matching the batch ID, including recipe information, interval readings for the thermocouples and vacuum transmitters, alarms, and all other batch specific information. A batch report is then created that contains all this information, as well as graphs and tables related to the run and logs it into a database.

HORIZONTAL QUENCH SYSTEMS, FASTER QUENCHING THAN EVER

Until recently, the vast majority of aluminum solution heat treatment was performed in drop bottom furnaces. This style of furnace is elevated on legs and has a door on the bottom through which the load is quickly lowered into the quench tank below using a hoist located on top. The quench tank rides on a traveling powered car so it can be moved into place beneath the furnace for quenching. (Figure 6)

The primary advantage of drop bottom type furnaces has traditionally been a fast quench speed, defined as the time from when the furnace door starts to open until the load is fully submerged. A quench time of 7 to 10 seconds is typical, and 5 seconds is even possible for smaller loads. The disadvantages are the price of the equipment and the space requirements within the factory. Also, there is a tendency for steam to rise from the tank during quenching and become absorbed into the furnace insulation, which can cause problems.

In recent years, an innovative alternative to the traditional drop bottom system has gained popularity: the horizontal quench system (HQS). In this design, the door is on the front of the furnace, as opposed to the bottom. After the load is heated, the door rapidly opens and a specially designed extractor quickly transfers the load from the furnace chamber onto the quench elevator in front of the furnace. The quench elevator then rapidly lowers the load into the quench tank. (Figure 7)

In the past, the state of horizontal quench technology was such that it was only suitable for pieces with a thicker cross section, typically cast parts, where a longer quench time is allowable. The first-generation horizontal quench systems had a typical quench time of 15 seconds or longer and could not meet the 5 to 10 seconds required for thinner materials in accordance with AMS2770 (Table 1).

Through advances in sensor and motion control technology, along with improvements in material handling techniques, the quench time for horizontal systems has progressively improved over the years. Quench times of 7 seconds are routine even for loads up to 12 feet long, weighing 3,000 pounds. This allows HQSs to meet aerospace heat-treatment requirements, while offering the advantages of lower capital cost and reduced footprint in comparison to drop bottom equipment.

With the increasing demand for aluminum horizontal quench systems, the trend is toward shorter quench times and larger loads, and the horizontal quench system is meeting these needs for the aerospace industry.

ABOUT THE AUTHOR

Mike Grande has a 30-plus year background in the heat-processing industry, including ovens, furnaces, and infrared equipment. He has a BS in mechanical engineering from the University of Wisconsin-Milwaukee and received his certification as an Energy Manager (CEM) from the Association of Energy Engineers in 2009. Grande is the vice president of sales at Wisconsin Oven Corporation.

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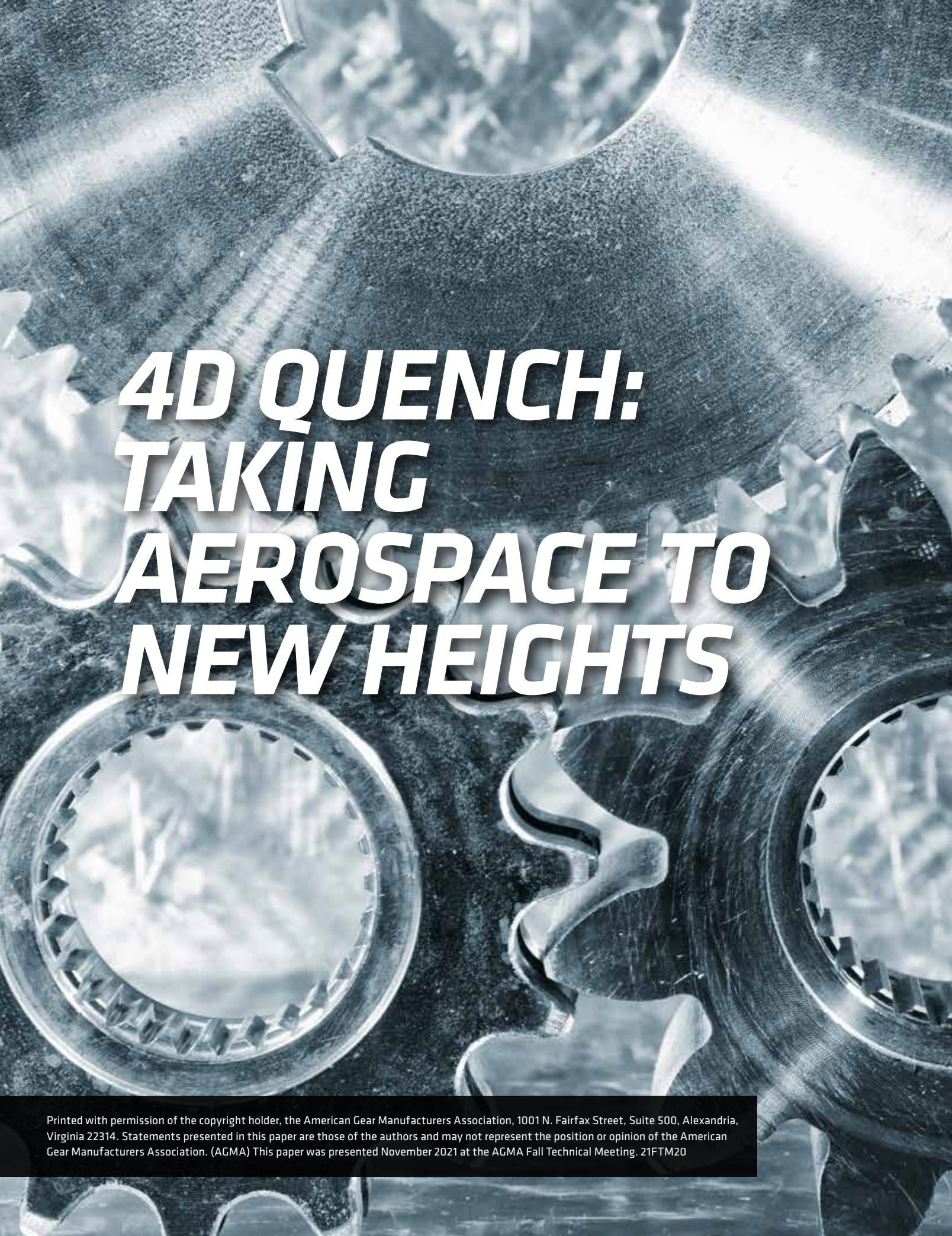

4D QUENCH: TAKING AEROSPACE TO NEW HEIGHTS

4DQ can be viewed as a new tool that manufacturers can now pull from their toolbox to have an answer for controlling distortion during heat treatment.

By THOMAS HART

When providing heat treatment for aerospace gears and bearing components, manufacturers are traditionally left with three choices for thermal processing: continuous flow atmospheric furnaces with press quenching in oil, or batch heat treatment in both vacuum and atmospheric furnaces with quenching in oil (or high-pressure gas, as in vacuum). All three techniques differ in benefits and disadvantages associated with geometric distortion, environmental impact, and safety concerns.

A single-piece flow (SPF) vacuum heat-treatment furnace with the capability to provide high-pressure contour gas quenching to a single piece or "4D Quench" (4DQ) provides continuous flow heat treatment with low geometric distortion, environmental impact, and personal safety concerns. This system has the flexibility of operating in a batch style work cell, or it can be sized up and inserted in a continuous work cell, operating without human interference. 4DQ technology equals the speed of an oil quench and the cooling gas nozzle profile can be optimized based on actual part geometry. By controlling the direction of the cooling gas spray with part rotation, manufacturers now have the ability to control how fast or slow a part section cools providing a better quench. With this improved uniformity, larger and previously pressed quenched parts can now be processed in a 4DQ system.

