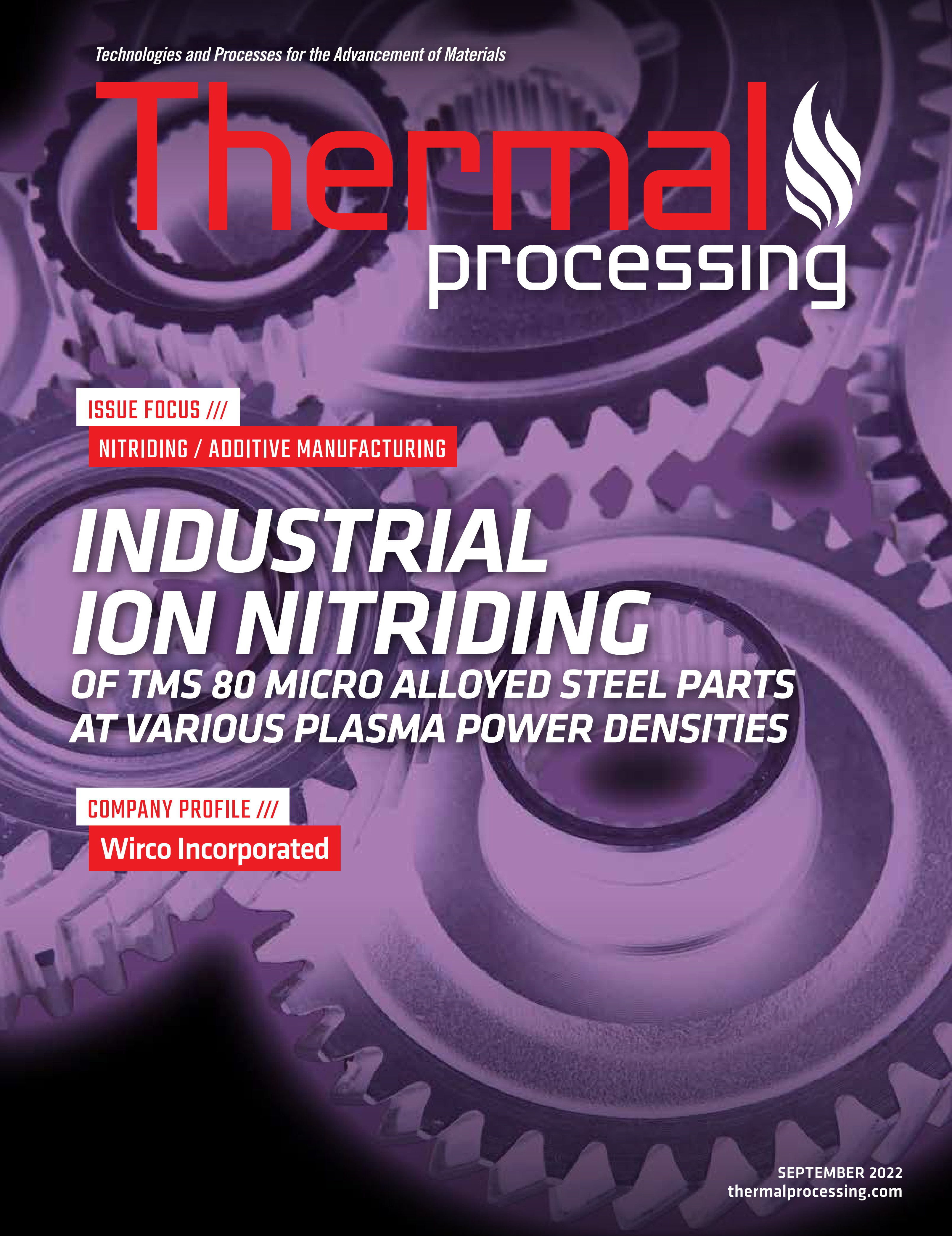

Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

NITRIDING / ADDITIVE MANUFACTURING

INDUSTRIAL ION NITRIDING

OF TMS 80 MICRO ALLOYED STEEL PARTS AT VARIOUS PLASMA POWER DENSITIES

COMPANY PROFILE ///

Wirco Incorporated

SEPTEMBER 2022
thermalprocessing.com

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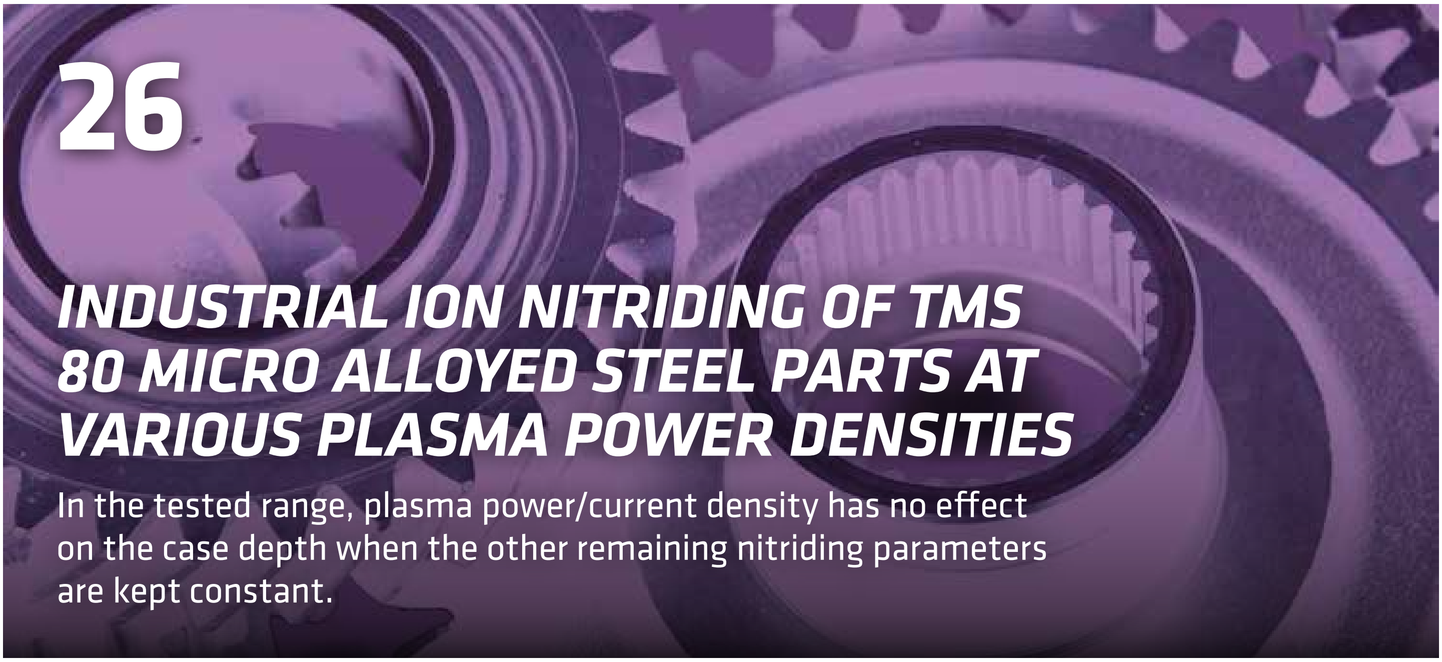

COVER PHOTO: SHUTTERSTOCK / ILLUSTRATION BY RICK FRENNEA

DEPARTMENTS ///

SEPTEMBER 2022 VOLUME 11 / NUMBER 9

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FROM THE EDITOR ///

Taking a look at nitriding and additive manufacturing

Nitriding is an important process that can increase the hardness of an alloy by diffusing nitrogen into the surface. But, if you're a seasoned heat-treater, then you don't need me to tell you that.

Not being a seasoned heat treater myself, sometimes I have to quiz myself on heat-treating processes, and nitriding is no exception.

Our September issue focuses on nitriding, and to that end, our cover story is a fascinating and highly technical look from Dr. Edward Roliński, Chad Clark, and Mikel Woods. In the article, these experts from Advanced Heat Treat Corp. discuss industrial ion nitriding of TMS 80 micro alloyed steel parts at various plasma power densities.

In addition to nitriding, this issue also looks at additive manufacturing. In an article from REM Engineering's Justin Michaud, he gives a recap of the recent 2022 Rapid + TCT Exhibition Tour organized by AGMA and the significant advancements of the metal AM industry. He originally wrote this piece for our sister publication, *Gear Solutions*, but I thought the information he presented would benefit our *Thermal Processing* readers as well.

Rounding out our feature articles is another piece on additive manufacturing from Peter de Groot with Zygo. In the article, de Groot looks at AM and innovative metrology technologies that are being developed to provide meaningful measurement data both efficiently and cost-effectively.

Along with our Focus articles, be sure and check out our monthly columnists. I feel certain the information they're sharing will come in handy.

You'll find that and more in this month's issue of *Thermal Processing*. I hope you find it all as fascinating as I did.

As always, thanks for reading!

Kenneth Carter

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UltraGlow® Induction Hardening heat treatment is now available at Advanced Heat Treat Corp.'s Alabama location. (Courtesy: Advanced Heat Treat Corp.)

AHT adds induction hardening at Alabama facility

Advanced Heat Treat Corp. (AHT), a leader in heat-treat services and metallurgical solutions, announced the addition of UltraGlow® induction hardening at its location in Cullman, Alabama. The induction equipment, which was custom built, has been delivered and the company is now accepting new induction jobs.

While the heat treatment will be a new service offering at its Alabama location, induction hardening is well-known to AHT. Induction is currently offered at AHT's Waterloo, Iowa, location where they have six units, hundreds of coils to accommodate various geometries, and almost 30 years of experience.

AHT's Alabama employees have been training in Iowa to prepare for the new service offering.

"We are pleased to offer induction hardening at a second AHT location," said Mikel Woods, AHT president. "After talking with many of our customers, we know this will be a welcomed service and we'll be able to provide better turnaround times than the area is currently experiencing."

In the past couple of years, AHT has invested in five new induction units and has plans for additional units as the customer base grows in Alabama.

Aside from the new UltraGlow induction hardening, AHT's Alabama location also offers ion nitriding, gas nitriding, ferritic nitrocarburizing, UltraOx®, stress relieve, and more. The location also holds many quality certifications such as Federal Firearms License, ISO 9001:2015, IATF 16949:2016, and is ITAR compliant.

Established in 1981, Advanced Heat Treat Corp. (AHT) is a leader in providing heat-treat services and metallurgical solutions to companies across the globe, with locations in Alabama, Iowa, and Michigan. Their UltraGlow family of processes includes plasma ion nitriding, ferritic nitrocarburizing (FNC), gas nitriding, UltraOx®, through hardening, carburizing, carbonitriding, induction hardening, black oxide, and more.

MORE INFO www.ahtcorp.com

Solar Atmospheres is Nadcap accredited for VOQ furnace

Solar Atmospheres of Western PA (SAWPA) has received Nadcap accreditation for its new, fully integrated vacuum oil quench (VOQ) furnace.

Designed and built by Solar Manufacturing, this two-chamber VOQ furnace is completely sealed, meaning a significantly cleaner and safer oil quenching process. The entire VOQ system is much "greener" than traditional integral quench or open-pit quench furnaces.

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.

Solar Atmospheres of Western PA's two-chamber VOQ furnace is completely sealed, meaning a significantly cleaner and safer oil quenching process. (Courtesy: Solar Atmospheres of Western PA)

With a maximum load weight of 2,000 pounds, the SAWPA VOQ furnace can successfully quench alloy steels and martensitic stainless steels to the most stringent of aerospace industry standards. Near-net shapes and finished products can be hardened by quenching in oil with minimal risk of surface contamination.

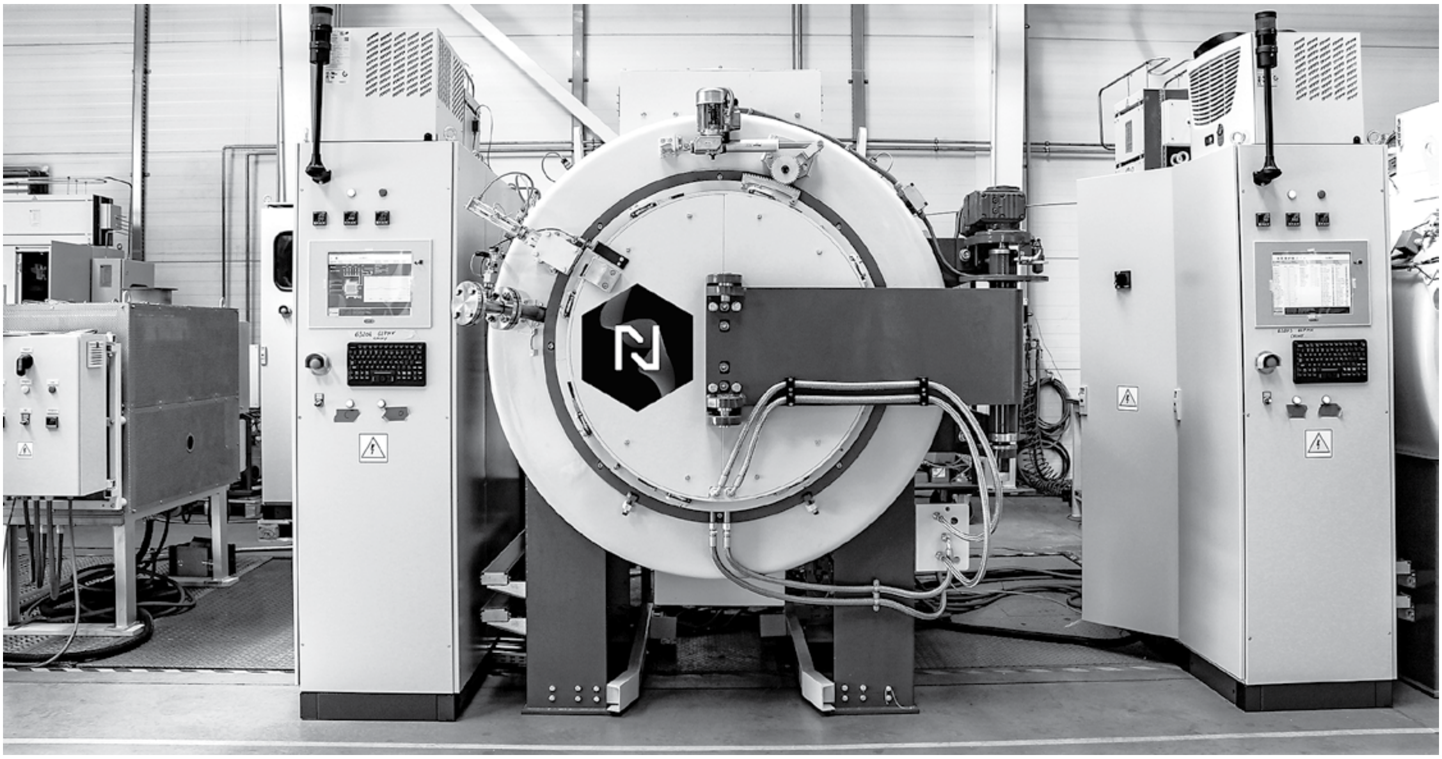
"I admit I was nervous the first time we ran low alloy steel parts for a military contract," said SAWPA plant metallurgist Greg Scheuring. "I assumed there would be a minimal partially decarburized layer. But when the low alloy steel parts came out with no decarburization with zero intergranular oxidation (IGO), I knew the VOQ was going to open up a whole new market for SAWPA."

MORE INFO www.solaratm.com

Nitrex delivers horizontal nitriding system to Norway

The Nitrex installation base continues to grow and expand at the world's largest aluminum extrusion profile company, Hydro.

While all of the Nitrex nitriding systems



Nitrex's horizontal-type furnace, a model NXH-6612, can handle loads up to 800 kilograms (1,760 pounds). (Courtesy: Nitrex)

at Hydro's worldwide facilities are pit-type furnaces, the latest delivery is a horizontal furnace.

The decision for this furnace configuration was made because Hydro Extrusion Norway had to replace an old decommissioned furnace at its Magnor plant, and the new nitriding equipment had to integrate with the existing infrastructure of the plant as well as fit in the specific floor space allocation.

Nitrex has had a relationship with global Hydro since 1999, having installed more than 20 nitriding systems in plants worldwide.

"Before placing the order, Hydro did its due diligence – visiting extrusion facilities with Nitrex equipment to get user opinions on the solution including the technology, die performance, extruded profile quality, and our support services," said Marcin Stokłosa, project manager at Nitrex. "Moreover, the test trials produced very good results. Thanks to this, we managed to beat the competition. Our added advantage was that we were able to deliver the turnkey nitriding system quickly."

The horizontal-type furnace, a model NXH-6612, can handle loads up to 800 kilograms (1,760 pounds). The delivered solution also includes the NITREG® technology to optimize process parameters for optimal die quality and a neutralizer for a clean process and pro-ecological solution.

MORE INFO www.nitrex.com

Cyber security talk set for MTI meeting, co-located with FNA

Joe Coleman, cyber security officer at Bluestreak™, will deliver two technical sessions during the Furnaces North America (FNA 2022) Conference in Indianapolis on October 3-5, 2022.

THROUGHPUT I Bluestreak™ is a leader in service-based manufacturing solutions for the metals treating industry.

"With digital transformation being so critical to heat treaters and manufacturers, cyber security has also become a priority. Integrity of your systems can no longer be ignored. Failure to adopt and maintain cybersecurity best practices, including NIST 800-171 and CMMC, can mean the loss of current contracts, the ability to remain eligible for new contracts, and reimbursing the government and taxpayers for all losses incurred," Coleman said.

