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ISSUE FOCUS ///

MEDICAL APPLICATIONS / THERMOCOUPLES

THE TRIBOLOGY OF DENTAL CERAMICS

COMPANY PROFILE ///

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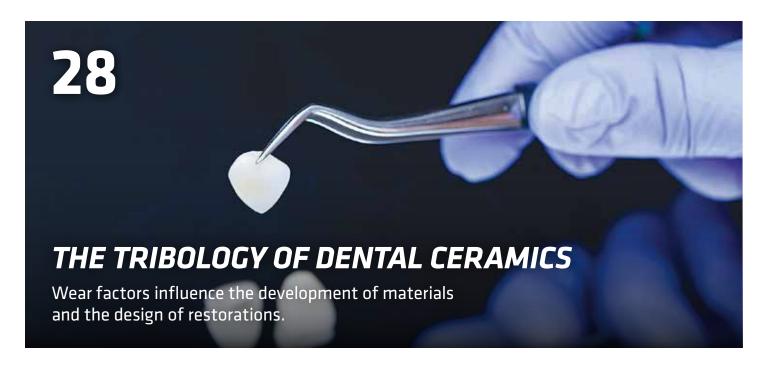
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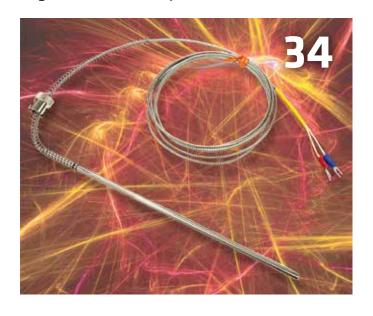


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ENHANCED THERMAL SENSITIVITY IN A SINGLE METAL THERMOCOUPLE

Noting a significance of thickness-engineering of the metal layers, this article introduces an alternative method to achieve higher thermal sensitivity from single metal thermocouples (SMT).





COMPANY PROFILE ///

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DEPARTMENTS ///

MAY 2022

VOLUME 11 / NUMBER 5

UPDATE ///

New Products, Trends, Services & Developments



- >> Arvedi finds innovative solution for EAF.
- >> Can-Eng delivers mesh belt heat treat system to Italy.
- >> L&L ships box furnace to valve manufacturer.

0&A ///

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RESOURCES ///

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International Federation for **Heat Treatment (IFHTSE)**



The international association whose primary interest is heat treatment and surface engineering shares news of its activities IFHTSE to promote collaboration

on issues affecting the industry.

Industrial Heating Equipment Association (IHEA)



The national trade association representing the major segments of the industrial heat processing equipment industry shares

news of it's activities, training, and key developments in the industry.

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Determining the appropriate heat transfer coefficients is critical for simulation accuracy to characterize equipment. 22

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FROM THE EDITOR ///



Putting heat treating where your mouth is

t always amazes me when I find out some of the eclectic ways heat-treating is used in almost every facet of what we do.

For the past few years, *Thermal Processing* has added a medical-applications Focus topic because, like aerospace, heat-treating is also a big part of products that not only keep us alive, but also help make living more comfortable.

We take so much of this for granted, so it's always nice to be reminded just how extensive heat treating is used in so many areas.

In our cover article, we take a look at the tribology of dental ceramics and how sintering is used in the development of materials and the design of dental restorations.

In addition to medical applications, our May issue also takes on thermocouples.

With that in mind, our next Focus article goes hardcore technical as it discusses the enhanced thermal sensitivity in a single metal thermocouple and the significance of the thickness-engineering of the metal layers.

May's company profile tells the fascinating story of Noble Industrial Furnace and how the company is celebrating 50 years of designing and building custom-made equipment.

In addition to these features, be sure to check out our monthly columnists as they tackle a variety of subjects vital to heat treating.

I hope you enjoy this month's content, and if you'd like to contribute to a future issue, please don't hesitate to contact me. I'm always on the lookout for expert advice that furthers the advancement of the heat-treat industry.

Yes, May is finally here with — hopefully — a relaxing summer close on its heels.