SPF vacuum heat treating system will thermally process and quench every part the same way, in the same position, with the same timing, one by one. All components undergo the same process parameters, producing consistent and high-quality results for an entire part series. With SPF vacuum heat treatment, aerospace gear and bearing manufacturers can safely and environmentally friendly output identically processed and uniform components while reducing geometric distortion of their heat-treated components. This article will also summarize a half decade's worth of research associated to SPF with 4DQ Vacuum Heat Treatment.

1 INTRODUCTION

Aerospace work ... what can you say ... well, you can say a great deal about the topic. Manufacturers who meet the rigorous standards set forth by the aerospace industry will say, "It is challenging." The demands of aerospace applications stretch the boundaries of material science daily, while they seek to maximize efficiency at the lowest possible weight. These rigorous standards also come at a high cost and lead manufacturers to seek cost saving opportunities in any area of the manufacturing process.

Aerospace vehicles are designed to oppose one of nature's most relentless forces: gravity. As such, the vehicles are designed and manufactured to overcome these forces to promote transport of humans and/or materials to both the accessible and not-so-accessible parts of the globe at a moment's notice. This means aerospace components have a common interest: Lighter is always better. But how do you get there? It's a constant struggle between a component being lightweight yet having good strength and mechanical properties. In addition, these components must maintain this strength in some of the harshest working environments on Earth.

Materials are constantly being developed to meet these rigorous requirements through improved strength at reduced weights. Yet, with all the material advancements, the capabilities of the heat-treating industry have remained nearly stagnant.

Why, you ask? There are many reasons, but one specifically pertains to the fact that historically, materials have been designed around "standard" heat-treatment techniques. This is counterintuitive. If you look at the entire manufacturing chain, there are countless efforts to improve quality, manufacturing time and mechanical properties. These improvements are achieved by manufacturers investing time and resources to incrementally (and sometimes drastically) improve various links in the chain. However, heat treatment now has finally made the turn and is catching up to other manufacturing advancements. This heat-treatment advancement has come from an unlikely, or should I say unexpected, source: the quenching chamber.

2 HELICOPTER PRODUCTION

Looking at helicopters, for example, a private helicopter cost can fall in the range of $250,000 to $2 million for a new unit. Contrast this with military applications where a new unit can cost up to $72 million.

Advancements have been made throughout these aircraft on a nearly continuous basis thanks to customer demands for higher, and in some cases, extreme performance. By default, these advances in components have resulted in advancements in the manufacturing process. This is true for one of the key systems needed to meet the extreme performance demands: the aircraft transmission systems. Here, advances in materials and machining are common, but heat treating remains stagnant. Manufacturers that produce transmission and bearing systems are under the highest levels of scrutiny to produce ultra-high-quality components to the tightest of tolerances with sophisticated machining centers and quality measurement systems. To do so, transmission system components are heavily reliant on heat treatment and its ability to ensure the components will survive the very demanding working conditions set forth. If the heat treatment fails while an aircraft is in operation, there can be catastrophic consequences. To ensure the aircraft will perform as intended, there is a large portion of the manufacturing process dedicated to the transmission system accounting for 9 percent of the overall cost to manufacture a helicopter [4] and in some cases can be as high as 15 percent. If you take the 15 percent cost of a transmission system against the overall cost of $72.1 million for the V-22 Osprey, this can amount to $10.8 million.

Transmission systems use (but are not limited to) hardening/case hardening materials such as 8620, 9310, Pyrowear X53, Ferrium C62, Ferrium C64, M50, 440C, 52100, BG-42, Pyrowear 675, etc. As such,

Table 1: Helicopter vehicles' costs.

these materials will all respond differently when subjected to thermal processing and quenching. With varying production methods, manufacturers must take special care when producing a gear/bearing as distortions attributed to the heat treatment are very expensive to correct/rework and even more expensive to start over if materials deviate too far out of specification. As a result, established thermal processes in this field are slow to evolve.

3 BATCH OIL, BATCH HPGQ & PRESS/DIE QUENCHING

When working with the various grades of materials, not only do machining practices require adjustment, heat treatment must be adjusted as well. A one-size-fits-all solution (as is in traditional heat treatment) is not the most effective or optimized way to thermally process materials. Batch processing leads to a high variation from part-to-part including but not limited to different thermal exposure, carbon absorption, heat transfer coefficient during quenching, and geometric distortions after the completed process.

Analyzing geometric distortions closer, batch processing (specifically when oil is the quenching media) provides the most inconsistent quenching platform among the common methods used. Batch processing in high pressure gas quench (HPGQ) systems will provide less distortion than that of oil as it is a much softer (less aggressive) quench. A tradeoff with HPGQ vs. oil quenching is that HPGQ in traditional vacuum heat-treatment systems does not have the same heat-transfer coefficient capability than that of oil. As a result, HPGQ has a more difficult time to quench lower alloy and thick cross section gears/bearings to achieve the desired mechanical properties.

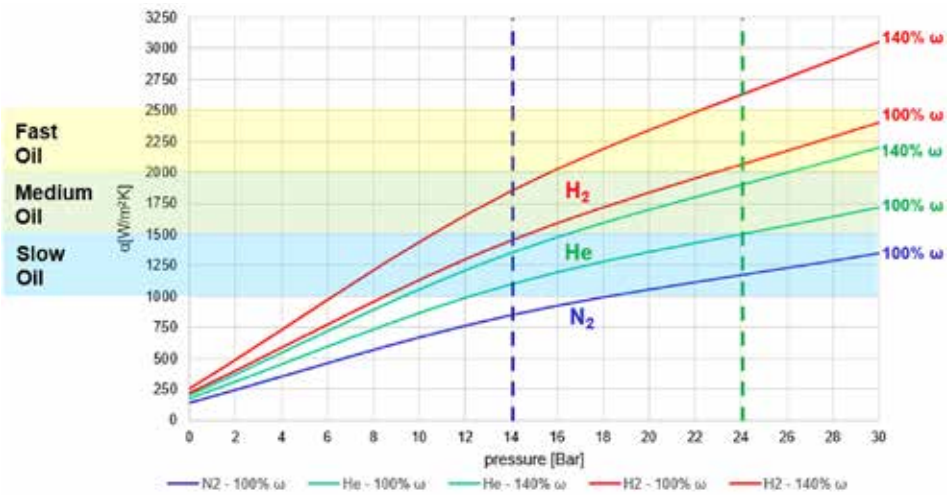

Figure 1: Batch HPGQ vs. batch oil quenching.

Figure 1 shows heat-transfer coefficient $\alpha[W/m^2K]$ when quenching in a batch furnace with high pressure gas quenching versus slow, medium, and fast oils. With nitrogen gas (most commonly used high pressure gas quench in the market), you will need a 16 Bar gauge to begin to quench as fast as a slow oil. Helium and hydrogen can be used; however, helium is very expensive, and helium-recovery systems are as expensive as the furnace itself. Hydrogen is abundant and very inexpensive; however, with safety concerns in mind, it is not a practiced quenching method. Referencing the ω lines, this represents the cooling power capacity when applying higher power loads to the cooling fans during the beginning of the quench cycle. Figures 2 through 5 represent traditional heat-treatment equipment for processing aerospace gear/bearing components.

When HPGQ is not strong enough and batch oil quench provides too much distortion, this can force a gear/bearing manufacturer to

Figure 2: Batch IQ with oil quench.

Figure 3: Vacuum furnace with batch HPGQ.