Two presentations are scheduled for October 4.

Joe Coleman

"DFARS, NIST 800-171, & CMMC 2.0 Cybersecurity... What You Need to Know" will be at 8:50 - 9:25 a.m. EDT

Key Takeaways:

» What is DFARS 252.204-7012?

» What is NIST SP 800-171?

» What is CMMC 2.0?

Who Needs to Be DFARS 7012 & NIST 800-171 & CMMC 2.0 compliant.

"NIST SP 800-171 & CMMC 2.0 Requirements/Details" will be at 10:30 - 11:05 a.m. EDT

Key Takeaways:

» NIST 800-171 framework consists of requirements that must be met in order to become compliant.

» Documentation needed for compliance.

» Timeframes for implementing DFARS

7012, NIST 800-171, and CMMC 2.0.

» Review DFARS Interim Rule.

» Rulemaking and timeline for CMMC 2.0.

FNA conference track topics include maintenance, equipment, energy, compliance, the future, quenching, ferritic nitrocarburizing, productivity, metallurgy, and cleaning.

MORE INFO www.furnacesnorthamerica.com

German heat treater buys Seco/Warwick Super IQ solution

Härtewerk Chemnitz GmbH, one of the largest German commercial hardening plants (Lohnhärterei), has purchased an innovative solution from Seco/Warwick.

The new system is a horizontal, two-chamber furnace from the CaseMaster Evolution product group — a Super IQ®, featuring FineCarb® low-pressure carburizing and oil quenching system.

This is the first Seco/Warwick furnace equipped with vacuum heating at the Härtewerk Chemnitz GmbH German plant and the first Super IQ solution (vacuum heating with optional atmosphere furnace style oil quenching) in Germany. Europe is the second market, after North America, to operate a furnace with the new generation technology for carburizing.

The system ordered by Härtewerk Chemnitz GmbH — the Super IQ — is a two-chamber vacuum furnace with oil or gas quenching and low-pressure carburizing. It has a heating chamber, loading and unloading vestibule, and a quenching bath. The load can be cooled dynamically in two different media: in an inert gas (1.5 bar abs) in the quenching vestibule above the oil table with gas flow forced with a blower installed in the ceiling of the vestibule or in quenching oil. Permanent graphite insulation in the heating chamber and graphite heating elements ensure long and reliable operation under industrial operating conditions. The heating system provides quick and even heating of the load, also in low temperatures, which makes it possible to reduce the heating time significantly. The highly efficient oil circulation system ensures thorough load penetration during quenching, and the load is cooled down quickly and uniformly. This equipment enables the users to perform a variety of heat-treatment processes, heat, and chemical treatment, as well as low-pressure carburizing and quenching.

"CaseMaster Evolution is a range of equipment perfectly suited for commercial hardening plants," said Maciej Korecki, VP, vacuum business segment at Seco/Warwick Group. "It can successfully replace legacy atmosphere equipment featuring gas carburizing that is not environmentally friendly. The furnace to be delivered to Germany will significantly increase the capacity of our partner and improve the quality of treated details. Super

IQ solves the nuisance associated with atmosphere furnaces for heat treaters since they can be switched on and shut down without spending additional time and energy. It is economical since it does not need to be maintained under specific temperature parameters during an outage, as in conventional atmosphere furnaces. Vacuum treatment also increases the final product's quality and improves the process's safety. It is performed under non-combustible conditions."

Seco/Warwick, one of the largest global suppliers of metal heat-treatment solutions, continuously invests in research and development, creating more and more innovative solutions. One is a two-chamber furnace from the CaseMaster Evolution – Super IQ range, featuring both an oil quenching system and the patented FineCarb low-pressure carburizing system. Its primary advantage consists of the high-quality vacuum carburizing technology and operational flexibility. The furnace works only when needed, thanks to the start-stop system. The unique design eliminates a flammable and explosive atmosphere. The risk of fire or explosion is thus wholly avoided. The perfect uniformity of carburizing (LPC) provides flawless effects even with tightly arranged loads and parts with complex geometry. Another advantage is the highly accurate and precise LPC process simulator (SimVaC).

The Seco/Warwick system ordered by Härtewerk Chemnitz GmbH — the Super IQ — is a two-chamber vacuum furnace with oil or gas quenching and low-pressure carburizing. (Courtesy: Seco/Warwick)

Super IQ, is a hybrid system combining the features of conventional and vacuum furnaces, designed mostly for carburizing processes under elevated temperatures and equipped with traditional oil-bath quenching. The industry requires a cleaner, faster, and more efficient carburizing method. Compared with conventional methods, Super IQ brings benefits in terms of increases in overall productivity. It operates under higher temperatures, which translates into shorter cycle times and thus more efficient production.

For an experienced European concern, Härtewerk Chemnitz, selecting Seco/Warwick technology is an excellent market recommendation. Commercial hardening plants are one of the most demanding industries since their needs are comprehensive, and the processes must be optimized. In the German plant, Super IQ will replace legacy atmosphere technology.

"With the furnaces from Seco/Warwick, we want to expand our capabilities for mass-produced processing parts," said Kai Werlitz, technical operations manager, Härtewerk Chemnitz GmbH. "The machines we have worked with so far had required time-consuming and expensive preparation, especially when the equipment was not at the right temperature. Unfortunately, this is the main shortcoming of atmospheric furnaces. They require constant readiness, so they must be kept at temperature even when empty and when the manufacturing process is halted or stopped. From a financial point of view, it is less beneficial to shut down and cool down existing furnaces than to keep the equipment ready for manufacture, resulting in high maintenance costs. The Super IQ furnace that we have ordered eliminates not only these difficulties but also enables efficient heat treatment with very high repeatability and uniformity of the carburized layer, which with atmospheric furnaces was only possible to a limited extent."

Combining a proven and reliable vacuum furnace design with conventional oil quenching technology guarantees reliable and very efficient operation. Super IQ enables efficient and clean hardening processes while providing stable economies. This is particularly important when energy prices are rising steeply across Europe.

Härtewerk Chemnitz GmbH is a leading commercial hardening plant on the German market. Chemnitz and Chomutov plants provide a wide range of services related to metal heat treatment and guarantee high quality. More than 500 customers in Germany and Europe's mechanical engineering, automotive, and metalworking industries have put their trust in Lohnhärterei Härtewerk Chemnitz GmbH.

MORE INFO www.secowarwick.com

STLE announces 2022-2023 conference schedule

The Society of Tribologists and Lubrication Engineers (STLE) — the premier technical society serving the needs of the tribology and lubrication engineering business sector — announced its 2022-2023 conference schedule featuring three distinguished events for lubrication and reliability professionals:

» Second Annual STLE Tribology and Lubrication for E-Mobility Conference, November 30-December 1, 2022.

» 77th STLE Annual Meeting & Exhibition, May 21-25, 2023 (abstract submission deadline: October 1, 2022).

» 2023 STLE Tribology Frontiers Conference, November 13-15, 2023 (abstract submission deadline: April 15, 2023).

"The shortage economy is causing radical shifts in the tribology and lubrication field," said Edward P. Salek, CAE, STLE executive director. "STLE's 2022-2023 conferences will help industry professionals and academia address these challenges head-on through informative technical sessions, face-to-face networking opportunities and cutting-edge research."

STLE will hold its Second Annual Tribology and Lubrication for E-Mobility Conference on November 30-December 1, 2022, at the Southwest Research Institute (SwRI) in San Antonio, Texas. The two-day, hybrid technical conference will offer virtual and in-person participants the opportunity to attend educational sessions, networking and group discussions, and panel discussions with industry experts on the latest advancements and outlook for the electric vehicles market. Presentations will cover a wide range of topics, including EV hardware, grease, EV drivetrain efficiency, testing requirements for EVs, thermal management, sustainable mobility, electrification, and EV lubricant formulation. Presentation suggestions on fuel cells, hydrogen internal combustion engines and other topics are also welcome along with panel discussion recommendations.

STLE's 77th Annual Meeting & Exhibition — the lubricant industry event for technical information, professional development, and international networking opportunities — will be May 21-25, 2023, at the Long Beach Convention Center in Long Beach, California.

The five-day event will feature daily keynote and plenary talks, live Q&A opportunities with academic and industry leaders, more than 400 technical presentations, application-based case studies, 12 industry-specific education courses, best practice reports, discussion panels on technical and market trends, in-person networking and social events, and commercial exhibits and student posters.

The STLE Tribology Frontiers Conference will be November 13-15, 2023, at The Cleveland Marriott Downtown at Key Tower in Cleveland, Ohio. The three-day conference, co-sponsored by the Tribology Division of the American Society of Mechanical Engineers (ASME), will feature more than 200 presentations exploring how tribology can solve today's technical, environmental, and societal concerns; plenary talks and technical sessions from leading tribology researchers and institutions from around the globe; and opportunities for networking and discussions with principal investigators.

MORE INFO www.stle.org

Exact Metrology named distributor of #HandsOnMetrology

The #HandsOnMetrology portfolio offers measuring systems including GOM ATOS Q. (Courtesy: Exact Metrology)

Exact Metrology: A Division of In-Place Machining Company and a comprehensive 3D metrology service provider and hardware sales company, has become the North American distributor of #HandsOnMetrology. The new digital platform HandsOnMetrology.com was set up to share the benefits of 3D metrology with a global community. As a representative of this new 3D scanning network, Exact Metrology will be an official contact for companies in the United States who want to optimize their quality control processes with new, state-of-the art 3D scanning and automation solutions.

Available at both the Brookfield (Milwaukee), Wisconsin, and the Cincinnati, Ohio, location, the HandsOnMetrology portfolio offers measuring systems including GOM Scan 1, ATOS Q, T-SCAN 10/20 and the hand-held T SCAN hawk. Exact Metrology also offers the GOM ScanCobot automation solution.

GOM Scan 1 delivers the foundation for detailed and accurate 3D meshes with industrial standards such as GOM fringe projection technology and Blue Light Technology. The sensor is built to deliver 3D data with high precision. Easy to operate, the scanner is ideal for simple and fast measurements of small to medium-sized parts, even in confined spaces. With pre-installed GOM Inspect software, users can generate precise meshes and obtain 3D data easily and quickly.

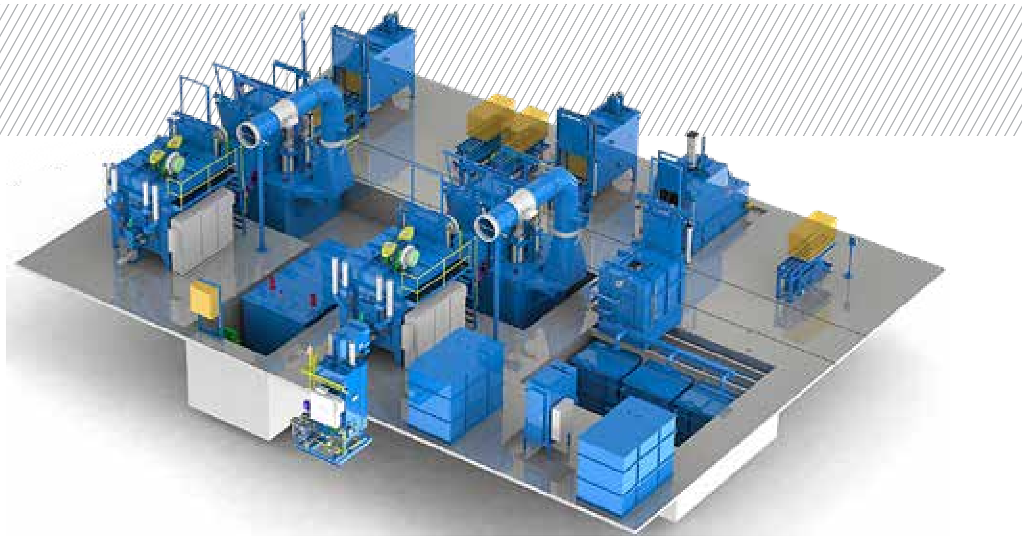
ATOS Q is a flexible 3D scanner for complex measurement and inspection tasks in different industries. The scanner delivers fully traceable measurement results, especially in harsh conditions. Optical and electronic systems of the robust, optical 3D sensor are dustproof and splashproof. ATOS Q captures quality information quickly and with a high degree of detail, providing a reliable basis to easily interpret the information. Its Triple Scan Principle offers advantages for measuring reflective surfaces and objects with indentations. The Blue Light Equalizer enables high-speed fringe projection and can achieve short measuring times on dimensionally challenging surfaces.

The compact hand-held 3D scanner T-SCAN hawk is designed to capture data whenever needed. It includes technical features such as photogrammetry of large objects, multiple laser sources, and three scanning models. This makes it an ideal solution for fine detail. Thanks to the GOM Inspect onboard, the T-SCAN hawk offers a complete solution to simplify workflow from scanning to evaluation and reporting.

The GOM ScanCobot, a mobile automated 3D scanning system, easily integrates with ATOS Q. With the high-precision quality of ATOS combined with an automated robotic arm, the GOM ScanCobot is cost-effective and easy to use. It improves efficiency in quality control of small to medium-sized parts, including plastics, fabricated metals, and castings. The combination of the GOM ScanCobot and the proven ATOS performance results in fast fringe projection, data processing, high throughput and a design ideal for industrial use.

MORE INFO www.exactmetrology.com

Manufacturer buys AFC-Holcroft batch austemper facility



A recently purchased AFC-Holcroft UBQA line will be used by a supplier of agricultural and lawn equipment. (Courtesy: AFC-Holcroft)

A major Midwestern U.S. supplier of agricultural and lawn equipment recently purchased a complete batch austemper facility from AFC-Holcroft.

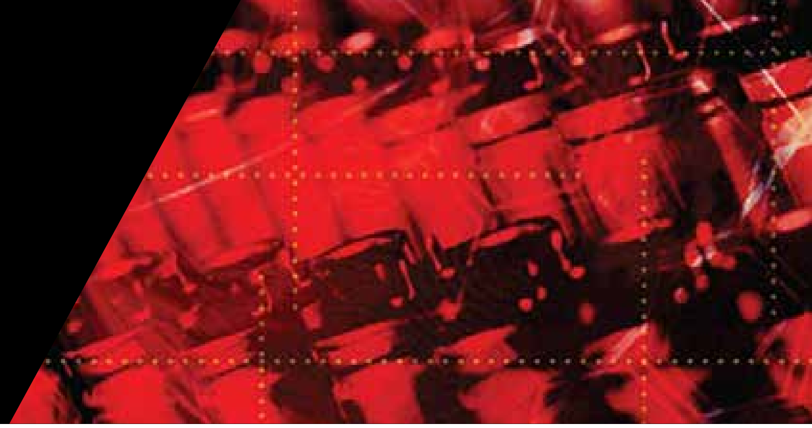
The complete line consists of two of AFC-Holcroft's UBQA (Universal Batch Quench-Austemper) units along with ancillary equipment including pre-treatment spray dunk wash and post-treatment multi-stage washer, pre-heat temper furnaces, salt reclaiming system, and salt holding tank. An AFC-Holcroft EZ™ 4500 endothermic gas generator was also purchased to provide endo gas to the furnace units.

The system includes BatchMaster™ Supervisory Control System, along with AFC-Holcroft's patent-pending Calibration Mode™ diagnostics software and Maintenance Module software, which comes pre-loaded with recommended maintenance tasks designed for easy access through the HMI touchscreen.

"This was a great customer to work with for this project," said Mike Coburn, technical sales for AFC-Holcroft. "They fully understood right from the start the environmental and economic benefits of the system."

"We have seen tremendous growth in our salt quench furnace lines, both continuous (pusher and belt) furnaces as well as our UBQA integral salt quench batch furnaces," said Tracy Dougherty, vice president of sales. "In addition to the positive environmental impact, these systems produce metallurgical results and distortion control that are second to none."

MORE INFO www.afc-holcroft.com



Conference updates – plan accordingly

27th IFHTSE-Congress and the European Conference on Heat Treatment 2022 is taking place in September in Salzburg, Austria.

27TH IFHTSE-CONGRESS AND THE EUROPEAN CONFERENCE ON HEAT TREATMENT 2022

The detailed program of events, including more than 100 papers in 16 sessions with five keynote speakers, is now online: submit.asmet.org/event/60/timetable/#20220906.detailed

ADVANCES IN MATERIALS AND PROCESSING TECHNOLOGIES

October 10-14, 2022 | Portorož, Slovenia

The Advances in Materials and Processing Technologies (AMPT) conference series provides a forum for academics, researchers, and practicing engineers to meet and exchange innovative ideas and information on all aspects of material processing technologies. It was founded in 1990 at Dublin City University, Dublin, Ireland, and has since then been held in many different countries around the globe. After being canceled in 2020 due to COVID pandemic, the AMPT conference returns in 2022 at the coast of Slovenia in Portorož.

»**More info:** www.AMPT2022.org

5TH INTERNATIONAL CONFERENCE ON HEAT TREATMENT AND SURFACE ENGINEERING OF TOOLS AND DIES (HTSE-TD)

April 24-27, 2023 | Hangzhou, China

This conference will finally resume the HTSE-TD series since being held online in January 2021. The call for papers is now posted at: htse-td.allconfs.org/meeting/index_en.asp?id=6861

Abstracts should be sent to Lihui LIU at chta@chta.org.cn

Abstracts are due October 31, 2022, with full papers due January 31, 2023.

The aim of the Korean Society for Heat Treatment is to develop into a core field of root technology in Korea.