So, grab our latest issue and take it to the deck. It may not keep you cool, but the information inside certainly is.

As always, thanks for reading!

KENNETH CARTER, EDITOR

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UPDATE /// HEAT TREATING INDUSTRY NEWS



ABB and Tenova receive final acceptance for innovative charging, melting and electromagnetic stirring solution on a large electric arc furnace. (Courtesy: Tenova)

Arvedi finds innovative solution for EAF

Leading metals industry suppliers ABB and Tenova have now obtained final acceptance from their customer, Acciaieria Arvedi, after partnering to deliver an innovative technology package, enabling optimal charging, melting, and electromagnetic stirring for the world's highest-yielding electric arc furnace (EAF).

The powerful solution combines a Tenova Consteel® EAF continuous scrap charging system with Consteerrer®, a model of the well-established ABB ArcSave® electromagnetic stirrer designed specifically for continuous charging EAF systems.

The record-breaking electric arc furnace has a 300-metric-ton tapping size and uses a charge mix which includes hot briquetted iron (HBI). It was installed to meet the demand for increased output following the

recent revamp of the continuous endless strip production (Arvedi-ESP) casting and rolling mill line at the plant.

"We're really thankful for the seamless collaboration between Tenova, ABB, and the Arvedi technicians and site personnel, and for the great efforts our teams have made during this world-class project. We're very proud of the contribution our technologies are making to Acciaieria Arvedi's ambitions as a steel industry trailblazer," said Silvio Reali, Tenova senior vice president.

"The metals industry is essential for the transition to a net zero world. Working together on this milestone project will support Acciaieria Arvedi to have one of the most sustainable, efficient, and modern steel operations," said Zaeim Mehraban, global sales manager, metallurgy products at ABB.

"We are already working with a modern plant based on Arvedi patented technologies, fulfilling productivity, technological, environmental, and safety objectives. An important achievement has now been reached on the melting side thanks to the work with our partners Tenova and ABB," said Andrea Bianchi, R&D director at Acciaieria Arvedi. "We are showing that it is possible to produce high-quality steel for our customers with the highest output from a single EAF, reducing the resources and the energy we need to use, and minimizing CO2 emissions."

Acciaieria Arvedi chose Tenova Consteel EAF for the second time in 2018, strengthening the plant supplied in 2008.

The new installation, built to comply with the higher productivity of the recently improved continuous casting and rolling line, takes into account the requirement for increased productivity and operational flexibility, particularly in relation to the metallic charge mix that is of strategic importance in the EAF process.

The careful design of the equipment and the operational results achieved demonstrate the reliability of the technology involved and the validity of this approach for the safe production of steel with minimal environmental impact.

The new electric arc furnace has a diameter of 9.1 meters and is continuously fed by a Consteel conveyor and the latest generation of Tenova injection system.

MORE INFO www.tenova.com

Can-Eng delivers mesh belt heat treat system to Italy

Can-Eng Furnaces International, Ltd., has prepared to ship an 1,800 kg/hr continuous mesh belt heat treatment system to an existing customer in the Piedmont Region of Italy. Can-Eng continues to demonstrate its commitment to support manufacturers of high quality, safety critical fasteners around the world and was the primary reason Can-Eng was chosen again by this customer for their second capacity expansion.

This European project represents its fifth



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.

installation for this globally recognized producer of specialty fasteners with operations in Europe, South America, Mexico, and the United States.

Can-Eng was chosen to supply this system based on proven reliability, efficiency, and soft-part-handling features, hallmarks of Can-Eng's mesh belt furnace systems. The new, high-volume fastener system integrates energy efficient combustion and waste heat recovery technology, atmosphere-controlled mesh belt hardening system, oil quench, post wash system, temper furnace, soluble oil system, bi-directional conveyor discharge, and Can-Eng's Process Enhancement Technology (PET™) system. Can-Eng's PET system provides the user with access to vital Industry 4.0 features which includes product traceability, detailed process data for continuous process improvements, comprehensive equipment diagnostics, cost analysis, and inventory management.