Figure 4: Rotary hearth atmospheric furnace.

Figure 5: Manual transfer to press quenching.

resort to the press/die quenching technique after thermal processing of the material. Press quenching is an effective technique to achieve proper hardness while reducing geometric distortion. The press quenching process is well suited for:

» Case and through hardening of steel parts (gears, rings, etc.).

» Parts sensitive on hardening distortion.

» Thin cross section and large dimension parts.

» Individual hardening.

» Maintaining dimensional stability which controls distortion.

» Good repeatability of the results.

» Distortion related to press quench hardening can keep the quality features from changing only 1 to 2 AGMA Class differences from a green gear condition.

With all the benefits associated with press quenching, there are tradeoffs to this approach as well. When considering the press quench method, disadvantages to be considered with the heat-up furnace include:

» Gear quality issues associated with intergranular oxidation (IGO).

» Equipment safety issues with open fires and radiation.

» Equipment environmental issues with carbon monoxide and carbon dioxide.

After heating the furnace, one must consider the process of transferring an individual gear/bearing from the furnace to the press quench equipment where:

» There are operator safety issues as they can be exposed to high levels of thermal radiation from the furnace and when manually handling the gear while it is at temperature.

» Additional quality issues are associated with IGO during transfer from furnace to the press quench.

Concerns with the oil press itself include:

» Safety issues related with the open fire.

» Health and environmental issues associated with oil vapor emissions.

» High costs associated with expensive quenching dies needed for each part geometry.

After press quenching, the need for a parts washer is required for oil removal prior to tempering and post machining:

» The washing process requires special chemicals and upkeep for system operation.

» Environmental issues associated with the neutralization of the washed oils.

4 AEROSPACE'S TRANSMISSION PROBLEM: DISTORTION

Traditionally, when heat-treating distortion is a problem (no matter

the heating or quenching method) but the mechanical properties are as desired and the component works in its application, there is a solution: Make more parts. To increase the volume of parts produced (over the required quantity), the attrition from heat treatment is accounted for. A newly released design can have above 70 percent in attrition where a mature design can have up to 25 percent. Materials distort for many reasons, raw material composition, Jominy of the steel (hardenability), aggressive machining, heating ramp, carburizing, quenching, etc. Engineering and production can then be led to choose the press/die quench method, which promotes less distortion, or it can be used to remove distortion already existent in the part before quenching.

An additional point to consider: Aerospace parts are not like automotive where aerospace runs are in small batches (say 20 to 40 pcs) from a wide variety of geometry and sizes. This fact alone has made it difficult to plan for the heat-treatment demands required for aerospace gears/bearings. In special cases, some of the most difficult aerospace gears can cost more than $50,000 per gear to produce. Because of this, maximum care must be taken at all areas of the manufacturing process to ensure the gear does not deviate from specification during production.

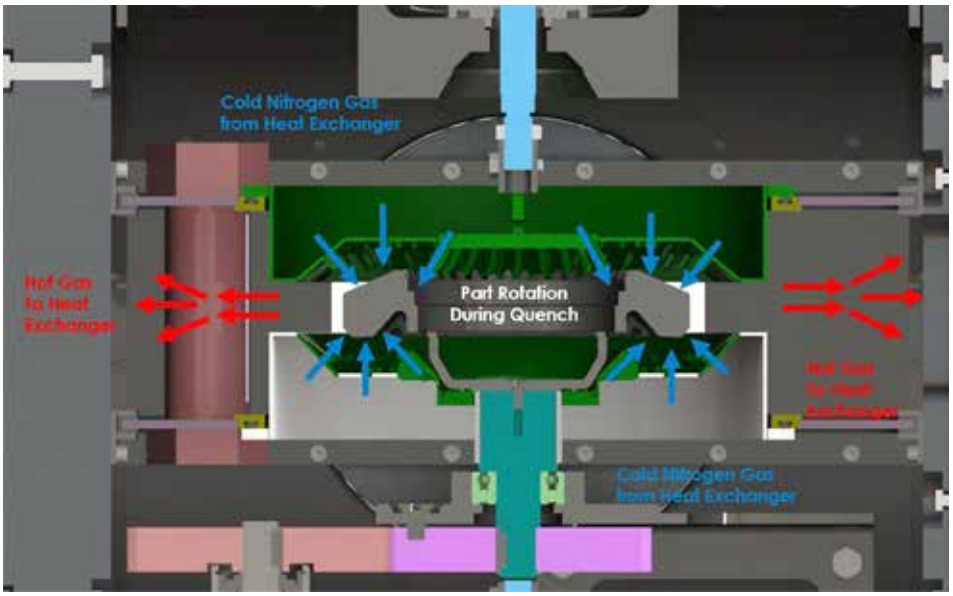

Figure 6: 4DQ gas flow direction.

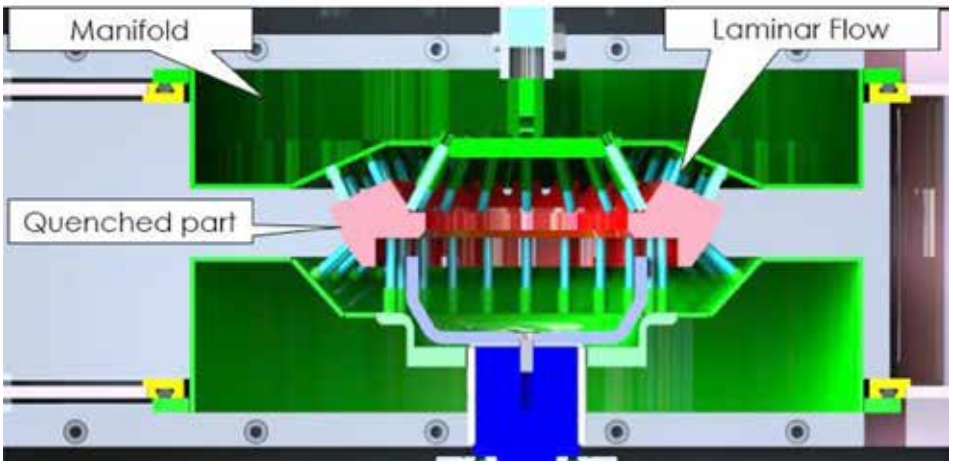

Figure 7: 4DQ gas flow out of the nozzles.

Feature	Description
Quench Pressure	1 to 10 Bar abs. gas pressure
Nozzle profile	Varying nozzle diameters, locations and angle of attack
Gas Velocity	Cooling blower RPM control with frequency drives
Table Rotation	ON or OFF with RPM and directional adjustment
Time Dependent Gas Flow	Gas flow can be set to a specific time duration

Table 2: 4DQ controllable/adjustable features.

5 AEROSPACE'S TRANSMISSION SOLUTION: 4D QUENCH

4DQ is a new technique that has six years of maturity and is the first heat-treatment advancement of this kind. 4DQ is a tool that can provide gear and bearing manufacturers significant improvements to the quench process as it gives full control of how fast or slow heat is removed from a component's geometric area. Quenching can now be engineered and planned vs. guessing based on years of experience. Heat transfer coefficients at specific sections of a component can be controlled, for example, in the case of a heavier cross section, one may want a much faster heat transfer; however, in a thin cross section, a much lower heat transfer may be desired (if any at all). This type of control allows for homogeneous cooling of the entire component throughout the 4DQ process.