SPOTLIGHT ON MEMBERS

Korean Society for Heat Treatment

This year marks the 34th anniversary of the founding of the Korean Society for Heat Treatment. Its focus is to actively respond to the rapid changes in the heat-treatment industry and the society of South Korea as a whole. It actively promotes research in heat treatment and the support of new researchers.

The Society strives to be a bridge between industry and academia so the fundamental research conducted can be directly applied in the field. They have been a member of IFHTSE since 1991, and hosted the 6th IFHTSE Congress in Gyeongji, South Korea.

IFHTSE UPCOMING EVENTS

SEPTEMBER 5–8, 2022
27th IFHTSE Congress / European Conference on Heat Treatment
Salzburg, Austria I www.ifhtseecht2022.org

OCTOBER 10–14, 2022
Advances in Materials and Processing Technologies
Portorož, Slovenia I www.ampt2022.org

NOVEMBER 2–4, 2022
HTS – 14th International Exhibition and Conference on Heat Treatment
Mumbai, India I www.htsindiaexpo.com

APRIL 24–27, 2023
5th International Conference on Heat Treatment and Surface Engineering of Tools and Dies
Liangzhu Dream Town, Hangzhou, China

OCTOBER 17–19, 2023
Heat Treat 2023
Detroit, Michigan I www.asminternational.org/web/heat-treat

NOVEMBER 13-16, 2023
28th IFHTSE Congress
Yokohama, Japan

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

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ONLINE www.ifhtse.org I **EMAIL** info@ifhtse.org

NEW MEMBER SPOTLIGHT

Energy-tech company Reuter-Stokes

For the process heating and combustion market, Reuter-Stokes manufactures harsh environment flame sensors for industrial burners for maximum efficiency and safety, including being certified for use in Zone 1 or Zone 2 locations.

Reuter-Stokes, a Baker Hughes business, is an energy-technology company, producing products that are vital to its customers' harshest measurement and mission-critical sensing applications.

For the process heating and combustion market, Reuter-Stokes, located in Twinsburg, Ohio, manufactures harsh environment flame sensors for industrial burners for maximum efficiency and safety, including being certified for use in Zone 1 or Zone 2 locations. In fact, its flame sensors have been proven under extreme use as standard components on the world's largest fleet of heavy-duty gas turbines used for power generation.

Reuter-Stokes product lines and applications include:

- Homeland security.
- Downhole drilling and wireline sensors.
- Neutron scattering.
- Nuclear instrumentation detectors.
- Environmental radiation monitoring.
- Flame monitoring.

As part of its ongoing commitment to quality and customer satisfaction, Reuter-Stokes is committed to maintaining ISO9001:2015 with design and AS9100:2016 with design certifications.

But Reuter-Stokes brings more than reliable products to the table. The company is dedicated to advancing the industry. Its aim is to play a vital role in helping its customers build safer and smarter applications.

From cultivating the next generation of engineers to supporting the next generation of industrial heating equipment, Reuter-Stokes invests intentionally in the future of their fields.

And the company is positioned well to do so. From its beginnings as a GE company, Reuter-Stokes has been a pioneer in its product lines, technologies, and applications. It now brings more than six decades of expertise to the research, development, manufacture, and installation of industry-leading energy technology solutions ranging from flame sensing to radiation monitoring, and from nuclear power-plant instrumentation to downhole navigation for oil and gas drilling.

From cultivating the next generation of engineers to supporting the next generation of industrial heating equipment, Reuter-Stokes invests intentionally in the future of their fields. The company is committed to serving the heat-processing industry and is excited to partner with IHEA to further the association's mission.

›› **More info:** www.reuter-stokes.com

DON'T FORGET IHEA'S FALL SEMINARS

Combustion Seminar and Safety Standards and Codes Seminar. IHEA will offer its Combustion Seminar and Safety Standards and Codes Seminar in Indianapolis, Indiana, October 3-4, 2022. The concurrent technical seminars will be at the Indiana Convention Center in conjunction with the Metal Treating Institute's (MTI) Furnaces North America (FNA). The schedule provides attendees the benefit of expanding their technical knowledge and allows time to visit with FNA exhibitors, including IHEA members and companies represented by IHEA seminar speakers.

›› **More info:** www.ihea.org/event/Combustion22

Powder Coating and Curing Processes Seminar. The Powder Coating and Curing Processes Seminar will be September 20-21, 2022, in Henderson, Nevada. Attendees learn everything from pretreatment and powder materials to curing processes and testing equipment for powder coating. There will be live demonstrations and time in a custom coater facility for attendees to see the processes up close and try their skills at spraying powder and curing a part.

›› **More info:** www.ihea.org/event/PCCSept22

IHEA 2022 CALENDAR OF EVENTS

SEPTEMBER 20–21

Powder Coating & Curing Processes Seminar
AR Iron LLC I Henderson, Nevada

OCTOBER 3–4

IHEA Combustion Seminar
Long the industry premier seminar for industrial process heating professionals, this two-day event offers attendees the chance to learn the latest in combustion technology and visit with industry suppliers.
Indiana Convention Center I Indianapolis, Indiana

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.

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

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JASON MEYER
MECHANICAL ENGINEER /// DANTE SOLUTIONS

Wire Arc Additive Manufacturing combines the well-studied process of arc welding with direct energy deposition. The process can be modeled using Goldak Flux Distribution.

Using welding simulation tools to model WAAM

In its simplest form, additive manufacturing has been used since before the common era where low temperature melting materials such as tin, silver, copper, or zinc were used to join materials in a process called brazing. This led the way for welding once man mastered the electric arc. In modern times, metal-based additive manufacturing can be classified in three main categories: powder bed fusion, sheet lamination, and direct energy deposition. Wire Arc Additive Manufacturing (WAAM) combines the well-studied process of arc welding with direct energy deposition to quickly and efficiently form parts at relatively low cost. WAAM is attractive to those entering the additive manufacturing space because of its low initial cost, high deposition rates, and wide range of materials. WAAM can be applied in large-scale production or small-scale rapid prototyping and machines can be built from existing welding systems and robotic controllers.

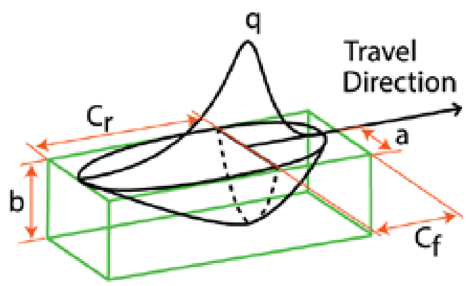

Figure 1: Goldak double ellipsoid parameters for flux distribution.

Computer modeling of any additive manufacturing process can be extremely difficult due to the high computational costs associated with material deposition. From a finite-element modeling standpoint, WAAM is analogous to a multi-pass welding simulation. Elemental activation, or elemental birth, is used to activate elements during the analysis to simulate the deposition of material. Common parameters for deposition are travel speed, wire feed rate, current, and protective gas flow rate. For modeling, travel speed and current are modeled, while the protective gas is assumed to be sufficient flow to protect the weld from oxidization and the feed rate is assumed to be sufficient to lay a continuous bead.

The amount of heat introduced from the weld, and the base material's specific heat and conductivity, contributes to the solid-state phase transformations and microstructural changes in the weld and heat-affected zones. A moving heat source is required to model the deposition of melted material during WAAM. As the thermal gradient along the weld causes expansion from heating, followed by contraction from cooling, plastic deformations, distortions, and residual stresses are generated. This heat source can be described in many ways, but the Goldak double ellipsoid is the most commonly accepted model used to represent the high-localized heating present in arc, laser, and electron beam welding. Goldak, Chakravarti, and Bibby [1] proposed a new model for welding heat sources in the mid 1980s that includes a Gaussian flux distribution over a non-axisymmetric, three-dimensional volume. Their work allows for parameters that control the front (Cf), rear (Cr), width (2a), and depth (b) of the heat source applied to the elemental volume, as shown in Figure 1, which offers a flux distribution that mirrors reality. This article will use modeling to evaluate the WAAM process, using a welding tool with Goldak flux distribution that also accounts for the dynamic phase transformations in steels.

STUDY

A common practice when developing a WAAM process is to build small "walls" by depositing material layer by layer on a build plate and then machining mechanical and microstructural samples to quantify the properties provided by the process. For this study, a simple finite-element model was constructed in Abaqus consisting of a 50mm by 100mm by 2.5mm build plate where eight layers of deposition welds are deposited along the center. The beads are 2mm by 1.5mm by 50mm and are deposited in the same direction after a five minute delay between passes to allow the heat to distribute into the plate. Figure 2 shows the build plate with each pass color coded, signifying deposition layers. The model was meshed with 15,123 nodes and 12,000 elements.

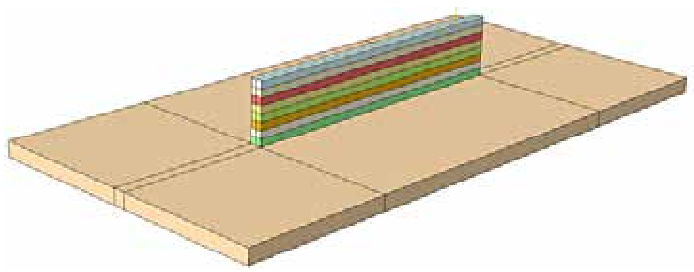

Figure 2: Finite-element model of build plate with color-coded welds.

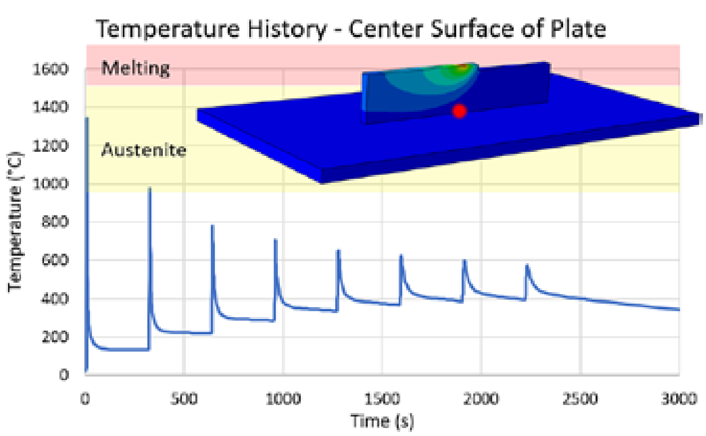

Figure 3: Temperature history for a point on the center surface of the build plate.

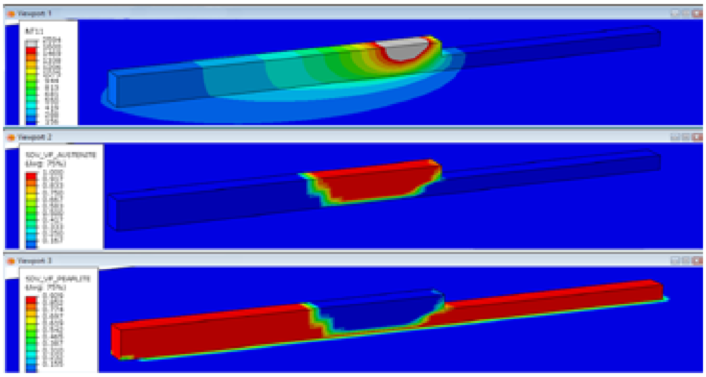

Figure 4: Temperature (top) and phase fractions of austenite (middle) and pearlite (bottom) during the second deposition pass.

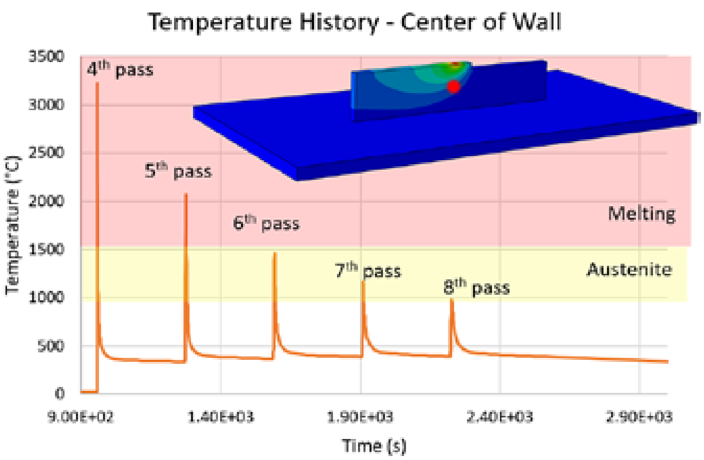

Figure 5: Temperature history of a point at the center of the build wall.

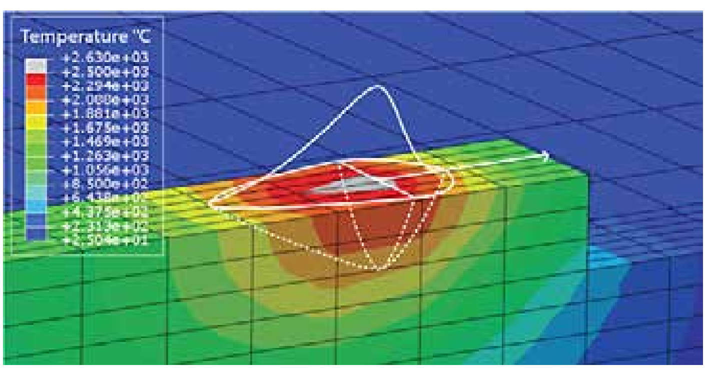

Figure 6: Goldak flux distribution overlaid on the temperature contour.

The complicated process of assigning the elemental activation, as well as the travel speed, current, and Goldak heating parameters, is accomplished using QustomWeld from QustomApps. Travel speed is set to 3mm/s while the power inputs are 15 Volts, 30 amps, and 70 percent efficiency. The Goldak parameters are a=1mm, b=0.75mm, Cf=1.5mm, and Cr=2.5mm. These values are held constant through each of the eight passes defined in the model.

The materials model from DANTE is coupled with QustomWeld to provide the material properties, phase transformation kinetics, and volume changes during the process. The material used for the build plate and beads in this study is AISI 1020. A sequentially coupled thermal and stress model was executed using the Abaqus solver and post processed using the Abaqus viewer.

The thermal history of a point on the center surface of the plate can be seen in Figure 3. During the first pass, the temperature of the plate sharply increases from the liquid metal deposited on the surface. Each subsequent pass raises the median temperature of this point until an equilibrium is met. The first pass is immediately quenched by the body of the plate which reaches a temperature of about 1,400°C before dropping back down to about 130°C. This spike in temperature is enough to convert the surface of the plate to austenite. The austenitized base material and bead then transform to pearlite due to the slow air cooling following the material deposition. Subsequent passes increase the temperature at the center of the plate, under the growing wall, until an average temperature of 400°C is maintained.

Figure 4 shows the temperature, austenite, and pearlite volume fractions mid-way through the second pass. The temperature legend is capped at the melting temperature to show the deposition of the liquid metal while the austenite contour follows closely to this high temperature zone. The pearlite contour shows clearly that the first pass is being transformed back to austenite due to the heat of the second pass before cooling again to pearlite. This transformation cycle is repeated for each subsequent pass.

The temperature history for a point on the center of the wall is shown in Figure 5. The first spike in temperature is the liquid metal deposition of pass four, activating the elements. Since the material has effectively been preheated by previous passes, the fifth pass remelts the surface of the fourth pass as it is being deposited. Even the sixth and seventh passes have enough thermal energy to reheat the fourth pass to austenite temperatures.

Figure 6 shows the Goldak flux distribution overlaid on the temperature contour. The temperature contour shows the double ellipsoid defined in QustomWeld with a clear heat concentration running down the centerline of the bead on every pass, consistent with the Gaussian distribution.

CONCLUSION

Simple models like these can tell a great story. From this study, it is clear that the power distribution should be lowered as the material comes to temperature. From the centerline temperature history in Figure 5, after pass four is deposited, it is almost completely remelted by the deposition of pass five. It is then transformed to austenite from the heat of passes six and seven. Reducing the power delivered to the part as it comes to temperature will eliminate the overheating predicted by the model.

The microstructure evolution is shown to be very dynamic due to the localized heat source produced by the Goldak parameters. The advantage of modeling is that a few simple models can help reduce the growing pains of developing a new process and shed light on refining established processes. While simple, the study described shows that the capabilities are available to model direct energy deposition with welding tools like QustomWeld, including the complex heating from the Goldak flux distribution, and the material phase evolution from DANTE.

REFERENCES

[1] Goldak, John, et al. "A New Finite Element Model for Welding Heat Sources." Metallurgical Transactions B, vol. 15, no. 2, 1984, pp. 299–305.,

[2] QustomApps - https://www.qustomapps.com/

ABOUT THE AUTHOR

Jason Meyer joined DANTE Solutions full time in May 2021 after receiving his Master's degree in mechanical engineering from Cleveland State University. His main responsibilities include marketing efforts, project work, and support and training services for the DANTE software package and the DANTE utility tools. Contact him at jason.meyer@dante-solutions.com.

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

A controlled environment and well-placed heat sources allow for high-volume parts output but this equipment isn't without hazards.

Heat-treating workhorse – integral quench furnace

In this column, we will discuss the workhorse of the steel heat-treating industry – the integral quench furnace.

The integral quench furnace, or sealed quench furnace (Figure 1) is the work horse of the heat-treating industry. It is found in all parts of the world, heat treating everything from tiny fasteners to large wind turbine gears.