The state-of-the art system also integrates Can-Eng's Energy Reduction System (ERS™) which significantly reduces the energy requirements of the system. The system will be commissioned Q2, 2022, to meet the client's performance and capacity expectations. Through proven results, Can-Eng's continuous mesh belt heat treatment systems



Can-Eng is shipping a continuous mesh heat belt treatment system to an existing customer in Italy. (Courtesy: Can-Eng Furnaces International)

remain a gold standard for processing highquality automotive fasteners.

As the demands of the automotive industry continuously grow, so do Can-Eng's mesh belt heat treatment systems' capability to meet and exceed processing standards.

Can-Eng Furnaces International Ltd is an ISO 9001:2015 certified company with its head office and manufacturing facility located in Niagara Falls, Ontario, Canada.

MORE INFO www.can-eng.com

L&L ships box furnace to valve manufacturer

L&L Special Furnace Co., Inc. has delivered a high-uniformity box furnace to a worldwide, leading valve manufacturer located in the southeastern United States.

The L&L model XLE 244 is a front-loading, refractory-lined box furnace and has an effective work zone of 22" wide by 22" high by 20" deep. There is a horizontal double-pivoted door with a safety power cutoff switch. A ceramic hearth and standoffs are provided as a workspace.

The XLE 244 is equipped with solid-state relays for fast, quiet cycle times to offer good control. These are housed in a NEMA 1 control panel with single-point power connection. All required fusing and interconnections are included.



UPDATE /// HEAT TREATING INDUSTRY NEWS



The control system is driven by a Honeywell program control with an over-temperature control to prevent the furnace from overfiring. A digital round single-input chart recorder keeps accurate recordings of the furnace process temperature. The Kanthal Iron Aluminum Chrome coiled elements located on the sides, back, and door are controlled in two zones for balancing of temperature gradients from top to bottom.

All L&L furnaces can be configured with various options and be specifically tailored to meet thermal needs. It also offers furnaces equipped with pyrometry packages to meet the latest revision of ASM2750.

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

MORE INFO www.llfurnace.com

Electronics component maker orders furnace

A global manufacturer of electronic components with engineering centers and factories worldwide has purchased a vacuum tempering furnace from Seco/Vacuum, a Seco/Warwick Group company, for one of its plants in Pennsylvania.

With a chamber of 48" x 48" x 72" deep, the furnace will be used to anneal copper and steel electrical connectors used in subsequent assemblies.

The new equipment will deliver added capacity to meet increased demand for the company's products. The order includes a turbo-cooling feature designed to improve turnaround time from batch to batch and maximize throughput.

VT tempering furnaces are compact in design and operate up to 1,382°F while providing vacuum tempering, annealing, stress-relieving, and other clean processing such as precipitation hardening.

"We are finding increasing opportunities in markets with broad supply chain stresses,"

said Peter Zawistowski, managing director of Seco/Vacuum. "We are doing our part with this global electronics supplier to provide the boost they need to achieve an integrated recovery with their customers. Every little bit helps, and we're pleased to be a part of the solution."

Processing equipment is often referred to as a "solution." In cases such as this where the problem to be solved is a production backlog, the dual meaning becomes apparent. Seco/Vacuum's entire line of products can be considered solutions equally well because they are all designed to solve specific heat-treatment challenges, some with unique technologies.

Electronics manufacturers worldwide turn to Seco/Warwick Group for various solutions, from the VT vacuum tempering furnaces to Vector® and CaseMaster Evolution®, single- and multi-chamber vacuum furnaces with integral high-pressure quench systems.

MORE INFO www.secowarwick.com

Nitrex now available in eight languages online

As a global company, Nitrex wants to ensure that the majority of its interactions, including the website, are conducted in people's native language. This effort aims to assist Nitrex in creating a more personalized experience while continuing to provide



With a chamber of 48" x 48" x 72" deep, a recently purchased Seco/Vacuum furnace will be used to anneal copper and steel electrical connectors used in subsequent assemblies. (Courtesy: Seco/Warwick)

excellent customer support.