4DQ works when a component is placed in the quenching chamber; the chamber is then pressurized (up to 10 Bar abs.); the powerful cooling blower(s) are engaged and starts the closed loop circulation of the pressurized gas. The cold quenching gas passes through the quenching manifold nozzles or orifices and passes across the desired section of the gear/bearing with the hot gas exiting out the side between the top and bottom manifolds and on its way to the heat exchanger to then return back to the manifold. This process only describes the system's 3D quenching capabilities, to introduce 4DQ, the gear/bearing is then rotated as the cooling gas passes over the component creating a contoured cooling profile around all desired surfaces. Combining the 3D gas flow from the nozzle manifold and the 1D of part rotation, you now have a true 4D quenched component.

6 4D QUENCH: LARGE COMPONENT CAPACITY

Unlike automotive components where there are vast quantities of the same gear manufactured, aerospace has a very different demand in the form of smaller numbers of complicated gear shapes. Thus, they require different thinking on how the manufacturing process will work. With the wide variety of component geometries, alloying elements, demand for reduced weight and low-production volumes to the aerospace industry, these constraints lead to the need for heat-treatment equipment to be flexible as to accommodate the

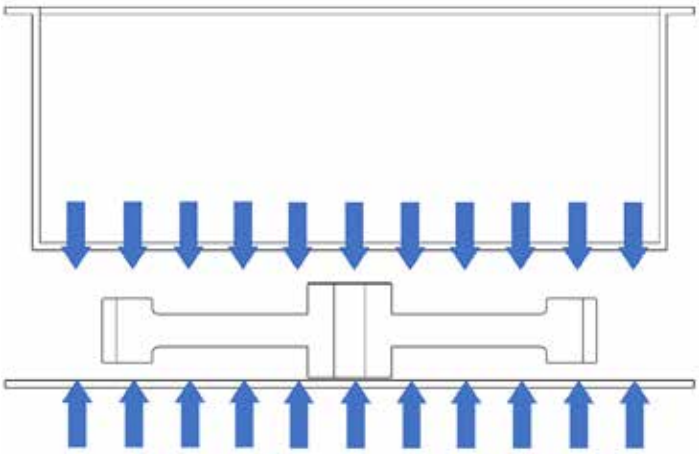

Figure 8: 4DQ Standard vertical flow quench manifold.

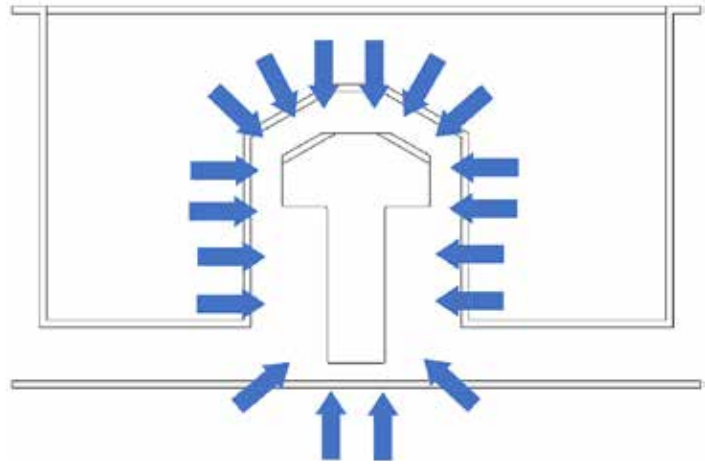

Figure 9: 4DQ "pinion" manifold.

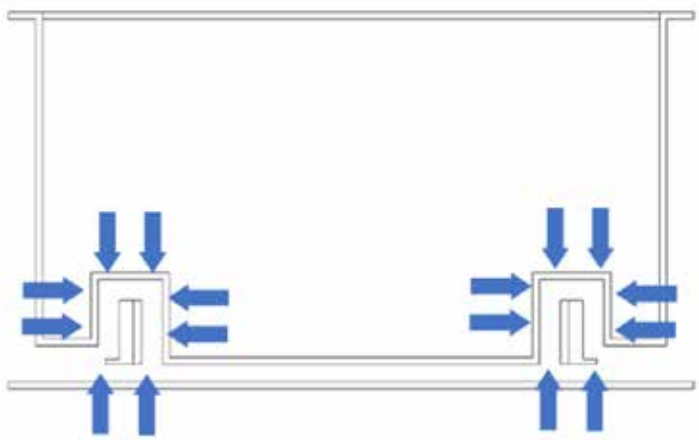

Figure 10: 4DQ "ring gear" quench manifold.

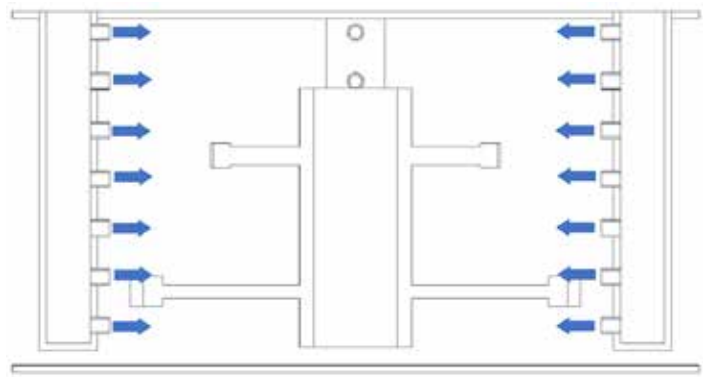

Figure 11: 4DQ generic quench manifold.

wide array of geometries with small lot sizes. When gear and bearing manufacturers have gears/bearings to produce that have diameters of 12", 18", 24", 36", etc., 4DQ has the answer. 4DQ systems are modular in design and are flexible to meet any gear/bearing size demand. A single-piece flow SPF vacuum furnace with low pressure carburizing (LPC) and a 4DQ system can accommodate the largest of diameter gears/bearings that the aerospace industry is required to produce. Able to process materials all under vacuum, this system has separate chambers for material handling, heating/carburizing, and 4DQ. Materials and fixtures of varying sizes can pass through this furnace allowing manufacturers not to have to worry about the wide variety geometric configurations and batch sizes they are required to produce. This type of furnace can also be placed in line with a machining work center where gears/bearings can be green machined, washed, pre-heat-treatment inspected, heat treated in the SPF furnace with 4DQ, and onto post processing.

Figures 9 through 11 show examples of various 4DQ manifolds for different geometric profiles. Figure 8 represents a standard vertical flow manifold as the nozzles/orifices are evenly distributed on both the top and bottom manifolds providing vertical quench flow. Figure 9 represents a pinion type manifold where the top manifold surrounds the length of the pinion and contains the majority of nozzles with a close concentration of nozzles where the pinion head is oriented. Figure 10 is for a larger ring type gear where the nozzles are concentrated around the entire contour of the ring gear. Figure 11 is an example of a 4DQ generic manifold that provides even and horizontal gas flow around the component and can be used with any geometric profile that fits within the furnace working volume. There can be multiple columns surrounding the working diameter.

7 4D QUENCH: MODULARITY

4DQ is not only designed to be adjacent to the SPF furnace; however, because it is a modular system, it can be paired with other furnace processing systems. The system in Figure 12 isolates the 4DQ system showing its main features such as the hardening chamber, heat exchanger, and blower. A nitrogen generator is presented in this example; however, nitrogen can be supplied by a bulk nitrogen system. When oxidation is not a concern, 4DQ can also operate with clean compressed air, allowing it to be a companion quenching system to an atmospheric heat-treatment system. What this means is that 4DQ not only can operate with vacuum equipment, but it can operate with atmospheric systems as well, giving manufacturers a new vision of how to better process their materials.

8 DIMENSIONAL STABILITY

In Figure 13, the 4D HPGQ process was completed on a coupling gear with internal teeth. Measurements were analyzed in a pre-heat-treatment condition and post hardening condition. The coupling gear was produced from 8620 and had a 6.3" [160 mm] outside diameter.