The integral quench furnace consists of three different chambers: the vestibule, hot zone, and quench tank. Doors are located at the entrance of the vestibule (outer door) to allow parts to be placed inside or extracted. Another door, located between the vestibule and the hot zone (inner door), allows work to be moved into the hot zone. Optionally, an upper chamber is located above the vestibule to allow work to be slow-cooled instead of quenched.

The vestibule is typically not insulated but constructed of thick steel plate. The outer door is also constructed of thick steel plate (usually 12.5 mm or thicker). At the entrance of the door, there is a series of flame safety equipment and a flame curtain to minimize the amount of oxygen that enters the furnace when a load is entered or extracted from the vestibule. This flame curtain ignites whenever the front door is opened and extends the full width and height of the outer door.

The hot zone of the furnace is fully insulated to withstand the high temperatures used in austenitizing or carburizing steel (750-1,100°C). High-temperature alloy grids or rollers allow the workload to move into the hot zone. Alternatively, high-temperature refractory skid plates are used to support the workload. The inner door is fabricated with steel plate on the outside and refractory on the inside. This allows the door to be fully protected. The inner door does not make a complete seal between the hot zone and vestibule to allow the furnace atmosphere to fill both zones. This is done for safety reasons and to prevent oxidation of parts in the vestibule.

The quench tank of the integral quench furnace contains the quenchant, and supplies agitation through a series of agitators, usually located on either side of the quench tank. The size of the quench tank is generally designed so that the temperature of the oil will not increase more than 30°C for the maximum allowable furnace load. The quench tank is designed to have adequate free board for the immersion of the workload and have an overflow should the height of the quench oil be too high. This freeboard is usually 15-20 cm below the level of the hearth of the hot zone. This overflow is designed to prevent the quench oil from entering the hot zone, and to allow for expansion of the oil as it is heated.

The sequence of operations of an integral quench furnace is explained referring to Figure 2.

Once the furnace workload has been assembled, and is ready for heat treating, it is usually placed on an automatic loader or tray in front of the furnace. The outer door is opened, and the flame curtain initiates. The workload is pushed through the flame curtain, onto an elevator in the up position. The inner door then closes. Once the workload is in the vestibule, it can sit for a short period of time to allow any residual oxygen that entered with the workload to dissipate.

Figure 1: Typical integral quench furnace (Courtesy: Surface Combustion, Maumee, Ohio).

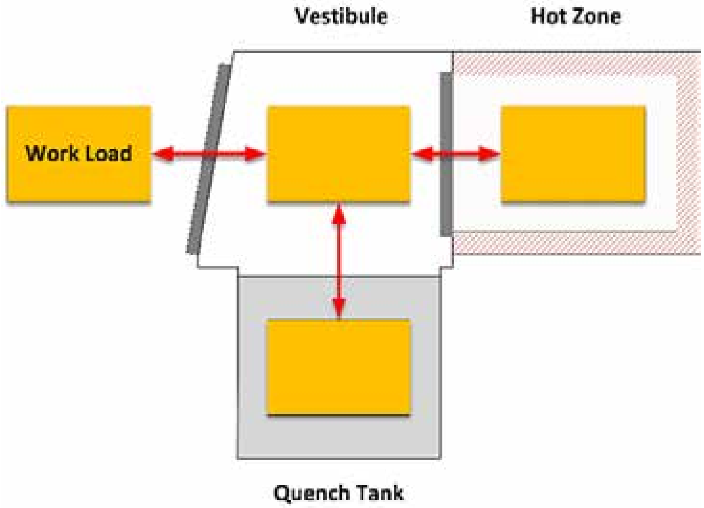

Figure 2: Cross-section of a typical integral quench or sealed quench furnace.

The inner door opens, and an automated chain extends from the hot zone to pull the workload into the hot zone. The inner door then closes. The workload is heated to the desired process temperature and soak at that temperature for the desired amount of time (typically one hour per 2.5 cm of thickness). If the load is carburized, longer

The atmosphere used in atmosphere furnaces is explosive below 750°C, so excluding oxygen is extremely important to prevent the outer door from being forcibly thrown from the furnace.

times are required to achieve the necessary case-depth.

Once the load has been soaked at temperature for the desired length of time, the inner door opens, and the load is pushed onto the elevator in the vestibule. The inner door closes, and the elevator is lowered into the quench tank. As the inner door closes, an atmosphere collapse occurs due to the removal of the heat from the hot zone. Because of this atmosphere collapse, a nitrogen purge or high atmosphere flow is initiated. This provides a positive pressure in the vestibule and prevents oxygen from entering the vestibule from the outside. This is critical. The atmosphere used in atmosphere furnaces is explosive below 750°C, so excluding oxygen is extremely important to prevent the outer door from being forcibly thrown from the furnace. Explosive vents are usually provided on the vestibule, as well as retaining locks on the door to prevent this from happening. Use of nitrogen purges and high atmosphere flow prevent this from occurring.

Once the load has entered the quench, fumes from the quenching operation escape from the furnace and are withdrawn using large hoods above the furnace. The oil fumes are vented in some fashion to the atmosphere, after particulate and oil fumes are filtered from the exhaust. Because oil fumes can condense in the hood and associated vents, it is important that the hood and vents be routinely cleaned to prevent the accumulation of condensed oil and potential fires.

The load is kept in the quenchant for the desired time until the load is at the desired temperature. The elevator is moved up to the unload position, and the workload drains off excess oil for about 20 minutes. This is important to minimize drag-out of the oil from the quench tank. Once the workload has adequately drained, the outer door is opened, and the flame curtain initiated. The load is then extracted from the furnace through the flame curtain. Often, residual oil on the workload can ignite for a short period of time. This is another reason why it is so important to allow the furnace workload to properly drain. Residual accumulated oil and sludge on the loader can also catch fire if not kept clear of oil and debris. Proper maintenance and housekeeping will go a long way in preventing fires.

CONCLUSIONS

In this column, we have described the integral quench furnace and how it works. We also described some hazards associated with the use of integral quench furnaces.

As always, should you have any comments on this article, or have any suggestions for further columns, please contact the author or the editor.

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

There are many reasons you might end up with nonconforming periodic test results and one very good way of determining the problem.

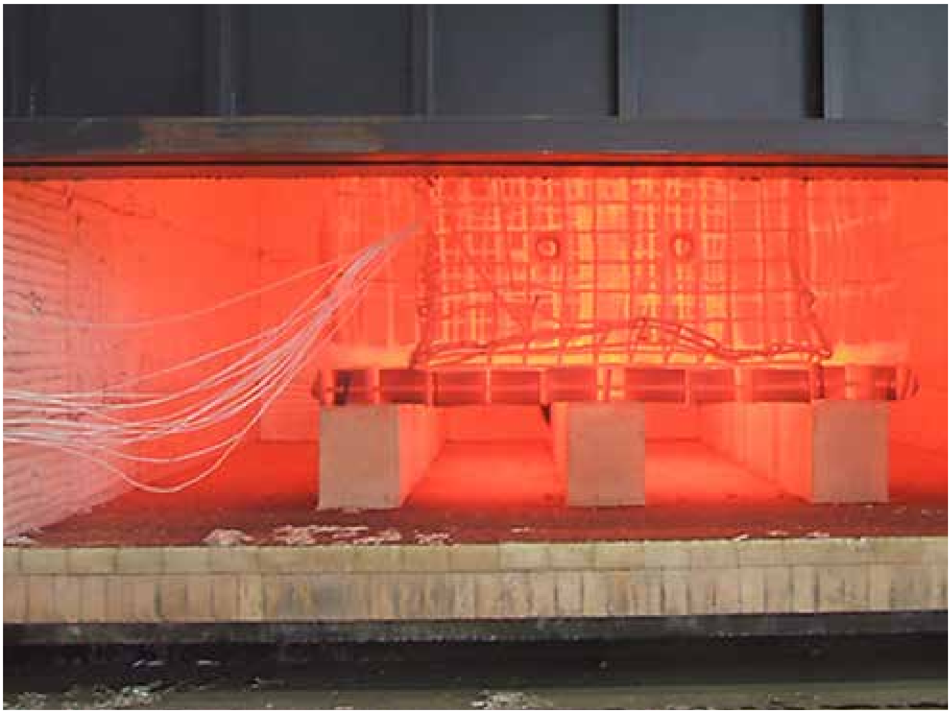
Keeping thorough test records key to resolving issues

Record retention is an important part of quality. Quality is tasked with keeping records of periodic tests performed on all equipment used for heat treatment and verification of heat treatment. These records are our objective evidence that required tests were performed in accordance with the referenced standards. Sometimes it's a statutory or regulatory requirement to retain documentation for a certain period. It can also be required by one of your customers; it all depends on the contracts you accept.

Regardless of what is required of you, it's widely understood that these records are important to the traceability of jobs and maintaining process approvals through compliance of these requirements. However, there is an added benefit to the quality department in keeping these records. In this article, I will identify two areas where retention of these records can help you troubleshoot nonconforming periodic tests. In my opinion, the two most important tests would be temperature uniformity surveys and hardness indirect verification.

Let's start with temperature uniformity surveys (TUS). For the sake of the article, let's assume that everyone requires AMS 2750 for qualification of furnaces. Depending on your furnace class or type of material you are processing, there are specific uniformity characteristics that must be met for your furnace to be certified to AMS 2750 — depending on its furnace class. I can say with confidence that everyone has dealt with a failing test at one point — if not many more — in their career. Longevity at your job will affect the frequency of this occurring but make no mistake about it, it will happen. You could have an overshooting test temperature that is outside the bounds of tolerance, or you have a test temperature that is too low outside the bounds of tolerance. What can you do at this point? The obvious answer to most would be to start with containment and stop all processing in that furnace, followed by contacting all customers who have had jobs in that furnace since the last passing TUS. Product impact can be done in various ways, and is mostly dependent on how your system works.

After these steps are complete, how can you get your furnace back into compliance with AMS 2750? Repair may or may not be required, but you need to know where to start. This is where record retention comes into play and can help you determine the best course of action. The records you maintain have important data on the functionality and efficiency of your furnace. Think of it as an ongoing report card that tracks how well your furnace performs. The data from your furnace can exhibit similar uniformity characteristics with each successful TUS, but the data will never be identical. This is where historical data comes into the picture. By isolating the failed TUS sensor, you should be able to make some type of chart or graph that tracks the drift using data from the sensor's history. Your chart or graph should show you where the drift of temperature is occurring and at what point it started to go in either direction. Personally, I like to use an Excel worksheet and color code temperatures to fit my needs, but there are many ways to accomplish this. It all depends on what works best for you. From there it's up to you to decide how that data is interpreted and what course of action you plan to take.



Temperature uniformity surveys (TUS): Depending on your furnace class or type of material you are processing, there are specific uniformity characteristics that must be met for your furnace to be certified to AMS 2750 — depending on its furnace class.

Indirect verification of hardness testers is another area where the records you maintain can help you identify causes of a nonconforming test.

Indirect verification of hardness testers is another area where the records you maintain can help you identify causes of a nonconforming test. If you are testing in accordance with ASTM E18, there are two ways you can use your records to help you. The two methods are your daily verification records and your periodic indirect verification records. My company uses ASTM E18 for Rockwell hardness testing. This means we perform daily verification of our hardness testers. Although ASTM E18 does not require you to retain daily verification records, I strongly encourage it. As with your TUS records, by retaining your daily verification you can use that data to understand when your hardness testers start to exhibit erratic or failed readings. In my opinion, daily verification can identify problems much earlier than records for TUS. The reason is that the gap between conforming and nonconforming tests can be found as early as the same day when performing daily verification.

As an example, you could have a passing daily verification for a certain anvil, and on the same day see a nonconforming test on a different anvil. You could dive deeper and make a chart or graph (Excel in my case) that isolates each anvil used and see what the data tells you. It's all up to you and your style. There could be numerous causes for a failed test — it could be a damaged indenter, or the machine was somehow moved out of its intended position. No matter what the cause is, retaining your records will help you identify a nonconforming test on your hardness tester and prevent you from using it to verify your heat treatment.

I understand that drift is not always the culprit to a failed TUS, and failure of hardness verification is not always as simple as a damaged indenter or a moved tester. There are numerous causes for each scenario. However, the records you keep are something that can help you when these situations happen. I have a philosophy that there is no such thing as too much data when it comes to quality. The more information you have and retain, the more prepared you are when failures occur. As I mentioned earlier, your longevity in quality will expose you more and more to these situations but you will have an arsenal of data to help you mitigate them.

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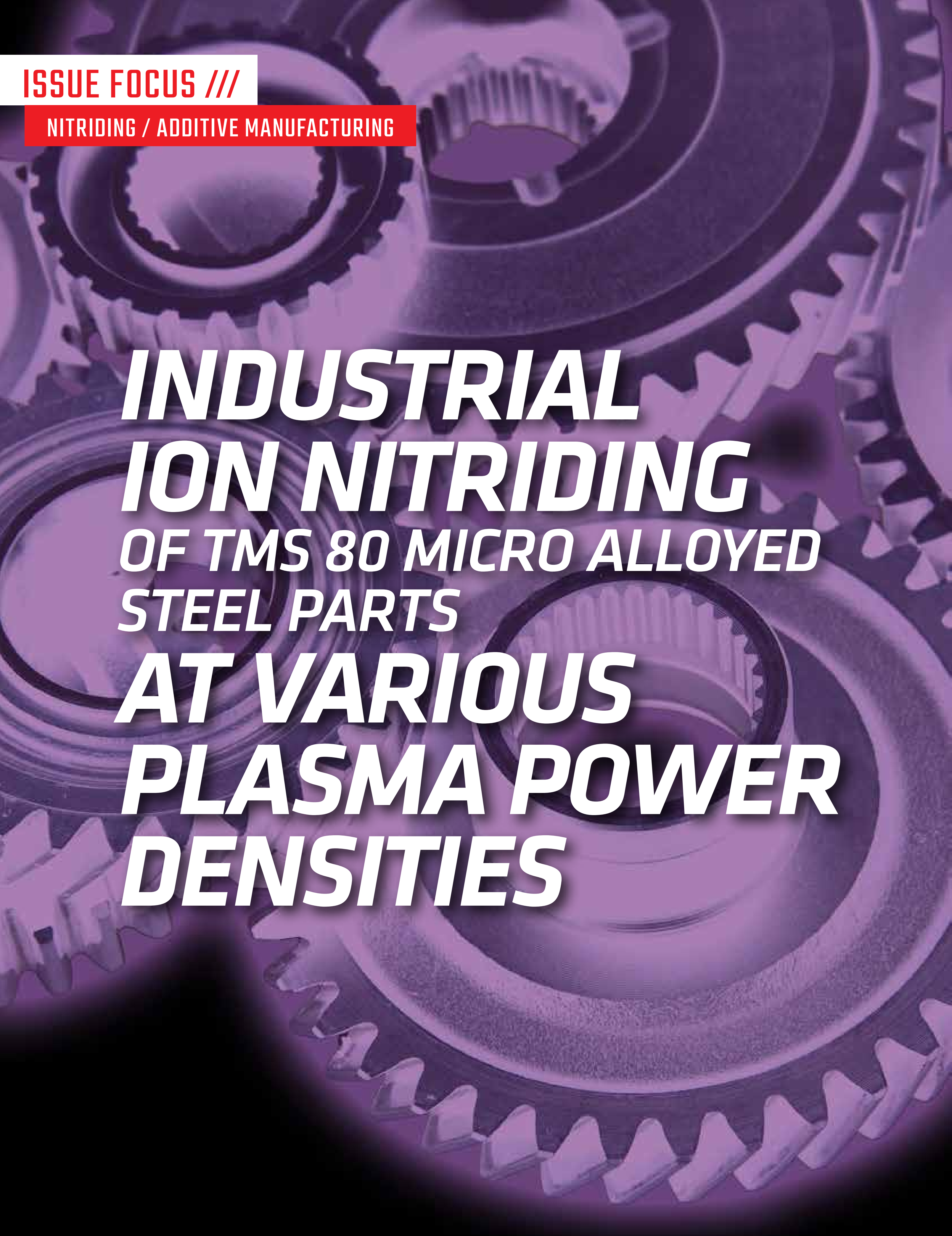


INDUSTRIAL ION NITRIDING

OF TMS 80 MICRO ALLOYED STEEL PARTS

AT VARIOUS PLASMA POWER DENSITIES

In the tested range, plasma power/current density has no effect on the case depth when the other remaining nitriding parameters are kept constant.

By E. ROLIŃSKI, C. CLARK, and M. WOODS

Control of the ion nitriding process is typically based on temperature of the work piece, composition of the gas mixture, gas pressure, nitriding time, gas flow rate, plasma frequency, and duty cycle. It has also been known that plasma density may have an effect on the thickness of the nitrided layer and specifically the compound zone formed at the surface [1-6]. However, plasma parameters, such as power or current density, cannot be considered as the values, which could be controlled easily during the regular processing of the commercial load. The published results were based rather on laboratory than industrial values. Literature on this subject is rather limited and vague. A. Marciniak investigated cold-wall systems and the effect of power density in the range of 0.61 to 1.16 W/cm^2 on the case depth and compound zone thickness in Nit135M and 3%Cr steels and concluded there was no effect on nitriding results. J. Conybear and B. Edenhofer tested the same issue in a hot-wall system in a power density from 0.23 to 0.87 W/cm^2, showing that the higher power density increases the thickness of the compound zone in several steels including 4140. They did not elaborate on the case depth but mentioned there was no effect [6].