"We invested in this project to ensure that of our employees, partners, and customers feel like they belong. Even though most of them speak English, we wanted our website to reflect the rich cultural diversity in our company," said Christine Hauben, director of global marketing at Nitrex.

Nitrex is a global leader in the surface treatment market, providing premium turnkey systems (nitriding, nitrocarburizing, vacuum), heat-treatment services, as well as instrumentation and automation solutions.

Nitrex is the only fully integrated global provider in the surface treatment market. The company was founded in 1984 in Montreal, Canada, and operates three business units — Nitrex Turnkey System (NTS), a turnkey nitriding, nitrocarburizing, and vacuum system; Heat Treating Services (HTS), a worldwide network of commercial heattreating service centers; and UPC, a leading provider of controls upgrade and automation solutions for heat treating and combustion.

With more than 450 employees and a market presence in more than 55 countries, Nitrex serves its customers globally from 14 locations across the United States, Canada, Mexico, Brazil, Germany, Poland, Italy, France, China, and Japan, and through a global network of representatives and licensees.

MORE INFO www.nitrex.com

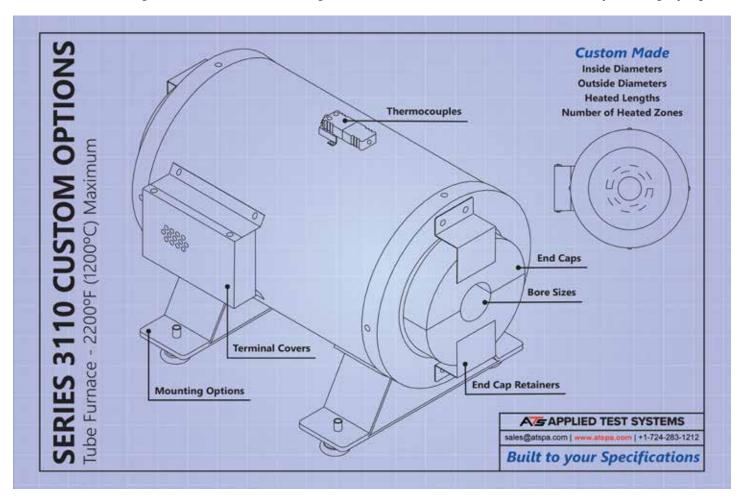
Aalberts surface technologies has U.S. business rebrand

Aalberts surface technologies, a leading global provider of specialized thermal processing, surface treatment, and material coating solutions, announced that its U.S.-based businesses will begin doing business as Aalberts surface technologies. This rebrand is a part of a global rebranding initiative that Aalberts began in 2020. The U.S.-based busi-

nesses included in this phase of the rebranding initiative include Aalberts Surface Treatment, Precision Plating Company, Roy Metal Finishing, Ushers Machine and Tool, Accurate Brazing, Ionic Technologies, Applied Process, and Premier Thermal.

"The Aalberts' brand is defined by its deep commitment to winning with people, mission-critical technologies, and a relentless pursuit of excellence," said Oliver Jaeger, CEO of Aalberts surface technologies. "At Aalberts we are entrepreneurs, we take ownership, we share and learn, we act with integrity, and we go for excellence ... good is never good enough. The teams at our U.S. based businesses are well aligned with 'the Aalberts way' and will do an outstanding job of representing the Aalberts brand."

Rebranding activities began in early 2022 and will continue through 2023. The activities will include changes to building signs, email addresses, websites, invoices, shipping documents, etc. Communication with stakeholders is under way, including any required



UPDATE /// HEAT TREATING INDUSTRY NEWS



Aalberts Surface Technologies rebranding will continue into 2023. (Courtesy: Aalberts Surface Technologies)

documentation updates.

"We are excited about our growth prospects in the U.S. Operating under one brand in the U.S. market will of course help to improve our brand recognition in that market, but, more importantly, it will help our customers, and the market in general, to better understand our wide array of products and services. With our commitment to cutting edge technologies and our global reach, Aalberts is well positioned to support progressive companies with an eye on the future," said Jaeger.