9 SUMMARY OF 4DQ BENEFITS

- Reduction, prediction, and control of distortion.
- Precision and repeatability of results.
- Improved safety and no fire risk.
- Total process automation and integration.
- Full single part traceability and reporting.
- Flexible, on-demand operation.
- No human involvement and impact.
- Compact footprint.

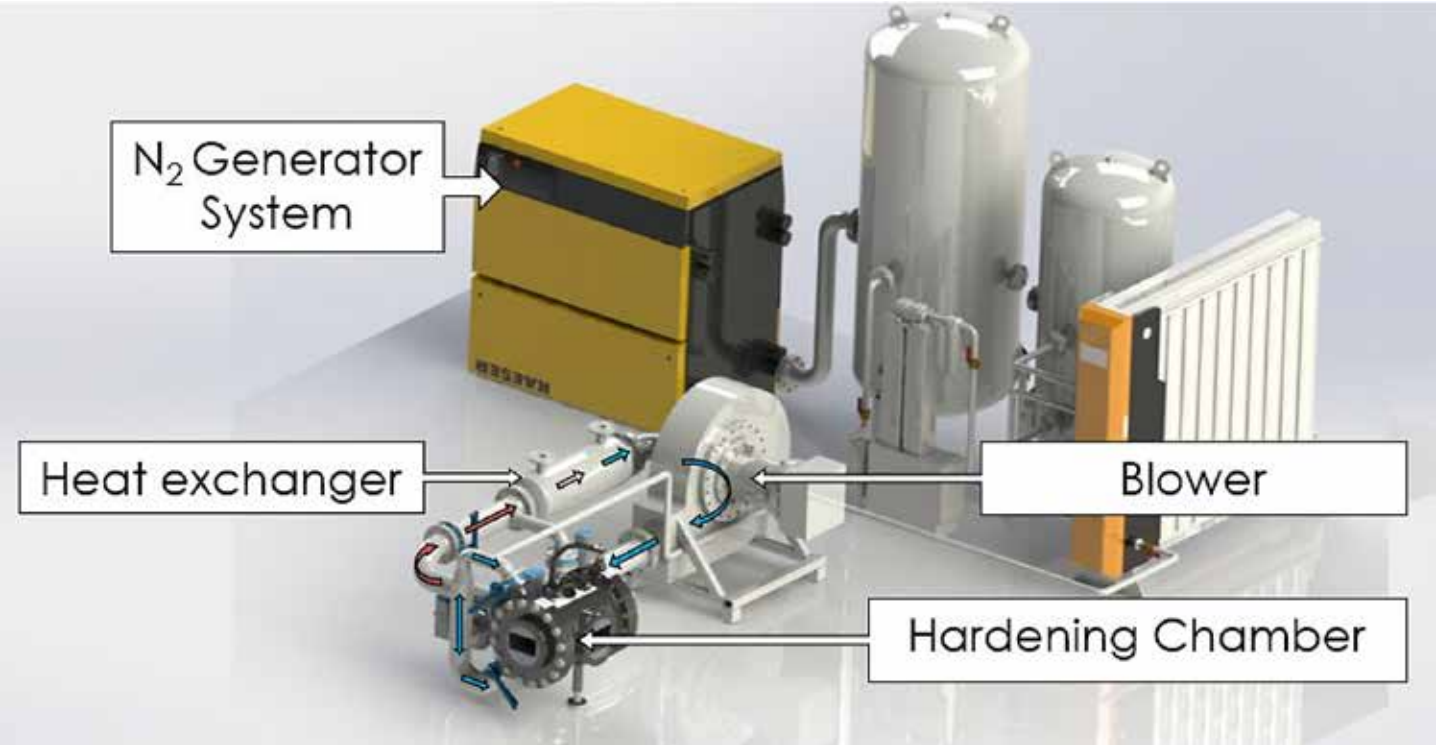

Figure 12: Modular 4DQ system example.

- Elimination of press tooling.
- Eliminates the need for furnace fixtures.
- No decarburization or oxidation.
- Clean part surface (vacuum).
- Nitrogen or Air quench (neither oil nor helium is needed).
- Elimination of copper masking or stop off paints.
- Elimination of high-temperature radiation.
- Elimination of oil and oil vapor contamination.
- Elimination of washers and cleaning chemicals.
- Safe and environmentally friendly process.

10 CONCLUSION

Heat-treatment distortion is a problem for aerospace gear and bearing manufacturers. Attrition due to heat treatment is a constant struggle that unfortunately has been a problem for far too long. Engineers are great at solving problems when given the proper devices to do so and machinists can do highly precise work with steel when they have proper amounts of steel to machine away. When material-size change during the manufacturing process is unpredictable, engineers and machinists become very ineffective at what they are good at. 4DQ can be viewed as a new tool that manufacturers can now pull from their toolbox to have an answer for controlling distortion during heat treatment. 4DQ is flexible, modular, and can be used in many heat-treatment applications. It is environmentally friendly and is a low-cost solution for extremely high- quality output. 4DQ provides controlled cooling, giving predictable results with minimal distortion ,which leads to a reduction to the amount of work in process, attrition, and increase of overall quality of the materials and downstream operations.

ACKNOWLEDGMENTS

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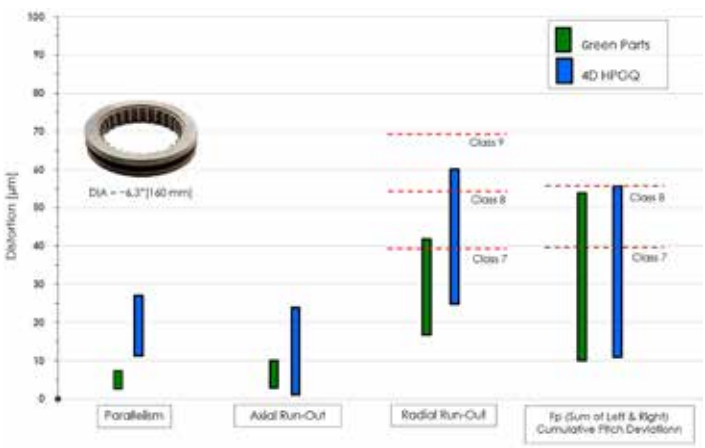

Figure 13: Coupling gear – internal teeth distortion.

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WHAT ISO 17025 CERTIFICATION MEANS FOR THE HEAT-TREATING INDUSTRY

(Courtesy: eyeSofsurf/Shutterstock)

ISO 17025 accreditation is a great way to showcase laboratory competence, as well as uphold high standards in the company organization.

By BIAGIO ORLANDO

ISO 17025 standards within the heat-treating industry are important when it comes to methods of calibration.

This is especially important at BASF, a company whose product portfolio includes precious metal (PGM) thermocouples, IR optical pyrometers, thermocouple recycling services, and calibration services. BASF's calibration laboratory is ISO 17025 accredited for calibration of several types of thermocouples including B, E, J, K, N, R, S, T, BN, BP, and P.

BASF also is active in several different markets such as glass, semiconductor, solar and turbine energy, calcining, and petrochemicals. The heat-treating industry covers a larger group of processes where the main scope is to alter physical and, sometimes, chemical properties of a material.

The industry has been through a deep change over the years, the main reason being to constantly improve process performances on several different aspects and through several different requirements.

THE ROLE OF QUALITY

During these changes, quality has played an important role to predict outcomes of industrial product production lines and detect early signals of process deviation using statistics and sampling methods.