It seems to be very obvious that, in industrial applications, the power density varies from one system to another and depends on the load size, density, its configuration, as well as the nitriding mode. However, in the systems without auxiliary heating — the so-called cold-wall vessels — power density can be controlled in a very limited range by using the mode with the cathode shields-off and the mode with the cathode shields-on.

It could be expected that how the heat is delivered to the cathode may play a role in formation of the active nitrogen spices reacting with the cathode. The heat balance can be written in the following way:

$$Q_{CATHODE} = G_{GLOW} + Q_{SHIELDS\ RADIATION}$$

Formation of the active nitrogen species such as N_2^+, $N_xH_y^+$ ions, active nitrogen atoms as well as NH_3 molecules by the glow discharge, depends on its density. Also, the heat delivered to the cathode directly from plasma only, $\mathbf{G}_{GLOW}$ is larger than the heat delivered by plasma when a significant radiation from the shields is added. Therefore, larger glow discharge intensity on the cathode may increase the quantity of the active nitrogen species resulting in a thicker compound zone/diffusion zone. A typical heating and nitriding in the cold-wall system equipped with the cathodic shields is shown in Figures 1-2.

The main purpose of our investigation was to test the effect of power density on nitriding results in these two modes:

1) Cathode shields-off with the base-on in the industrial-size ion nitriding furnace.

2) Cathode shields-on with the base-on in the same furnace.

EXPERIMENTAL

The experiments were carried out at constant temperature of 499°C (930°F) and 460°C (860°F) with 20% nitrogen, 80% hydrogen, at pres-

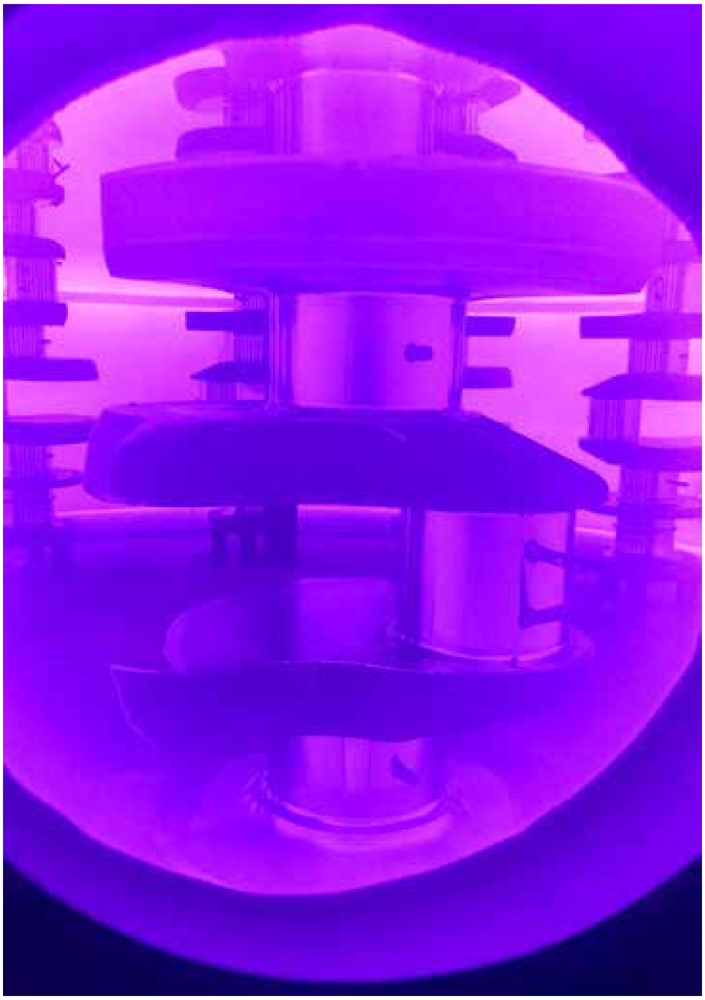


Figure 1: Preheating of the load of crankshafts with cathodic shields.

Figure 2: Load of crankshafts at final nitriding temperature with the full base-on cathodic polarization.

sure of 3.46 mbar (2,600 microns) and a nitriding time of 48 hours. Ramping details were identical, and the processing was carried out with a frequency of 7.143 kHz. The first experiments were carried out in the "base-only" mode, and the second experiments were with the "base and shields" mode.

The samples used for the experiment were a portion of the actual production crankshaft ("nose"), which are made of quenched and tempered TMS 80 micro alloyed steel. Both samples were sand blasted before each cycle. Every sample had a hole of the same depth of 30.8 mm for the thermocouple as shown in Figure 3.

Special care was taken to make sure the samples and their arrangements in the vessel were identical in all tests and that the only difference between both groups of tests was the difference in the power (current) density. Run data analysis confirmed both experiments were like mirror copies of each other.

Both samples were sectioned in the area at the end tip of the thermocouple and tested metallographically. There were two areas tested in each sample: one referred as a "flat surface," and the other referred as the "round surface." Microhardness was tested using a Knoop indenter and a load of 200 g. For better statistical validity of the tests, there were two technicians involved in testing of each sample. The data was plotted for each sample using a TableCurve2D® statistical program. The same curve-fitting equation number, 8090 (Asym Sigmoid), was used for plotting all graphs. The 95 percent level of statistical confidence was used to plot the confidence and predictive intervals on the graphs. The confidence interval is the region in between the two blue lines, and it deals with the estimate of the fitting function. The prediction interval is the region in between the two pink lines, and it deals with the data. The total case depth was determined using criterion core hardness plus 50 HK0.2 based on the hardness profile calculated from the best-fit equation for a given data set.

Mode	Shields on		Base-only (Shields off)	
Cathode Set Point Temperature, °C/°F	499/930	460/860	499/930	460/860
Shields Temperature, °C/°F	382/720	340/644	<220/428	
Plasma Power Density W/cm2	0.4	0.3	0.6	0.5

Table 1: Temperature and plasma power density of the ion nitriding experiments.

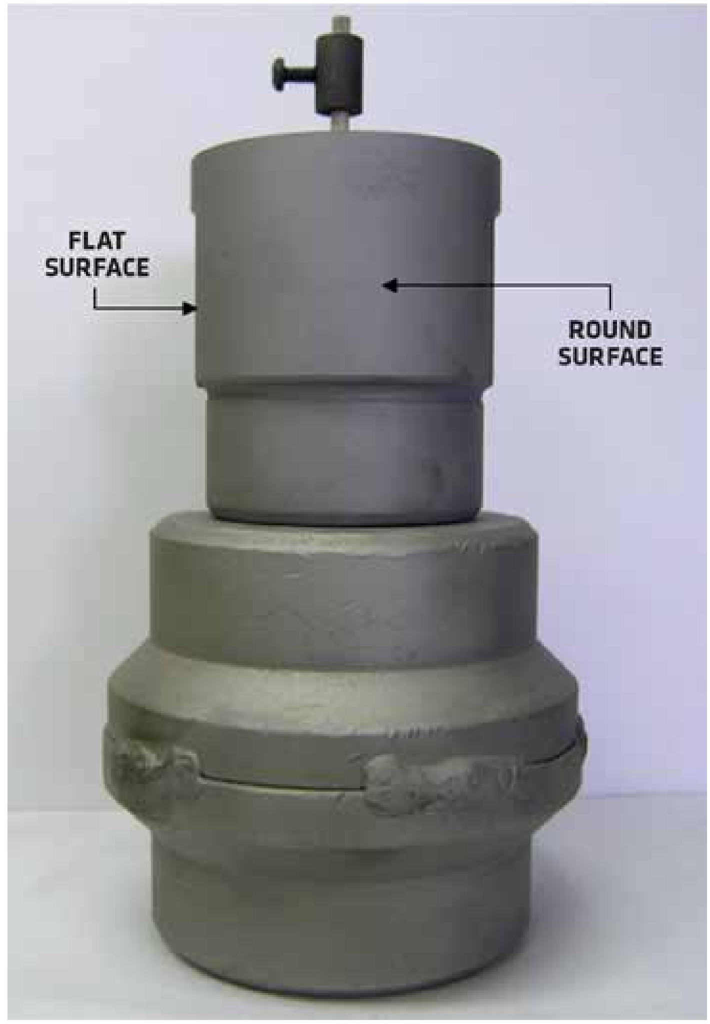


Figure 3: Arrangement of the sample complete with ceramic and splitter.

RESULTS AND DISCUSSION

Pre- and post-hardness data for both samples are presented in Table 2. They were taken on the flat and round portions of the samples. (Figures 4-7)

The results indicate that there might be small differences between the two samples. Are these differences statistically significant? Can it be justified to say the "base only" mode produces better results, deeper case depth, hardness, etc., than the "base and shields" mode? The hardness data seen in Table 1 seems to be almost identical. The HR15N results are different only by 0.3 for the flat surface samples and by 0.4 for the round samples. The hardness of the samples in HR30 N is similar. We can then conclude the hardness data justifies us to say there is no difference between the samples.

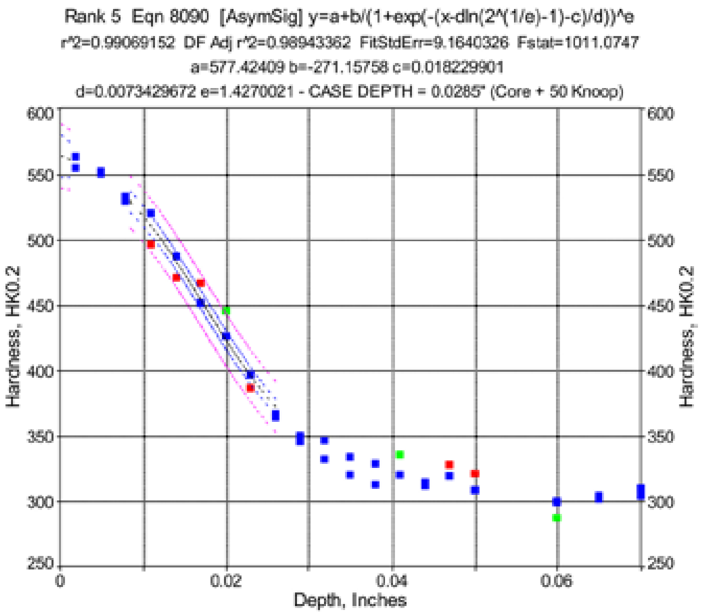
The case depth data summarized in Table 3 may look, at first, as if there are more significant differences between the two samples. Are they really significant? The case depth results vary from 0.0238 to 0.0285". The data produced by Person 1 and Person 2 are not exactly from the same location of one sample but from the eight locations of the four different samples. Therefore, there are several potential errors cumulated here:

1) Effect of surface preparation on diffusion rate. The flat surfaces of the samples were machined (milled) after a turning operation applied to the round surfaces. They are then not identical even if both of the surfaces were blasted before nitriding. We must not exclude there is no difference in the nitriding rate between such prepared surfaces. Perhaps the most "distorted" steel (flat) has a slightly higher rate of nitriding than the round steel. This may actually be true. When we look at the case depth data for the flat surface sample only, we can see the results are systematically higher than for the round surface

M10877J (Base-Only)	Pre-Nitride (HRC 150kG)	Post-Nitride (HR15N)	Post-Nitride (HR30N)
Flat	27.2	86.6	70.1
Round	26.5	86.2	70.3

M10992J (Base & Shields)	Pre-Nitride (HRC 150kG)	Post-Nitride (HR15N)	Post-Nitride (HR30N)
Flat	27.2	86.6	70.1
Round	26.5	86.2	70.3

Table 2: Average (of 3 results) surface hardness of the samples nitrided at 499°C (930°F) in the "Base-Only" (M10887J) and "Base and Shields" (M10992J) modes.



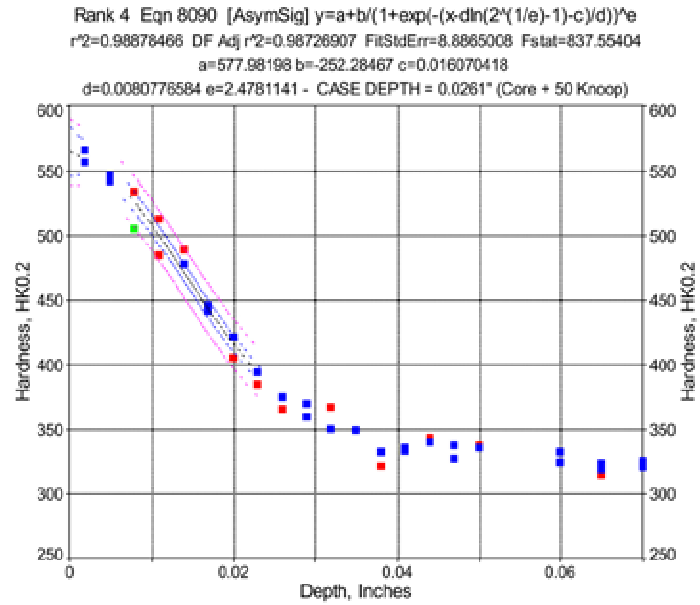
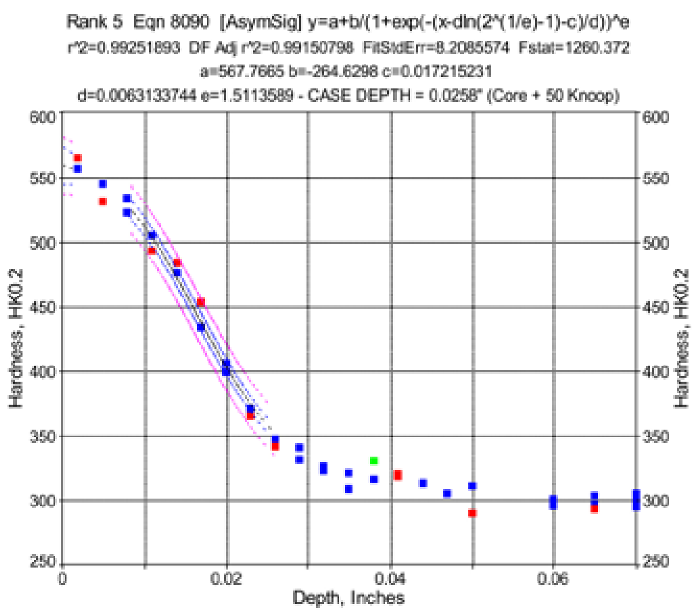


Figure 4: Hardness profile of the flat surface sample nitrided at 499°C /930°F in the "Base-Only."

Figure 5: Hardness profile of the round surface sample nitrided at 499°C /930°F in the "Base-Only."



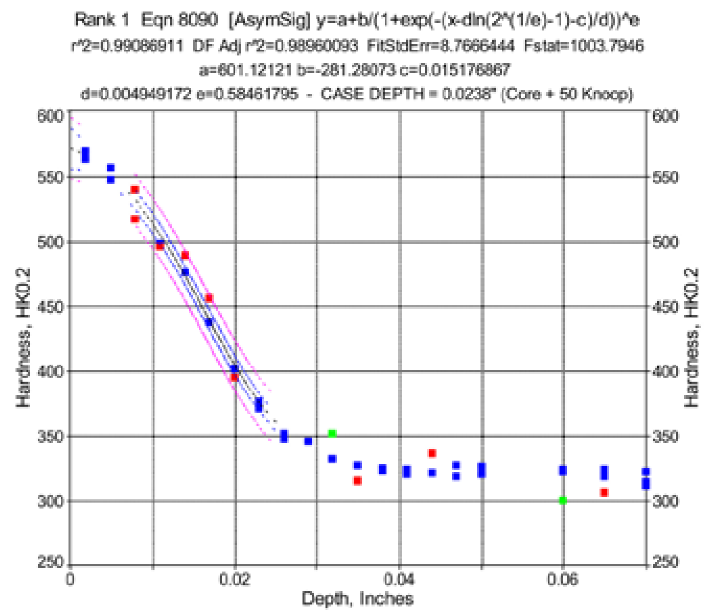


Figure 6: Hardness profile of the flat surface sample nitrided in the "Base & Shields" mode.

Figure 7: Hardness profile of the round surface sample nitrided in the "Base & Shields" mode.

Sample Identification	Case Depth, inches/mm
Base Only-Flat*	0.0285/ 0.655
Base Only-Flat**	0.0265/0.673
Base Only-Round*	0.0261/0.663
Base Only-Round**	0.0247/0.627
Base & Shields-Flat*	0.0258/0.655
Base & Shields-Flat**	0.0284/0.721
Base & Shields-Round*	0.0238/0.605
Base & Shields-Round**	0.0255/0.648

Table 3: Total case depths as calculated from the best-fit curves for the "Base-Only" (M10887J) and "Base and Shields" (M10992J) runs.

(*) Indicates testing Person 1 and (**) for testing by Person 2.

M10877J	Compound Zone Depth (μm)	Standard Deviation (μm)
Flat	7.94	0.41
Round	7.83	0.22

M10922J	Compound Zone Depth (μm)	Standard Deviation (μm)
Flat	8.40	0.26
Round	8.10	0.23

Table 4: Average compound zone depths (10 measurements per sample) complete with standard deviations from the "Base-Only" (M10887J) and "Base and Shields" (M10992J) runs.

Figure 8: Photomicrograph of a typical near-surface zone in one of the samples. Nital etched. Note uneven thickness the compound zone, which demonstrate how difficult is to determine accurately its thickness.

sample and are independent from the person doing the actual testing. These results for the flat surface are in the range from 0.0258 to 0.0285”. The similar results for the round surface are in the range of 0.0238 to 0.0261”.