Aalberts surface technologies has five divisions on three continents and is part of the globally-positioned technology company Aalberts N.V. which has 134 locations worldwide and more than 14,000 employees.

MORE INFO www.aalberts-st.com

Ipsen hires Navid Gamerschlag in management role

Ipsen has hired Navid Gamerschlag in the role of European sales manager – vacuum technology. Based out of Cologne, Germany, Gamerschlag is responsible for promoting Ipsen vacuum equipment within the greater European region.

Gamerschlag will work alongside Ipsen's European based sales representatives to bolster vacuum furnace sales and support.

"We are excited to welcome Navid back in this important sales management role," said Patrick McKenna, president and CEO of Ipsen USA, Ipsen's Vacuum Technology Excellence Center. "With global demand



Navid Gamerschlag

for Ipsen furnaces continuing to accelerate, his return to Ipsen comes at an ideal time."

Gamerschlag was most recently the sales manager for a global manufacturer of induction heat-treating

equipment. Prior to that, he served as regional sales manager for Ipsen Germany, where he was responsible for promoting Ipsen products and services in multiple international regions. He holds a Dipl.-Ing. in mechanical engineering from the University of Applied Sciences, Cologne.

"Being back at Ipsen feels like coming home to family," said Gamerschlag. "I am looking forward to collaborating with my colleagues with a big focus on customer-centricity. This means continuing to build relationships with our customers and earning new business. We can best serve our customers by understand-

ing their needs and use that feedback to drive our products and service offerings."

MORE INFO www.ipsenusa.com

Registration open for Ceramics Expo 2022

North America's premier event for the advanced ceramic and glass supply chain is back, taking place August 29-31 at the Huntington Convention Center of Cleveland, Ohio, co-located with the newly launched Thermal Management Expo 2022.

Source the latest materials and technologies and understand where the advanced ceramics industry is heading in the exclusive Ceramics Expo conference sessions.

Alongside the exhibition runs a comprehensive two-day conference program exploring the topics and trends that matter to attendees. Hear from industry leaders on new market applications, sustainability, composite material innovation, electrification, novel manufacturing techniques, plus many more relevant topics.

Ceramics Expo 2022 welcomes 250+ exhibitors showcasing the latest cutting-edge ceramics materials and technologies. Exhibitors have the solutions needed to reduce costs, scale-up manufacturing processes, and take products to market sooner.

Ceramics Expo brings together engineers, decision makers, end-user OEMs and buyers from across the globe to source new materials, components and technologies, network with like-minded professionals, and discuss the challenges and opportunities in the ceramics industry.

Running concurrent to the exhibition is the free-to-attend Ceramics Expo Conference, where industry leaders will share their technical expertise in ceramics and provide real-world case studies, new technologies and materials, along with information on industry trends. This year, the program will deliver leadership on topics including material advancements, key applications, manufacturing developments, and industry trends. Spread across two days, this event promises to provide crucial insights into the industry.

MORE INFO www.ceramicsexpousa.com

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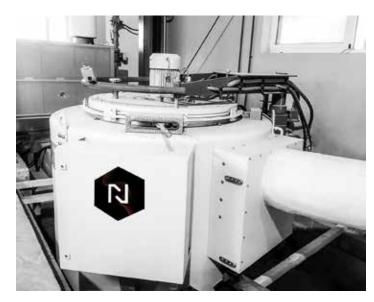
Qalex turns to Nitrex system for second extrusion plant

Qatar Aluminium Extrusion Co. (Qalex) received a second nitriding system from Nitrex. The aluminum profiles manufacturer wanted to equip a second extrusion plant with an independent nitriding furnace to save on handling, processing time, and costs associated with having to transport extrusion dies back and forth from its first factory for nitriding work.