Quality scope implemented through a quality management system (QMS) has created more sustainable initiatives involving both investor and customer and creating systematic control methods, documentation, and software. The system is focused on two main aspects: customer satisfaction by meeting customer requirements and the alignment with the organization's purpose and strategy.

Quality standards are the result of this initiative. The ISO 9000 family is probably the most widely implemented worldwide.

ISO 9001:2015 emphasizes the two main aspects of QMS by defining targets, policies, documents, and resources needed to implement and maintain the QMS. In particular, the standard defines several different aspects:

» Management, design, materials, facilities, production, and process controls.

» Corrective and preventive actions.

» Documentation and data storage: How to follow and keep trace of processes and changes.

In general terms, the system requires the performance of these processes to be measured, analyzed, and continually improved, and, because the ISO 9000 standard covers a broad spectrum of products and processes, it allows some degrees of freedom: It is left to manufacturers to determine the necessity to extend some quality elements, develop and implement procedures tailored to their particular processes and devices, and to select specific parameters of the process to keep under control.

We can say the system defines the guidelines to validate both products and services, but it does not define the methods on how to do it.

STANDARD'S REQUIREMENTS

ISO 17025 answers this need by defining "General requirements for the competence of testing and calibration laboratories." This standard is intended to be used as requirements for the competence, impartiality, and consistent operation of testing and calibration laboratories of all sizes or numbers of employees, regardless of industry. It includes the following main requirements:

ISO 17025 is intended to be used as requirements for the competence, impartiality, and consistent operation of testing and calibration laboratories of all sizes or numbers of employees, regardless of industry. (Courtesy: Shutterstock)

» **Process requirements (requests, tenders and contracts):** How do you ensure you can do exactly what the customer wants done?

» **Method selection, validation, and verification:** What procedures are used to select, verify, and validate the methods intended (defining the scope)?

» **Handling and sampling:** What procedures, planning, and documentation are required?

» **Records and reporting:** What technical records should be kept,

what should they contain, and how to report the results to the customer?

» **Measurement uncertainty:** How do you evaluate and report the measurement uncertainty of your calibration?

» **Complaints and nonconformity:** How do you need to handle complaints and work you have done that is found to be nonconforming?

» **Data and information management:** How do you manage your data and laboratory information system to ensure it is valid and that you have access to what you need?

With those premises, the question to address is: What values does ISO 17025 bring to heat-treating industry?

Following the ISO 17025 approach, we need first to define the scope of the product validation method. To do so, we need to define the specific requirements.

All heat-treating processes can be categorized based on several different aspects:

» Treatment type such as annealing, hardening and tempering.

» Market such as automotive, computers, machinery, or construction.

» Application type; the most common is metallurgical, but there are many others such as glass, insulation material, or crystal-growth.

GLASS-CONTAINERS MANUFACTURING

Different processes means different requirements. Let's take glass-containers manufacturing as an example:

A stream of molten glass is cut with a shearing blade to form a solid cylinder of glass, called a gob, where it is guided into a molding machine and into the cavities where air is forced in to produce the neck and general container shape.

In this process, temperature represents one of the most important process parameters to be kept under control. The measurement of the temperature is done using thermocouples and/or an optical pyrometer.

The precision of the measurement has a direct impact on both process and product: The difference between the real and the measured temperature has a direct effect on the quality of product, increasing the number of defects.

The reliability of the reading has also mid- and long-term consequences: The thermocouple shows what is called "electromotive force (EMF) drift" — the difference between the real and measured value increase during that time. Positive drift effects are very rare, and it is almost always in the negative direction. This means the difference between the desired temperature value and the measured value is always negative, and the energy given to the system to keep the temperature setpoint is higher than needed, and the process yield decreases.

Precision and reliability are called "process requirements" as per ISO 17025. In this case, but also in many others, temperature is one of the most important measurement parameters for process monitoring and control in various industries. It is evident how measurement error and progressive deviation need to be defined and monitored as well as the process itself, and the calibration laboratory has the target of measuring this error.

It is also evident how the ISO17025 starts by defining the process requirements. This is translated into the scope of the accreditation where the system asks the laboratory to define what is going to be measured and how.

Together with the methods of the accreditation, it also guarantees the laboratory activities and management are committed to impartiality and shall identify risks to its impartiality on an ongoing basis.

The laboratory is responsible for the management of all information obtained or created during the performance of laboratory activities and must establish and maintain metrological traceability of its measurements through a documented, unbroken chain of calibrations.

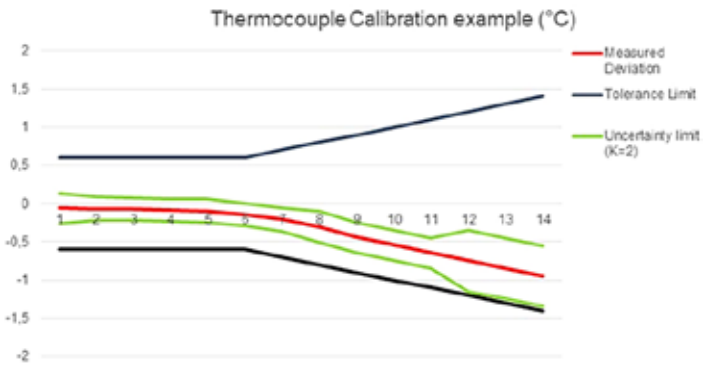

Figure 1

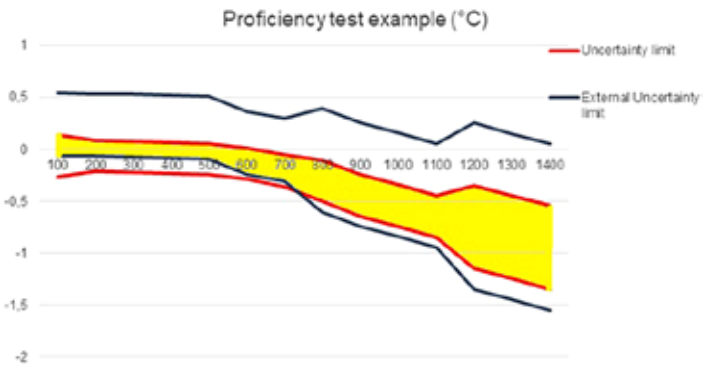

Figure 2

Precision and reliability are called "process requirements" as per ISO 17025.

IMPORTANT ACCREDITATION ELEMENTS

Once the scope has been defined, there are several important elements the accreditation brings to the calibration method and to the measurement data. From my point of view, there are three.

The first element of the standard is the uncertainty budget, which is the uncertainty of a measurement that defines the variability of the output by combining the variability of all its contribution.

As one of the most representative examples, a thermocouple calibration's target is to measure temperature reading deviation within a specific temperature range. This calibration method produces data to the customer together with all relevant information related to both measurement and method.

Figure 1 shows a typical example of a thermocouple type R calibration measurement. Data has to be compared with a measurement tolerance to establish pass/fail criteria (in this case, an internationally recognized spec such as ASTM E230/E230M special grade). Data also has to be provided together with the uncertainty specification and with the used coverage factor. All the information the ISO standard gathers with the measurement data defines its quality level. The customer is able to get all the information relevant to its process — not only the numbers, but also the level of confidence on how they have been provided.

The second element that distinguishes the ISO 17025 standard

is the proficiency test: Once the method is selected, it needs to be validated and continuously verified. A proficiency test is the way the accredited labs keep the calibration method under control. In most cases, this means the lab performs a calibration alignment with other accredited labs.