2) Lack of structural homogeneity of the steel. It is very likely the steel does not have a perfectly uniform grain structure, exactly identical chemistry, etc., and this statement is supported by the hardness “pre-nitride” results. They are close but not identical. This is absolutely normal and is very well described by the sentence: “Heat treatment is not exact science.”

3) Systematic difference between testing persons. There was no systematic difference in the testing between the persons involved, like one person always testing deeper than the other one; Person 1 vs. Person 2. They both had systematically slightly deeper cases in the flat sample than in the round sample. This supports conclusions of error 1 above. Since both of them had also rather contradictory results of the round samples, Person 1 had a slightly deeper case in the “base-only” sample than the “base and shield” sample, and Person 2 had it reversed; we can conclude there was a difference in between the round samples.

Differences in compound zone thickness are very minimal as shown in Table 4. The thickness achieved in the “base and shields” mode might be a little higher than in the “base-only” mode. However, all the data for two of the modes of nitriding are in the range of ±3 standard deviations. Also, careful examination of the microstructure shown in Figure 8 illustrates very well how much variation is in the compound zone itself. We can assume then, statistically, the results are identical.

RESULTS OF ION NITRIDING AT 460°C (860°F).

The same size sample was nitrided at 460°C (860°F), which was recorded as the lowest temperature occurring in the load of production runs. As it is verified, the runs were extremely stable and exactly at the required temperature.

The “shields and base” nitriding mode was used, and the remaining processing parameters were kept the same as in previously described experiments. Hardness profiles curves are presented in Figures 9 and 10. As it can be seen from the graphs and Table 5, the case depth is at the bottom of the specification, which is 0.5 mm (0.01969”) or slightly below it.

The results presented in Table 6 demonstrate one more time there is a small variation in the case depth in the sample itself and more likely a variation in testing and between the people conducting the test. All this conforms to our prior statements.

Conclusions of this last experiment are there was no difference in nitriding response between “flat” and “round” sample nitrided at 460°C (860°F).

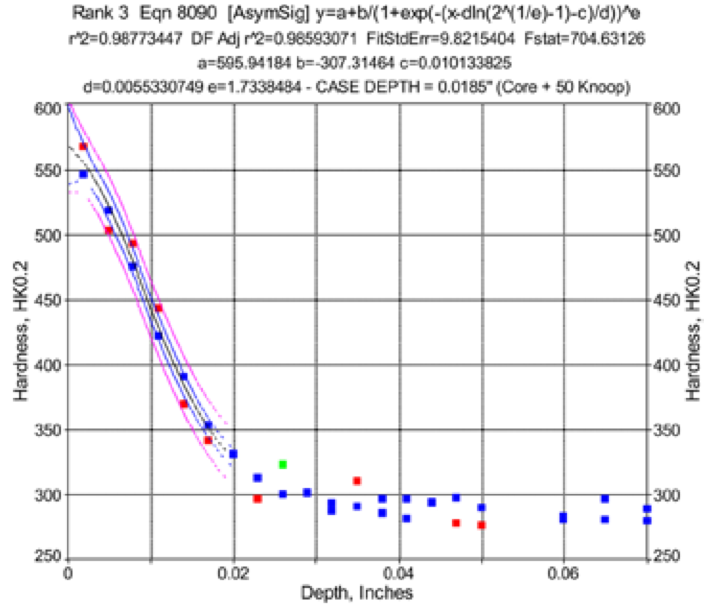


Figure 9: Hardness profile of the round surface sample nitrided at 460°C (860°F) in the “Base & Shields” mode, as tested by Person 1.

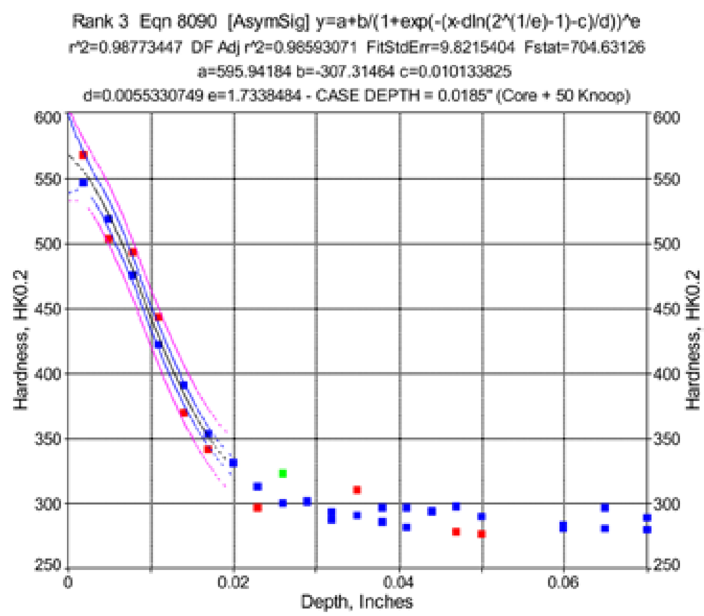


Figure 10: Hardness profile of the flat surface sample nitrided at 460°C (860°F) in the “Base & Shields” mode, as tested by Person 1.

FINAL CONCLUSIONS

The results confirmed that in the tested range, plasma power/current density has no effect on the case depth when the other remaining nitriding parameters are kept constant. This is very likely the case in all the situations, where the structure of the nitrided layer contains both compound and diffusion zones.

In situations where the compound zone is not required (example tools made of M-2 or similar) or does not form (example austenitic stainless steels), the nitriding rate will depend on power density. The nitriding rate will be faster with a greater power density.

The effect of power density on thickness of the compound zone is not very clear. However, the literature data strongly suggests the thickness of the compound zone is increased when plasma power

Sample Identification	Case Depth, inches/mm
Base & Shields-Flat*	0.0185/0.470
Base & Shields-Flat**	0.0197/0.500
Base & Shields-Round*	0.0188/0.478
Base & Shields-Round**	0.0200/0.508

Table 5: Total case depths as calculated from the best-fit curves for "Base and Shields" for the sample processed at 460°C (860°F) (M11062J).

(*) Indicates testing by Person 1 and (**) for testing by Person 2.

M11062J	Pre-Nitride (HRC 150kG)	Post-Nitride (HR15N)	Post-Nitride (HR30N)
Flat	24.7	85.7	68.3
Round	26.5	85.5	68.4

Table 6: Average (of 3 results) surface hardness of the samples nitrided at 460°C (860°F) in the "Base and Shields" (M11062J) mode.

density is raised. The change of power density may also have an effect on morphology and phase composition of the compound zone, and this may have a potential effect on kinetics. There are some suggestions in the literature that this (different morphology and phase composition) has an effect on kinetics of gas nitriding.

REFERENCES

[1] E. Rolinski, G. Sharp, "Controlling Plasma Nitriding", ASTM International, Materials Performance and Characterization, Vol. 6, No 4, 2017, pp.698-716, https://doi.org/10.1520/ MPC20160051. ISSN 2370-1365.

[2] E. Rolinski, "Plasma Assisted Nitriding and Nitrocarburizing of Steel and other Ferrous Alloys", Chapter 11 in Thermochemical Surface Engineering of Steels, Ed. E. J. Mittemeijer and M. A. J. Somers, Pub. Woodhead Publishing, 2014, pp 413-449.

[3] B. Edenhofer, 1996, Process and apparatus for controlling the electric current density in plasma processes, Patent DE 19 52 1548 and EP 749 147.

[4] A. Marciniak, (1983), 'Processes of heating and nitriding of the cathode during glow discharge diffusion treatment'. Doctoral Thesis, Ed. Politechnika Warszawska, Warsaw, Poland, in Polish.

[5] B.Y. Jeong and M. H. Kim, (2001), 'Effects of pulse frequency and temperature on the nitride layer and surface characteristics of plasma nitrided stainless steel', Surface and Coatings Technology, 137, 249-254.

[6] D. Günther, T. Hirsch, F. Hoffman and P. Mayr, (1998), 'Einfluß der Plasmaparameter auf die Schichtstructur beim Plasmanitrocarburiren.' Härterei Technische Mitteilungen, 53, 4, 203-210.

[7] J.G. Conybear and B. Edenhofer, (1988), 'Progress in control of plasmanitriding and –carburizing for better layer consistency and reproducibility', Proc. 6th International Conference on Heat Treatment of Materials, 28–30 Sept. 381-394.

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ADDITIVE MANUFACTURING AND ITS ROAD TO INDUSTRIAL MATURITY

The 2022 Rapid + TCT Exhibition Tour organized by AGMA presented an update and some significant advancements of the metal AM industry.

By JUSTIN MICHAUD

The American Gear Manufacturers Association's (AGMA) Emerging Technologies Committee (ETC) recently organized a show floor tour of the Rapid + TCT Exhibition (Rapid). The ETC's 3D Printing Sub-Committee (3DPC) has been monitoring the developments in the additive manufacturing (AM) industry for several years, providing AGMA members with distilled industry updates via webinars, white papers, and other news updates. The 3DPC previously arranged a tour of Rapid in 2019 where members visited booths of a wide range of AM companies including machine OEMs, materials designers, independent printing shops, and post-processing suppliers. The conclusion at the time was that polymer/plastic AM for tooling, jigs, and fixtures was an established application with strong potential to aid gear manufacturers, gear users, and adjacent gear manufacturing suppliers. However, metal AM had limited traction relative to gears at the time, for several reasons:

- Standard gear alloy availability for AM was limited (despite general availability for non-AM powder metal applications).
- Printing resolution limitations dictated that any precision gear applications would require subsequent machining steps.
- Printing costs were considerably higher than traditional manufacturing methods excluding special-case, small lot batches.
- Printing quality ranging from parameter optimization, to in-process monitoring, and even post-print inspection was an additional challenge creating more costs/hurdles for gear application adoption.

As a result, the 3DPC and the ETC determined that AM should continue to be watched, but was not likely to have a significant impact on AGMA members' business in the near term.

However, as a fast-moving and developing industry, much has changed in AM in recent years. Thus, the 3DPC organized another Rapid tour this year. Mary Ellen Doran, AGMA director, Emerging Technology, arranged for members of the 3DPC to visit a range of AM and AM-related companies, including: 3DEO, Desktop Metal, SPEE3D, JEOL, DM3D Technology LLC, Nidec Machine Tool, Hoganas, AddUp, MELD Manufacturing, QuesTek Innovations, FormAlloy, RPM Innovations, and REM Surface Engineering. The committee wanted to focus heavily on two areas — large-format metal AM technologies and binder jetting — while also visiting with new industry entrants and relevant adjacent suppliers such as powder manufacturers, material designers, and surface finishing technology providers.

'OF-INTEREST' TECH

Large format metal AM technologies such as directed energy deposition (DED), cold spray, and friction stir welding were deemed "of interest" to the committee due to their potential to serve in a repair capacity for large-scale gearing. Sourcing replacement components for any low-volume application is very difficult. Large-scale gearing fits this mold and has the additional challenge of being (typically) very expensive given the obvious material demands and limited supplier options. Thus, a potential gear repair option for significantly damaged large gears where material addition would be required would be of interest.

Binder jet gear example printed by Azoth 3D and polished by REM Surface Engineering's Extreme ISF® Process.

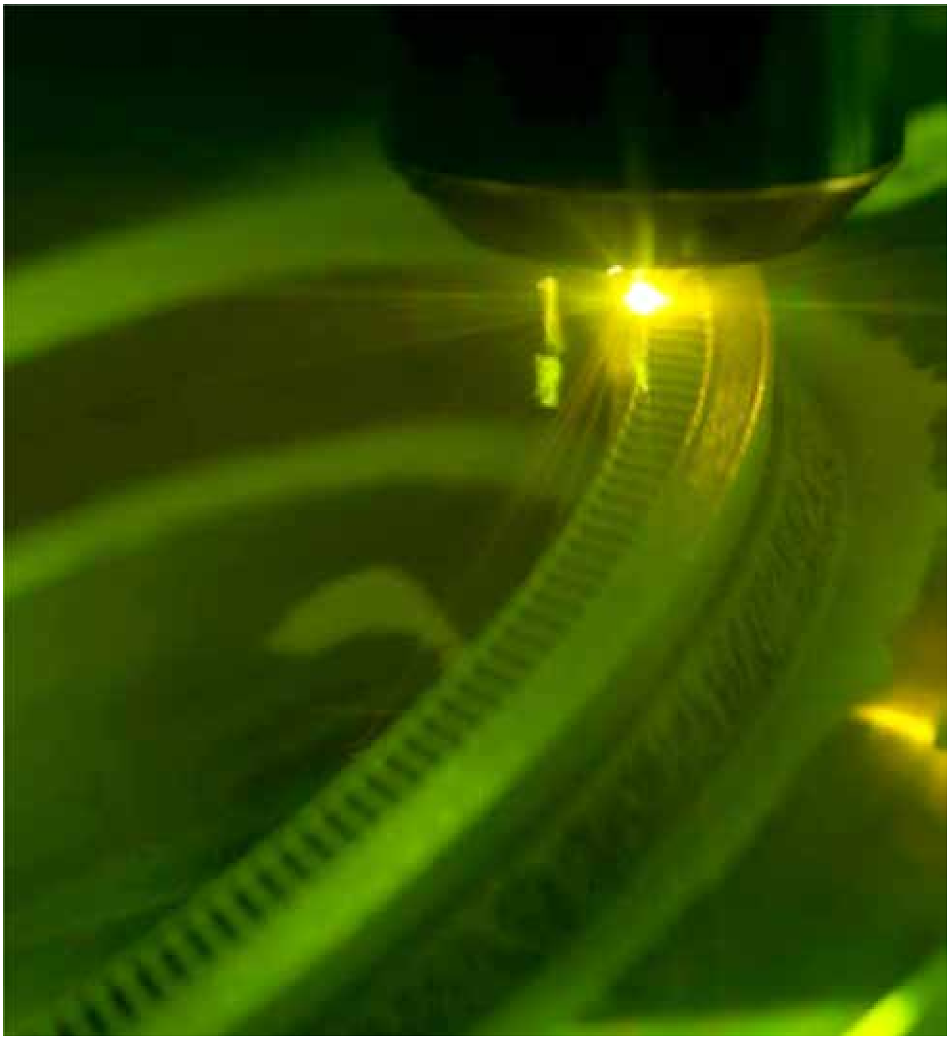
Binder jetting, on the other end of the spectrum, has been known as the "fastest" and "lowest cost" metal AM technology for some time. However, prior reviews of the technology have not shown significant use in the gear industry due to some known challenges relative to the required sintering operations as well as reduced material properties as compared to wrought/forged materials. Therefore, the committee was interested to understand what developments and/or maturation had occurred relative to binder jetting.

Lastly, it was determined by the committee prior to attendance that L-PBF technology remained unlikely to significantly impact AGMA members outside of specialty cases; thus, AddUp was the only L-PBF machine manufacturer visited as they were not visited on the previous (2019) tour and they also offer laser blown powder directed energy deposition (LBP-DED) machines.

HIGH-VOLUME APPLICATIONS

The 3DPC started the tour with binder jetting/binder jet-like companies 3DEO and Desktop Metal. Both companies were a part of the 2019 tour, and thus provided interesting insight into the rate of change/advancement in metal AM. Committee members learned of advances made by both of these companies to increase productivity, part quality, and alloy range — all features that contributed to the 3DPC's prior conclusions that AM was not "ready" to strongly impact gear manufacturing. 3DEO's commitment to serial production as both a machine maker (although not currently a machine seller) and a user of the technology provided a strong perspective on the potential to use AM for high-volume applications. Desktop

Metal's newer machine offerings, the Shop System™ and Production System™, boast industry-leading deposition rates and offer flexibility to users based on their build-bed volume, which allows for multi-part batches and nesting. In both cases, part size is still a limiting factor due to sintering challenges that exist with larger parts; it should be noted that this challenge is present for essentially any binder jetting applications and is not limited to 3DEO/Desktop Metal. However, in both cases, potential gear materials exist, and for non-high speed/high load applications with medium- to high-volume demand, binder jetting is a valid forming technology to consider. Given the inherently lower density of binder jetting, it is not likely to be a preferred option for most high load gear applications, but there certainly are MIM and similar powdered metal gears where binder jetting should see application growth in the coming years.



In-process image of laser blown powder directed energy deposition. (Courtesy: RPM Innovations, Inc.)

SPEE3D was the tour's next stop. SPEE3D is a relatively new entrant into the additive manufacturing industry. They use cold spray technology rather than sintering or melt-based forming techniques. Cold spray was invented in the 1980s and has been used for repair and coating applications for some time. It functions by shooting metal particles onto a surface at supersonic speeds in order to create a metallurgical bond. The technology is interesting, in part because the bonding process does not require heat or create heat-affected zones (as would be produced by welding operations). Recent developments (many SPEE3D) have brought cold spray to market as a part fabrications technique, using a multi-axis robotic deposition nozzle and a rotating, multi-axis build plate. In addition to being a non-thermal/melt-based forming process, cold spray is exceptionally fast. The 3DPC was able to watch a part being built in its entirety during the roughly 10 minutes that we were at SPEE3D's both. The drawbacks of cold spray are that it tends to be more effective/viable with softer metals such as aluminum and copper alloys, and it is generally not as dense as L-PBF, EBM, or traditionally machined components. SPEE3D does, however, list some hardenable stainless steels within their material capabilities. And, taking its deposition speed advantages into consideration, it is a technology worth considering for large, specialty gear repair operations where a tooth (or teeth) needs to be rebuilt and/or in the event a gear blank cannot be obtained quickly enough to address an immediate production downtime event. Subsequent machining operations would be required to eliminate the fairly pronounced layer lines present on cold spray components. As a result, outside of non-standard situations, cold spray is not likely to have a major impact on the gear-manufacturing industry in the near future without additional steel materials being available.