Figure 2 shows a result of a proficiency test. The standard requires the laboratory to define pass/fail criteria to the test as well as for the normal calibration process. The comparison of the data takes into consideration the uncertainty of each calibration method. The standard also requires that the lab defines the proficiency test time frequency and that the test covers the entire scope of the accreditation.

The customer is, therefore, sure the data are valid because of the standard requirements. Any deviation of the calibration process needs to be properly addressed according to the proficiency test results.

The last important element of the accreditation is how the data is being reported. The standard defines common requirements with a set of information each test report must contain. The laboratory shall ensure technical records for each laboratory activity contain the results, report, and sufficient information to facilitate identification of factors affecting the measurement result.

Specific requirements for the test report are also included, such as test conditions, statement of conformity, the already mentioned uncertainty, and, where appropriate, opinions and interpretations.

The purpose of the accreditation, in this case, is to provide the results accurately, clearly, unambiguously, and objectively, usually in a report that includes all the information agreed to by the customer, what's necessary for the interpretation of the results, and all information required by the method used. In other words, the calibration report gives the customer a clear explanation of the calibration method and the meaning of the data reported in the calibration certificate.

CONCLUSIONS

ISO17025 accreditation is a great way to showcase laboratory competence, as well as uphold high standards in the company organization. Customers are assured the process is reliable and conducted in the correct manner. The ISO 17025, therefore, also gives the customer opportunities internationally, due to its global recognition. It represents a guarantee to the customer about the validity and consistency of the calibration results.

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Biagio Orlando is a global product technology manager with BASF's temperature sensing group, which is focused on providing accurate, precise measurement of mission critical temperatures.

ENSURING COMPLIANCE WHILE SAVING TIME AND MONEY

The technology offered by C3 Data performs pyrometry tests that must be done to comply with the necessary specifications needed to make a quality product. (Courtesy: C3 Data)

C3 Data provides a software platform built specifically for the thermal-processing industry to help ensure furnace compliance to a number of industry requirements such as Nadcap, AMS2750, CQI-9, and more.

By KENNETH CARTER, Thermal Processing editor

Ensuring certifications for heat-treating applications are performed correctly and documented properly is an often time-consuming but necessary final step in verifying crucial work has been done accurately.

But what if there was a way to perform that final step quickly while maintaining that accuracy? The minds behind C3 Data have developed an innovative application that can do just that and more.

"We help heat treaters be more efficient," said Nathan Wright, who, along with his brother Matt Wright, is a founder of C3 Data. "We do this by providing them with the tool that helps them comply with a specification or maybe a group of specifications — heat-treat-specific specifications they're required to follow to produce a product. We're essentially building efficiency into that compliance process surrounding these specifications while also helping ensure their compliance."

PERFORMING PYROMETRY TESTS

The technology offered by C3 Data performs pyrometry tests that must be done to comply with the necessary specifications needed to make a quality product, according to Matt Wright. There are three main tests, one being the System Accuracy Test — a comparison of a test system to find out what the temperature inside of a furnace is against what the control system says the temperature is. The goal is to verify whether the control system temperature is close enough to the test system temperature.

"There are dozens of measurements and interpolations that have to be considered to get the correct answer," he said. "Before C3 Data — and what a lot of people who don't use C3 Data have to do — is do all that stuff every single time they perform an SAT, over and over and over and over again. With our app, it's a function of going out, entering what you see on the screen of your test system and your furnace system, hitting enter, and being done. Everything else is built-in, and all the checks and balances are integrated into the C3 software. You don't have to worry about additional work; you get an immediate pass/fail result and a fully compliant SAT report."

Every required pyrometry test has a solution through C3 Data's technology, according to Nathan Wright.

"We built the software around each specification," he said. "Unlike spreadsheets that attempt but can fail to ensure compliance, we asked ourselves, 'What does the spec require? And let's build a piece of software around every one of those requirements to help ensure the heat treater's compliance 100 percent of the time.' We did that for the SAT. We also did it for the TUS test (for every make and model of data logger). We also have an instrument calibration test module and a module for the alternate SAT that automatically generates all your A-SAT reports for you. In all of our test modules, C3 offers full compliance by taking into consideration every single requirement in the 56-page document — that most of us in the heat-treat industry are familiar with — called AMS2750. We're currently in Rev G of that specification, and just after Rev G was released, all C3 customers gained automatic and instant access to those new requirements. As I mentioned, all the requirements of the specifications are integrated directly into the C3 software so that you aren't — as a user of the software — even allowed to make a mistake, whether it was intentional or accidental. You just simply can't make those mistakes when using C3."

BEYOND AEROSPACE APPLICATIONS

The specifications within C3 Data's software aren't limited to AMS2750, which is the aerospace side of heat treating, according to Nathan Wright. The software also includes specifications needed for the automotive industry and other areas, such as CQI-9 specifications.

"C3 has what we call PRECANNED specifications, which are the most popular and well-known in the industry," he said. "But sometimes there are one-off specifications, and in C3, our customers can optionally create what we call a customized specification. These custom specifications can be built by the end-user within C3 without assistance from a third party."

By offering a variety of necessary specifications, Nathan Wright emphasized that his company's goal is to make heat treaters and pyrometry labs' lives a little less hectic.

"What we strive to do in our everyday life and the C3 Data world is to stay true to this idea of making the work life easier and more enjoyable for the people who use our software," he said. "When we started the company, originally it was designed for just pyrometry labs, but now it's become available to the entire heat-treat industry. We want to be able to make sure we're providing a piece of software that continues to reinforce that philosophy of that work-life balance and making that work-life portion of it easier and more enjoyable."

Matt Wright echoed his brother's sentiment.

"At the end of the day, people are paying good money to use our software, and it needs to provide a value," he said. "The two main values we infuse into our product are saving time and avoiding errors and audit findings. Those are the things that people want, and that's what we strive to deliver every day. We get a lot of feedback from many of our customers, particularly after audits, and we're always happy to learn that our customers have zero non-conformance findings related to the use of the C3 Data software."

WORKING WITH CUSTOMERS

In creating and fine-tuning its innovative products, the Wrights pointed out that C3 Data has developed quite a symbiotic relationship with its customers.

"When you look at many of the features that our customers enjoy today, many of them have come from our customers' requests," Matt

Every required pyrometry test has a solution through C3 Data's technology. (Courtesy: C3 Data)

Wright said. "We started with a base product that Nathan and I — from our experience — envisioned. And then, as the user base grew, we kept getting, 'It works great and all, but what about this?' or 'Have you ever considered that?' We'd love to be able to brag and tell you that we're the brainchild of all the good ideas. Still, really, we're just smart enough to be able to listen to the voice of the customer and implement good ideas that we can see are going to be valuable across the customer base."

Nathan Wright boils that down to excellent customer support.

"A lot of the feedback that we get when a customer comes to us with a challenge is often related to a nonconformance," he said. "We 'hold their hand' throughout that entire process — helping them address the non-conformance. Then, moving forward, we offer 24/7, around-the-clock support for any questions they may have and follow up after that audit and leading up to future audits. That's a part of the service that comes prepackaged with our subscription services. We offer that kind of technical support. Not only is our support team available, but both Matt and I, as founders of the company, offer our cellphone numbers to be available to our customers around the world whenever they call."

A MUCH-NEEDED TOOL

With the time gap between specification revisions growing shorter, Nathan Wright said C3 Data's software has become a welcome addition to a heat treater's toolbox.

"One of our primary value propositions to our customers is that all our customers are always on the front edge of any industry change," he said. "As an example, every time a new spec is released, and I mentioned the Rev G version of AMS 2750, C3 anticipates that change, participates in what the changes are going to be, knows what they're going to be before they're released, and we update our software as those specifications are released. Whenever an update occurs (no matter how large or small), C3 customers simply log into their C3 Data account, and all the new requirements flow down automatically into their system. It minimizes the training our customers need to invest in to ensure their compliance. It keeps going back to this idea of helping ensure our customers are always compliant with whatever the industry throws at them. We're constantly evolving, not only with the new ideas that our customers bring to us but as the industry itself changes, so do we. We're ahead of it; we're anticipating it, and we're making sure our customers are always there to meet that challenge."

TURNING IDEAS INTO REALITY

C3 Data is still a young company, but the ideas that became the crux of the company were born more than 20 years ago when Nathan Wright started a pyrometry service company called Tru Cal.

"I was in search of a way to reduce error and spend less time on paperwork and all the other necessary administrative tasks so that we could spend more time focusing on the majority of the things that were important to our customers, such as the collecting of data and the analyzing of that data," he said.

He intended to create a product like C3 Data that would eliminate error and help save time; however, the technology needed for the software wasn't available yet.

"Back in those days, there were no iPhones; there were no app stores, and there certainly wasn't broadly available high-speed wireless data available," he said.

Matt Wright said that what would eventually become C3 Data was further developed after the brothers started a pyrometry lab GTS (Global Thermal Solutions) in Mexico in 2013.

"We were constantly trying to find ways to make our technicians'

By offering a variety of necessary specifications, C3 Data's goal is to make heat treaters and pyrometry labs' lives a little less hectic. (Courtesy: C3 Data)

lives better and easier," he said. "More than anything, we wanted to retain them, to make GTS a company they wanted to stay with. And so, in asking them, 'What do you not like about your job?' the answer kept coming back, 'I don't like sitting in an office or a hotel room after the end of a long, sweaty day writing reports.' I said, 'Well, Shazam! We don't like paying you to do that, so let's see if we can find a way to eliminate that.'"

That epiphany led them back to Nathan Wright's original idea he had a decade earlier, but now, the iPhone and the Cloud were real things.

"We developed this first utility to make our lives and the lives of our technicians better," Matt Wright said. "But as we started developing it, we realized this is something that the whole industry can use."

MOVING INTO THE FUTURE

Being the data wranglers that they are, the Wrights' company is poised to be a necessary tool in an ever-evolving heat-treat industry.

"That's where C3 Data comes in," Nathan Wright said. "As we look to the future, C3 continues to expand its digital integration capabilities with thermocouple manufacturers and pyrometry labs across the globe to provide C3 customers with seamless digital access to the ever-growing amount of data that those entities provide to heat treaters."

"We also see the compliance data that our customers produce becoming better leveraged to their benefit," he said. "C3 Data has invested in the ability to provide predictive failure analysis. For example, C3 will soon be able to anticipate when a thermocouple is likely to fail before it fails, and will notify the customer of this prediction. In this example, and there are many others, the end goal is to empower our customers with the information they need to ensure that their furnace conditions can never get to a place where they would otherwise produce scrap."

It sounds cliché to say that data will drive the future of heat treating, but providing meaningful data in a way that is actionable for the heat treater will be something C3 will offer, and Nathan Wright emphasized that will drive a better future for all heat treaters across the globe.

MORE INFO www.C3data.com

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"We're looking at how our burners can utilize alternate fuels like hydrogen and other alternate fuels that don't have any or as much carbon as natural gas or oil."

What do you do at Honeywell?

I'm part of Honeywell Thermal Solutions. We're a group of companies that Honeywell has acquired over the last couple of decades that included some larger companies in the industrial combustion arena such as Maxon Corporation of Muncie, Indiana; Eclipse Combustion that was based in Rockford, Illinois; Kromschroder out of Lotte, Germany; and Hauck Manufacturing that was out of Pennsylvania. As Honeywell Thermal Solutions, we supply safe, efficient, and sustainable thermal solutions for industrial applications. Just about any industrial process that needs heat, that's where we fit.

My role at Honeywell Thermal Solutions is applications engineering manager. I tell people that my job is to keep the company out of trouble. My group advises our sales engineers, engineering group, as well as our customers on the application, design, and control of thermal systems to achieve the required goals. We supply a hundred different type burners for a lot of different applications from high to low temperature.

There's been an industry-wide drive to lower carbon emissions. What is Honeywell doing to contribute to that goal?

We are doing a lot, actually, and this is in many different divisions of Honeywell as well. From a Honeywell Thermal Solution side of it, we're looking at how our burners can utilize alternate fuels like hydrogen and other alternate fuels that don't have any or as much carbon as say natural gas or oil to reduce CO_2 from the combustion process. We offer products, burners, and systems to fire more efficiently, so they reduce the amount of fuel use that's not only reducing the customer's fuel bill, but it's reducing the carbon going out the stacks.

From an overall organization, there are divisions of Honeywell involved in the development of catalyst systems to drive down the cost to produce green hydrogen as well as carbon-capture technologies and even low carbon sustainable aviation fuels. Honeywell has a commitment to be carbon neutral by 2035, as have many large companies.

How can you reduce pollutants without sacrificing quality and performance?

There is a variety of ways to reduce emissions in thermal processes from burner design, burner control, fuel choice, and overall system design. Depending on the temperature of the process, there are different burner techniques and technologies to reduce emissions like NOx that not only reduce emissions but maintain or even enhance performance. NOx reduction has been one of the biggest focuses of a lot of industry for a long time, and it's getting stricter all over the world. Some of the techniques that are used there are high temp such as staging technologies as well as flameless, where with lower temperature, we can use premix and excess air to reduce those emissions.

Certainly, carbon reduction or neutrality is the focus of almost every industry today. The reduction of CO_2 is only done by reducing the consumption of carbon-based fuels or carbon capture and sequestration. Whatever we can do to reduce that ensures we're running the system more efficiently. We're using less fuel. That happens with self-recuperative burners or using waste heat to preheat the combustion air via heat exchangers to the combustion system. You don't take as much energy to raise the product's combustion up from cold air to the process temperature. That's less energy required, so less fuel used, less emissions coming out on both NOx on a pounds per hour as well as your CO_2. You can also fire the burners in different control methods that can be more efficient, even if you're using a different fuel.

What innovations has Honeywell developed to help deal with this challenge?

It's looking at total emissions, where Honeywell has developed innovations to help with the emissions with more advanced self-recuperative type burners and controls. These are smaller, multiple burners on, say, heat-treat furnaces that preheat the combustion air in a nice package so you don't have to deal with hot air piping and maintenance.

Different designs are getting us lower NOx, but also during the development, they are tested with alternate fuels — fuels that are byproducts of different processes — as well as hydrogen, which has, of course, gotten a lot of talk because it is carbon free. But hydrogen is going to just take you just so far depending on availability, which will continue to increase and cause the price to decrease. Other innovations are control technology as well as connectivity. We've got devices that can be connected and remotely tuned, but also can remotely monitor the health of a customer's burner system or their furnace and can alert them to possible issues. What we see in the industry is less and less combustion expertise/experience at the customer/end-user level, so we see it as an opportunity to assist those customers in maximizing their uptime and therefore profits.

How has Honeywell been able to help your customers obtain this reduction in pollutants such as NOx?

Really it is working with them to learn their processes and applications. Honeywell Thermal has hundreds of years of combustion knowledge and expertise, and this is an advantage to our customers. We can take a consultative approach to their processes. It's our job to work with these customers, to know their applications. This is an exciting time in the thermal processing industry and we will continue to develop and innovate to lead the market and deliver to our customers.

MORE INFO process.honeywell.com