ELECTRON BEAM MELTING

JEOL USA/Ltd. was the tour's next stop. JEOL is the first "industrial-focused" electron beam melting (EBM) machine supplier to enter the market since Arcam AB — now a part of GE Additive. The EBM process differs from the L-PBF process in a number of ways, including its powder/melting source (electron beams), its build atmosphere (heated vacuum), and its standard powder size (large than L-PBF). Outside of some very notable, large-scale aero-engine applications (the GE9X's lower pressure turbine blades), EBM has noticeably lagged behind L-PBF in its industry adoption. The 3DPC wanted to visit JEOL and understand what their machine may bring to the table as compared to existing EBM equipment as well as well-known L-PBF equipment. While EBM is certainly a good technology for many potential applications, its build time (as with L-PBF) limits its potential gear applications, and the alloy capabilities (primarily limited to titanium and nickel-chrome alloys) are largely not applicable to the gear industry. The 3DPC did not find any major differences or advancements with the JEOL EBM machine that would sway the pre-existing conclusion that neither L-PBF nor EBM are likely to have significant impact on the gear-manufacturing industry, but it is good to see growth of machine supply in the EBM space. Further, if JEOL is able to increase EBM use and establish broader availability of gear steels, especially high heat resistant/high strength specialty steels such as Ferrium® C64 or Pyrowear® 53, then it may become a more interesting technology for high-strength gear applications.

An additional tour stop was MELD Manufacturing. MELD, like JEOL, is a new entrant to the AM market. They are industrializing friction stir welding as an additive manufacturing process. Friction stir welding is a solid-state joining/deposition process that functions by rapidly rotating a tool which deposits a material onto a specified

As-printed/heat treated image (top) and after REM Surface Engineering's Extreme ISF® Process image (bottom) of a LBP-DED rocket nozzle. (Courtesy: NASA MSFC)

surface. The friction-generated heat causes the material being deposited to rapidly melt (and subsequently cool) allowing for the joining of dissimilar materials, the addition of new part features on already fabricated components, and the building of wholly new components. As the process uses bar stock, it theoretically has an extremely wide range of material options, including gear steels. However, gear steels were not listed in MELD's material capabilities, nor were they currently a focus for the company. As with cold spray, while there is obvious potential for friction stir welding to be applied to large gear tooth repair and/or large gear blank/near net shape component fabrication, the technology does not appear ready to impact the gear-manufacturing industry strongly at the moment.

Based on the 3DPC's interest in DED, a number of suppliers were visited on the tour including AddUp, DM3D, FormAlloy, Nidec Machine Tool, and RPM Innovations. The 3DPC was primarily interested in understanding these companies' capabilities for their laser blown powder DED (LBP-DED) equipment as this technology offers considerably higher part resolution as compared to wire-based DED. Similar to cold spray and friction stir welding, LBP-DED can be used as a repair (i.e. component feature rebuilding) process or as a new component forming process. Recent developments with LBP-DED relative to the fabrication of large-scale rocket nozzles and member experience regarding the advancement/improvement of deposition accuracy and surface finish drove the 3DPC's interest in this technology. Tour observations confirmed many of the committee members' understandings and assumptions relative to LBP-DED, most notably that it represents, currently, the best option for AM-based large gear repair due to it being available for numerous suppliers as well as being a generally established technology, and having attractive deposition rates and accuracy (minimizing post-machining requirements). A current drawback is that there are not many steel material options that are "developed" for LBP-DED, but there are some (maraging steels/tools steels) as well as a number of hardenable stainless steels. FormAlloy even offers a custom new material development print head specifically designed for rapid, new parameter development. Thus, the 3DPC would encourage large gear users and gear manufacturers to investigate LBP-DED as a potential technology to support their repair/replacement/refurbishment needs.

METAL POWDER PRODUCTION

Lastly, the tour visited three AM suppliers not directly related to primarily part-forming operations: Hoganas, Questek Innovations, and REM Surface Engineering — all members of the 3DPC. Hoganas is a well-known leader in metal powder production. They shared information with the 3DPC about their steel materials with potential applicability to gear applications such as 16MnCr5. Questek Innovations is a leading materials design company that uses an integrated computational materials engineering (ICME) approach to designing alloys for specific applications in the aerospace and energy industries (to name a few). Questek shared information about projects they are leading to qualify some of their Ferrium materials for L-PBF and binder jet gear applications. Lastly, REM Surface Engineering is a leading surface finishing supplier whose ISF® Process is widely used in precision gear applications and Extreme ISF® Process is a leading performance-enhancing AM surface polishing solution for rocket engine, aerospace, medical, and semi-conductor fabrication applications. REM shared updates regarding their new alloy processing and process scaling developments as well as current work on government awards including AM support structure removal and internal channel finishing. These three suppliers are currently and are expected to continue supporting and enabling the application of AM to gear applications in the near future.

SUMMARY

In conclusion, the 3DPC observed significant advancements and maturation of the metal AM industry. While it is certainly an industry still in need of industrialization relative to process control, repeatability, and costs, there are two defined avenues (large format gear repair/replacement and low criticality/small-sized gear production) whereby AM is ready to support gear manufacturing today.

ABOUT THE AUTHOR

Justin Michaud is president and CEO of REM Surface Engineering, where he works closely with the research team, supports REM's government projects and awards, and focuses heavily on REM's surface finishing solutions for metal additive manufacturing applications. Michaud serves on the American Gear Manufacturers Association (AGMA) Emerging Technology Committee and is the chair to the 3D Printing sub-committee. He is an author of multiple technical papers on topics including additive manufacturing, isotropic superfinishing, gear failure modes, surface texture and measurement, high value gear repair, and the superfinishing of high hardness steels.

ADDITIVE MANUFACTURING
NEW FRONTIERS FOR PRODUCTION AND VALIDATION

AM parts have a unique set of characteristics that render traditional measuring technologies impotent in some situations, and today innovative metrology technologies are being developed that can provide meaningful measurement data efficiently and cost-effectively.

By PETER DE GROOT

Over the last few decades, additive manufacturing (AM)/3D printing has fundamentally changed the way that manufacturers approach product development. Industry is now almost universally aware of the term rapid prototyping, using AM to convert 3D CAD data into physical models in a matter of hours. The role of AM in prototyping has become embedded across all industrial sectors.

AM has enabled concurrent engineering — where all relevant departments can be engaged early in the product development process. Concurrent engineering replaces traditional "over-the-wall" product development, where design iterations could be delayed by weeks to accommodate tooling and machining considerations. The benefits are dramatic time-to-market reductions and cost savings in product development.

AM is a uniquely disruptive technology; 25-30 years ago, it changed the manufacturing paradigm by altering the way that manufacturers produced prototypes. Today, it is disrupting the way that manufacturers produce end-use parts and components and is increasingly seen as a truly viable production technique. Now the conversation among manufacturers is around the most judicious use of AM for production, its advantages, the sweet spot in terms of production volumes, key opportunities, and barriers to entry. Many of these barriers relate to precision quality control of AM parts, which challenge traditional methods of surface metrology.

GOOD ENOUGH?

With the focus today being on the use of AM for production, the analysis of the accuracy and repeatable tolerance attainment of AM has become a far more critical issue. When used as a prototyping technology, absolute adherence to tolerances and precise design intent is not always necessary, and a "good enough" approach can be taken. Hence the proliferation of quite inexpensive desktop 3D printing machines that provide sufficiently accurate rapid prototypes that do the job without needing to be pitch perfect.

For production applications, however, "good enough" is no longer sufficient. If an AM part is integral to a safety critical aerospace or medical application, it is essential to achieve dimensional and material tolerance targets consistent with design intent. It is here that the role of metrology to validate the quality of finished parts is so important. It is also an area where providers like ZYGO of 3D optical metrology solutions can make a difference.

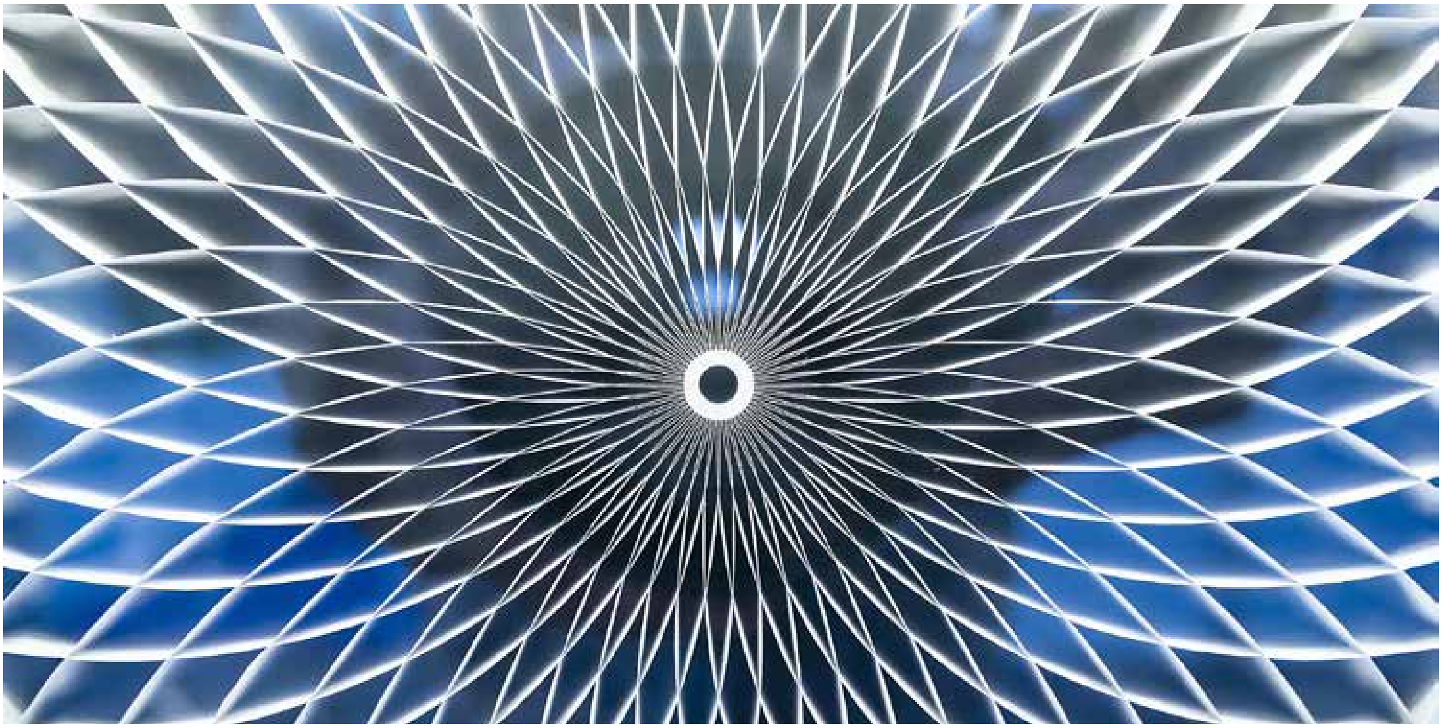
INDUSTRY RESPONSE

Legacy manufacturing processes for metals and plastics have established quality control methods for validating and measuring parts. The production processes are understood, as are the most critical dimensional and surface finish requirements. AM, however, does exactly what the name implies — it produces parts layer by layer "additively," and this opens up an array of unique issues that can affect the integrity of a finished product and also a unique set of surface characteristics that make the job of measuring and validating that much more difficult.

How the sector is responding to the metrology and validation conundrum was highly visible at the recent (and largest) AM-related event on the calendar, Formnext in Frankfurt, Germany. At various learning events on-site, metrology issues featured prominently, acknowledging the fact that measurement and validation of AM parts is a big deal today. In addition, AM technology providers are now developing in-process metrology (IPM) solutions to overcome the specialized challenges of verifying the integrity of AM processes.

If an AM part is integral to a safety critical aerospace or medical application, it is essential to achieve dimensional and material tolerance targets consistent with design intent. (Courtesy: ZYGO)

AM technologies and metrology techniques have also captured the attention of professional societies that organize conferences and symposia worldwide. These include the American Society of Precision Engineering (ASPE), the International Society of Optics



When compared to more familiar and established manufacturing methods, AM technology is dynamic and rapidly evolving. (Courtesy: ZYGO)

and Photonics (SPIE), and the International Academy for Production Engineering (CIRP). ZYGO participates in these events actively as an industry supporter, exhibitor, and presenter of scientific and engineering papers on the latest developments.

RESEARCH IN AM METROLOGY

In the search for relevant metrology critical to process control, industry is still trying to understand what to look for on and under the surface of an AM-produced part, and how these relate to part functionality. Surfaces of AM parts challenge existing surface topography measurement and defy characterization using standardized texture parameters because of high surface slopes, voids, weld marks, and undercut features.

Research into new and improved metrology for AM is advancing through a wide range of industry and academic partnerships, many in cooperation with ZYGO. An example is work at the University of Nottingham, where the Manufacturing Metrology Team (MMT) led by Prof. Richard Leach is investigating the full range of solutions, from high-precision interference microscopy to X-ray tomography of the internal structure of completed parts.

In just the past four years, MMT has published 43 research papers on AM, ranging from methods to optimize measurements on specific instruments to new feature-based analysis and machine learning to interpret results. Of particular interest is IPM for evaluating the quality during manufacture, following each additive line and layer in real time. This information can be used to inform control strategies and later in-process metrology developments. An important part of IPM development is correlating to reference metrology, including benchtop surface metrology instruments.

Another example of leading-edge research is at the University of North Carolina at Charlotte, where Prof. Christopher Evans and co-workers have been using interferometry and electron microscopy to study AM materials in collaboration with the U.S. National Institute of Standards and Technology (NIST) and Carl Zeiss GmbH at Oak Ridge National Laboratory (ORNL). These researchers have been studying Inconel 625 — a high-temperature Ni superalloy for AM that exhibits an intriguing variety of surface signatures. These surfaces have areas rich in oxide films that are visible in true-color, 3D surface topography maps obtained with ZYGO's interference microscopes. These instruments also serve as excellent workhorses for examining large areas with high detail, such as distorted weld pools, by assembling or "stitching" together multiple high-lateral resolution images, each with millions of data points.

While the challenges of quality control of AM parts are a great concern for those who make these parts, these same challenges present an attractive opportunity for new solutions and spinoff businesses.

While the challenges of quality control of AM parts are a great concern for those who make these parts, these same challenges present an attractive opportunity for new solutions and spinoff businesses. Founded in 2018 in the U.K., Taraz Metrology is an example of a spinoff enterprise that combines university research, practical engineering, and commercial experience into a unique product development capability customized to the needs of AM. Taraz offers freestanding final inspection solutions for all types of AM parts and leverages proprietary software for advanced fringe projection and photogrammetry of topography.

STANDARDIZATION AND TRACEABILITY

The ability of AM to produce geometrically complex parts, its role as an enabler of mass customization, and the potential time and cost savings associated with its use are all important for the future of industry. However, when compared to more familiar and established manufacturing methods, AM technology is dynamic and rapidly evolving, and technology innovators are working to overcome the barriers to the adoption of AM for production applications, including those related to quality-control standards.

ZYGO is actively researching calibration, traceability, characterization, and verification for surface topography measurements, with 16 papers published in the last five years alone on these topics, and a further seven specifically focused on physical modeling of optical measurements of surface structures — including complex, steeply-sloped surfaces characteristic of AM parts — and five more papers on the measurement of AM parts per se.

ZYGO is also a partner in the 2.2 million euro EMPIR 20IND07 TracOptic project, with the title “Traceable industrial 3D roughness and dimensional measurement using optical 3D microscopy and optical distance sensors” — of obvious value to the AM sector.

National and international standards are critical both to industry adoption and to assuring quality control across multiple, developing manufacturing technologies. ZYGO is an active member of ISO TC213 WG16 for the development of the ISO 25178 surface texture standards, working in collaboration with international experts on the ISO 25178-603 and 25178-604 standards for interference microscopy, and the 25178-700 standard for instrument calibration and traceability. ZYGO is also a member of the ASME B46.1 working group on surface texture analysis, which currently includes a task team concentrating on AM metrology standards.

With AM now an established production technology for certain applications, there are barriers to mass adoption that are being addressed, including the need for in-process and post-process metrology technologies that can validate the quality and accuracy of the parts produced. (Courtesy: ZYGO)

POST-PROCESS METROLOGY

Measurements of AM parts post-process serve to validate conformance with design intent and to provide clues into fabrication problems left by surface signatures. However, the uniqueness of AM processes and produced parts lead manufacturers to use an array of different mechanical and metrology verification techniques. They adopt an empirical approach as no one solution is trusted to provide accurate enough data. Gage R&R is used as a stand-in for a more rigorous measurement uncertainty approach. As a consequence, AM parts are often “over-tested” to improve confidence, but this means extra time and extra cost — areas that must be addressed to make AM for production more viable.

The open question is how to improve this situation for greater efficiency while maintaining confidence. The answer is for metrology solutions providers to adapt existing metrology technologies to better align them with the unique characteristics of the AM process and end-use AM parts, which are characterized by irregular, steeply sloped surface topography that many measurement technologies fail to capture.

Through extensive research and development of the foundational coherence scanning interferometry (CSI) technology in the ZYGO 3D optical profilers, high-accuracy AM metrology tools are now available to industry. Both instruments use innovative hardware and software upgrades, the package of improvements being referred to internally at ZYGO as “More Data Technology,” which makes the instruments much better suited to AM parts.

“More Data” significantly improves the baseline sensitivity of CSI and enables high-dynamic range (HDR) operation making it valuable for a wide range of parts, from steeply sloped smooth parts to exceptionally rough textures with poor reflectivity. Additionally, HDR measures parts with a wide range of reflectance, often a struggle for other instruments that use interferometry as a measurement principle. ZYGO was the first to demonstrate full-color surface topography measurement of metal additive manufactured surfaces using interferometry, and ZYGO engineers actively use AM internally for instrument prototyping and applications development.

SUMMARY

With AM now an established production technology for certain applications, there are barriers to mass adoption that are being addressed, including the need for in-process and post-process metrology technologies that can validate the quality and accuracy of the parts produced. AM parts have a unique set of characteristics that renders traditional measuring technologies impotent in some situations, and today innovative metrology technologies are being developed that can provide meaningful measurement data efficiently and cost-effectively. Only when such issues are addressed will the use of AM become mainstream as a viable production technology across an array of industry sectors and applications.

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ABOUT THE AUTHOR

Peter de Groot, Ph.D., is chief scientist at Zygo Corporation, which is owned by AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices with annual sales of approximately $5 billion. ZYGO designs and manufactures optical metrology instruments, high-precision optical components, and complex electro-optical systems, and Its products employ various optical phase and analysis techniques for measuring displacement, surface shape and texture, and film thickness. For more information, go to www.zygo.com.

CUSTOM DESIGNED HEAT-RESISTANT CASTINGS AND FABRICATIONS

If it's stainless steel going into heat-treat furnaces, Wiro can provide that. (Courtesy: Wirco)

Wirco has been trusted for more than 50 years to develop and manufacture high-temperature heat treatment tooling for numerous industries in the form of both castings and fabrications.

By KENNETH CARTER, Thermal Processing editor

Whether it's supplying stainless steel for furnaces or fabricating custom tooling, Wirco Incorporated has made its mission to be a one-stop shop for a wide range of heat-treating needs for more than 50 years.

"That's the unique part about Wirco," said Chris Dankert, vice president of sales for Wirco. "If it's stainless steel going into the heat-treat furnaces, we can provide all of that. We can provide the radiant tubes for the heating system. We can do all the tooling that holds parts, furnace trays, the fans that spin the atmosphere, and the entire roller rail and chain guide assembly that holds up the tooling inside the furnace."

For the stainless-steel parts needed for furnaces, Dankert said some of those items may be fabricated, and some of them may be cast, but most all of them are made per the specifications of Wirco's customers.

"We're a custom-tooling, custom-part manufacturer," he said. "If we have a particular heat treater that wants something a certain way, we make it exactly how they want it. We're not making thousands of things. We're making dozens of things. And that's always been a huge strength for us: to just to be adaptable to whatever our customers need. We make that a reality for them."

DEDICATED TO EMPLOYEES

To be able to take good care of its customers means Wirco must first take good care of its employees, according to Dankert.

"We have a very strong mandate that this company is 100 percent about the people who work here," he said. "We can't take care of our customers without people, so there's been a huge reinvestment by Wirco to have people present. And that's what we've done first. And by doing that, we're able to be present and help our customers reach their goals. It's important to have facilities, equipment, and people that can allow our customers to meet those goals. To be able to run operational foundries, to be able to bear those expenses, and then to have a staff that's able to be present for our customers, that's quite an expense, but we found a great market niche doing that."

To that end, Dankert emphasized that Wirco is a vertically integrated company.

"We try to do as much, in-house, as we can," he said. "We're a Christian-based, faith-based business. We always have been. Our company was founded with those type of ideals. We treat our people that way. We try to treat people with kindness, fairness, and everybody's a partner here. Everybody's opinion matters. We've always been that type of family business."

INNOVATION ORIENTED

Over its half century of business, Wirco has made a point to offer an ever-evolving industry the latest innovations its customers need, according to Dankert.

Wirco has developed alloys and different designs to increase alloy life. (Courtesy: Wirco)

"We have had to change the type of products we offer to fit with different types of heat treating and the new equipment our customers are using," he said. "When I started 26 years ago, furnaces were more typically smaller in size than we see today. With the great upsizing in furnaces, we have had to make many changes to the tooling and maintenance parts we provide. There's been a lot of demand, especially from our steel industry customers and a lot of our heat-treat customers, to increase the life of the furnace alloy they purchase. The fewer times somebody has to do maintenance, obviously that's a huge cost savings on those furnaces. We've developed alloys, and we've come up with different designs to increase alloy life. We've also designed improved manufacturing techniques, like robotic welding, to make sure our customers experience the greatest value possible with their alloy budget."

INCREASING EQUIPMENT LONGEVITY

The bottom line, according to Dankert, is that Wirco stays in tune with what its customers require in order to increase their through-

When customers need stainless-steel parts for furnaces, Wirco can make most all of them per customers' specifications. (Courtesy: Wirco)

put and increase their bottom line.

"We've had to look at unique scrap programs for customers," he said. "We recycle 3 million pounds of alloy scrap per year through partnering with our customers to purchase their scrap alloy. We offer those type of programs to our customers so they can see a continued return on their initial alloy investment. All those castings and fabrications have value after they're done being useful inside of a furnace, and our various Wirco Scrap Programs (WSP) help our customers realize this value."

Dankert and his team work with customers to find out what their needs are and how best Wirco can meet those needs. Customers want to know what they can buy that's going to last longer and what they can get with the most value attached to it, according to Dankert.

"This doesn't necessarily mean we're going to be the cheapest option, but our goal is to help our customers realize the total value of the purchase," he said. "We're going to get you great alloy life. We can do that through alloy selection. We have a great team of design and process engineers that work for us who are involved in many levels of our manufacturing processes. They are coming up with new designs, testing designs, and doing theoretical modeling to try to increase life for our customers and have a better user experience with the alloy."

TAKING ON CHALLENGES

And Dankert said Wirco is willing to take on any challenge, no matter how difficult it may seem.

"If somebody is a new customer to Wirco, we typically would want to take the worst project they have," he said. "What's the hardest project? Where have other foundries failed? Where have other fabricators failed? We believe that's where we can shine for our customers, so we take that project. We can prove to you we've got the people and the competence to be able to bring a solution to market. We always like to take the hard projects on, because if we can solve those problems, our customers know we can take on all their alloy projects."

Some of those challenges are tackled using 3D modeling in combination with finite element analysis before a single product is ever physically made, according to Dankert.

"We go through a detailed design review process with our customers to get the critical questions answered on how the alloy casting or fabrication will be used; this way we ensure our design will be prepared how our customers expect," he said. "We'll go through a first-piece sample inspection, which will include X-ray and destructive testing. We can also create 3D-printed sections of castings that our customers can use to determine proper fit and alignment of the parts they want to heat treat. We can also theoretically model the tooling we design to see what type of deformation we get and what type of life our customers could expect. There are a lot of steps we take on the front end of a customer's request to help bring our products to market. We don't see those steps being taken from overseas manufacturers or our few domestic competitors."

CONSTANTLY GROWING

Over the years, Wirco has invested in many acquisitions and other purchases to help maintain that quality of excellence its customers have grown to expect.

The last 15 years have seen Wirco purchase and integrate four businesses. In addition to that, it's invested heavily in designs for robotic welding as well as other innovative technologies.

"We've improved the equipment, and I would say that's definitely one thing," Dankert said. "I think, secondly, would be that we are constantly reinvesting in equipment and people. We're not just sitting on profits or funds. We constantly reinvest back in our equipment, while bringing more modern equipment in and constantly keeping our facilities upgraded and safe."

"We're going to get you great alloy life. We can do that through alloy selection. We have a great team of design and process engineers that work for us who are involved in many levels of our manufacturing processes."

The last 15 years have seen Wirco purchase and integrate four businesses. In addition to that, it's invested heavily in designs for robotic welding as well as other innovative technologies. (Courtesy: Wirco)

EXCELLENT SAFETY RECORD

And that reflects heavily on Wirco's safety track record as well, according to Dankert.

"We've had — knock on wood — an excellent safety record in all our facilities," he said. "We think that's been a great thing. We want to keep our people working safe, get them home safe, and protect them in dangerous working environments in the best-case scenario. We've had an excellent record of taking care of our people that way."

Safety and investment are very important to Wirco, and those goals were never more apparent than when a massive fire at its Champagne foundry in 2016 almost required the company to close the facility, according to Dankert.

"Over the next two years, we rebuilt that facility with close to a $20 million reinvestment to bring that facility back to a world-class, modern operational foundry," he said. "We did that. It could have killed us. It could have closed our company at the time. And we found a way, with a lot of great people here, just to figure out how to make it go. Some competitors stepped up to help us keep our customers taken care of. And through all that time, with a lot of pain, we've been able to rebuild back stronger than we ever were in 2016. I think if you ask people that have been here for a decent amount of time, they'd probably point to those couple years as one of the biggest challenges of their career but yet one of the most rewarding because the end result was building a facility back bigger and stronger than it ever was before."

LOOKING TO THE FUTURE

As Wirco continues into the future, Dankert said he sees a greater reliance on domestic made castings and fabrications similar to what Wirco produces. That also includes a reinvestment by heat treaters into larger furnaces and technologies such as vacuum heat treating and nitriding.

"We've worked with a lot of those type of projects," he said. "With vacuum furnaces and the different nitride tooling along with all those different vacuum processes that exist, you're just seeing a much greater demand now. I think you're going to see another huge reinvestment within the market. And that's somewhat helping to modernize North American heat treating."

That dedication to North American heat treating is a goal that Wirco believes in without exception, according to Dankert.

"We're an extremely dedicated USA manufacturer," he said. "We source everything here domestically. That costs more money a lot of times, but that's definitely served us well. We don't have quality concerns because of, say some type of material grade from China or piece of equipment. There's just a total dedication to U.S. manufacturing."

MORE INFO www.wirco.com

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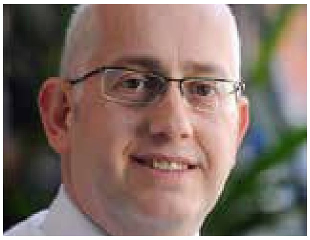


DR. MARK CROSS /// GLOBAL BUSINESS DEVELOPMENT DIRECTOR – DIE CASTING /// QUAKER HOUGHTON

"We see opportunities for the die-casting world to implement new and efficient die-casting processes, which are more sustainable and have a significantly improved cost of operation."

The automotive industry is continually pushing new boundaries. Advancements in engineering technology show no signs of slowing down with increasing developments in manufacturing processes. Larger structural die-casting solutions, often called Mega or Giga casting, are one of the advancements in aluminium die casting for car body construction, and with one major manufacturer already leading the way, others are following.

Megacasting was a hot topic of conversation at this year's EUROGUSS event in Nuremberg, and Dr. Mark Cross, Global Business Development Director – Die Casting at Quaker Houghton was on hand to talk about the opportunities for die casting in the automotive industry.

What did you want to achieve from showcasing Quaker Houghton at Euroguss?

We wanted to introduce our intelligent solutions approach to die casting to the market, which we call Diecast iQ™. A complete single-source solution for die casting lubricants, equipment, and ancillary products, this includes an unmatched range of die and plunger lubricant technologies, from conventional water-based die lubricants to our market-leading electrostatic technology, as well as full turn-key equipment supply and integration.

Where does Quaker Houghton see opportunities for manufacturers in the automotive industry when it comes to die casting?

We see opportunities for the die casting world to implement new and efficient die casting processes, which are more sustainable and have a significantly improved cost of operation. This is what DieCast iQ™ is all about — intelligent, modern die-casting solutions.

How much of an impact are Giga and Mega casting processes having on the automotive industry?

We are starting to see a significant impact from Giga and Mega casting, which is leading to a fundamental change in the way cars are made, and we are seeing significant interest from OEMs and die casters in these new, very large structural castings for body and chassis assemblies. Without a doubt, we expect to see widespread adoption of these Giga and Mega processes as other mainstream automotive manufacturers look to adapt to die casting.

How can the DieCast iQ™ support Giga and Mega casting?

Our electrostatic die lubricant systems are ideally placed to help customers unlock the potential of Giga and Mega die casting processes. We provide a full turnkey solution from spray simulation through to supply and integration of the die lubricant spraying equipment and post-installation process optimization. As our electrostatic lubricants are water-free, die life is dramatically increased and effluent eliminated.

What does the future of the die-casting market look like?

At Quaker Houghton, we see significant changes coming to die casting. This is not just from the development of larger Giga and Mega processes, but also the drive to more sustainable and more advanced lubricant solutions. We expect to see markets start to shift away from widespread low-performance high-cost conventional lubricant solutions and the adoption of more advanced MQL and electrostatic systems.

How does Quaker Houghton work with foundries to ensure sustainability to help reduce their environmental footprint?

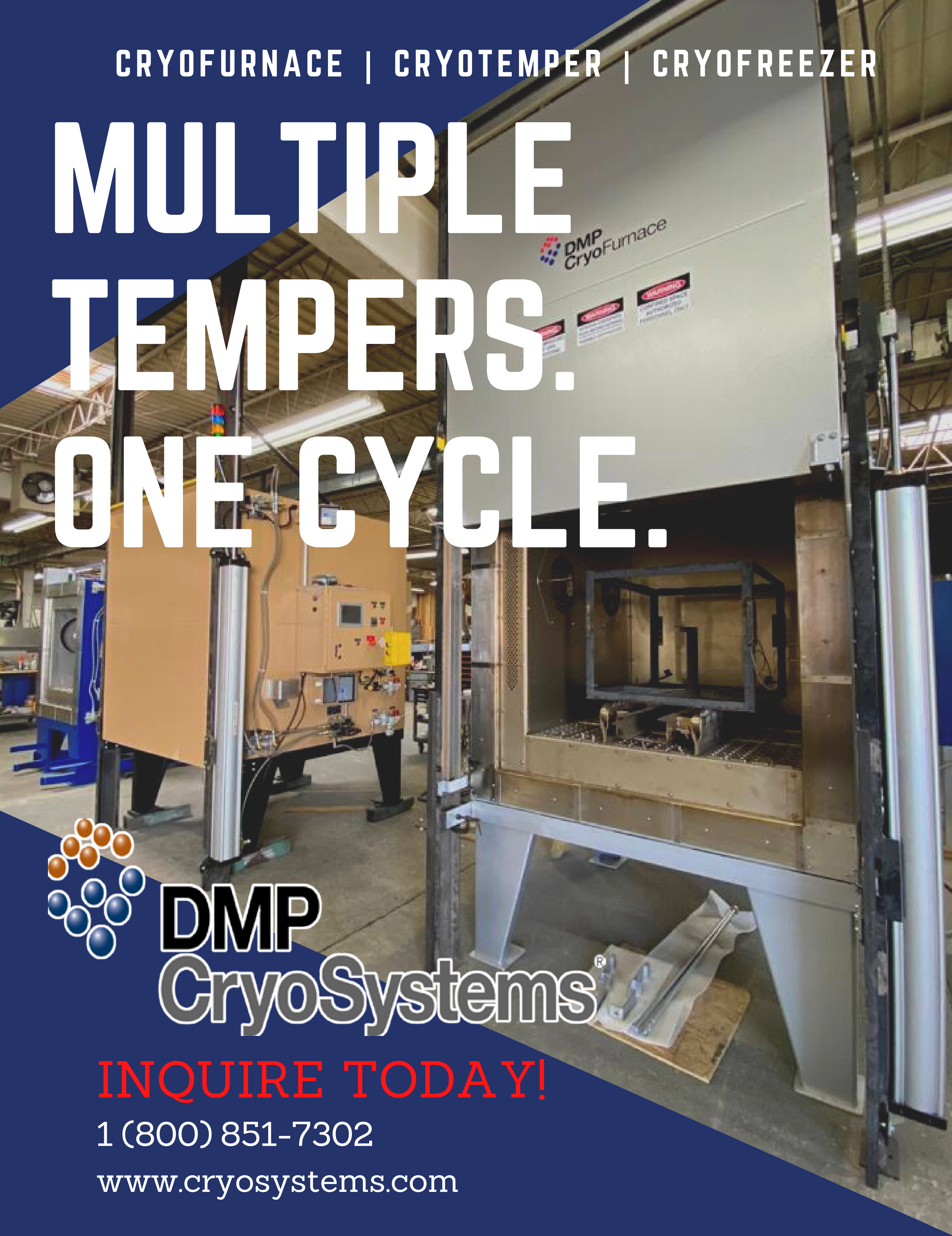
We offer customers a consultative approach, to review their current die castings processes and help them identify where they can adopt more sustainable products and procedures. This could be an MQL solution or even an electrostatic system. As a solutions provider, we can, of course, be a single point of contact for a customer to supply and integrate any necessary equipment to upgrade their process and implement a new solution.

So, the future is bright for large structural components?

There is no denying the advantages of Mega and Giga casting — improved production efficiency and lower costs will be music to the ears of the automotive industry. Being able to cast large single-piece structural components will help eliminate certain assembly operations, streamline processes, and improve productivity.

With smart technology continually evolving, engineers and manufacturers must work hard to keep pace with the competition. Cost-efficient methods of production need to be developed to meet industry requirements, without compromising the overall performance and quality of the automotive parts. Quaker Houghton's complete turnkey solution ensures a seamless approach to die casting, backed by a global team of industry experts and die casting professionals.

MORE INFO diecastiq.quakerhoughton.com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