"This is the second turnkey system, but it might not be the last one," said Marcin Stok osa, project manager at Nitrex Poland. "The story for the initial furnace we sold to Qalex is very long but interesting. Discussions lasted a few years and the customer eventually decided on an order in 2017. In 2021, Oalex boosted the company's production capacity with the acquisition of a second factory in Qatar dedicated to aluminum extrusion manufacturing and equipped with two extrusion presses. They knew they couldn't nitride all dies from both factories in one furnace. Every part of this order went like clockwork. The decision to invest in another Nitrex nitriding system was quick thanks to drivers like customer satisfaction, operational efficiency, and the guaranteed levels of die performance and expected results achieved with the first system. Qalex was also very pleased with our technical support and spare parts accessibility. What they ordered is an exact copy of the first Nitrex installation-an identical configuration with the same furnace model, size and process technology."

The customer chose the Nitrex compact system, a model NXK-1015 furnace equipped with process technology designed for nitriding extrusion dies. Nitrex ensured a quick delivery at the request of the customer. Installation and startup were completed in January 2022.

Qatar Aluminium Extrusion CO. (Qalex) is the brainchild of the Qatar Industrial Manufacturing Company (QIMC). Located in New Industrial Area, Qatar, this multimillion project houses modern extrusion production facilities. Qalex is equipped with two extrusion presses (7-inch and 8-inch). The facilities also include a vertical powder



Qualex chose the Nitrex compact system, a model NXK-1015 furnace equipped with process technology designed for nitriding extrusion dies. (Courtesy: Nitrex)

coating line, the first complete automatic anodizing line in Qatar, installations for thermal break polishing and brushing, nitriding and extrusion dies, and a laboratory.

MORE INFO www.nitrex.com

Plibrico supports ELYSIS in smelter technology

The Plibrico Company, a leading supplier of monolithic refractories and installation services, announced its refractories are being used by ELYSIS to safeguard the operation of the world's first carbon-free aluminum smelter. ELYSIS is a joint venture between Alcoa and Rio Tinto Group that is financially supported by Apple as part of its Green Bonds program. ELYSIS smelting technology takes the novel approach of leveraging an inert anode that eliminates all greenhouse gas (GHG) emissions, emitting instead only pure oxygen as its by-product.

According to the International Aluminum Institute, for each ton of aluminum produced, approximately 11.5 tons of carbon is released. The groundbreaking smelter technology from ELYSIS, protected by Plibrico refractory linings, represents an innovative new strategy for aluminum processors to reduce their carbon footprint and address global climate change in the drive to a Net Zero carbon future.

Plibrico nonwetting refractories protect

the linings of ELYSIS smelting units, acting as a thermal barrier between the liquid aluminum and the walls of the vessel, therefore preventing corrosion while ensuring maximum heat retention for greater energy efficiencies.

During development, Plibrico collaborated closely with ELYSIS in identifying the critical refractory specifications required for safe, long-term operation in temperatures approaching 1,000°C. Research highlighted the need for a refractory that provided:

- >> Superior resistance to aluminum wetting and penetration.
- >> Chemically stable, with no silica diffusion
- >> Durability and dependability, field tested.
 - >>> Excellent thermal shock resistance.
 - >> Outstanding thermal storage capacity.

Plibrico engineers and project managers pinpointed the precise formula needed from the company's vast portfolio of refractory materials, setting ELYSIS on the fast track toward bringing its technology to market as quick as possible.

Plibrico's alliance with ELYSIS extended beyond designing the lining specifications and providing the refractory materials, to include casting lining sections, and meticulously installing the linings inside the equipment at Plibrico's Salem, Ohio, location.

Supported by Plibrico refractories, ELYSIS is ramping up production to a commercial scale at its Industrial Research and Development Center in Saguenay (QC), Canada. Apple has used the first batch of its



Plibrico refractories protect a groundbreaking new smelting system designed to significantly reduce the carbon footprint of aluminum processors. (Courtesy: Plibrico Company)

commercial-purity, low-carbon aluminum in the new iPhone SE. In addition, Audi has announced plans to manufacture the wheels for its e-tron GT sports car using a combination of ELYSIS aluminum and Alcoa low-carbon $\text{EcoLum}^{\text{TM}}$ aluminum.

"Plibrico is proud to have supplied enabling refractory technology to ELYSIS to help it lay a pathway for the aluminum industry to a more sustainable future," said Brad Taylor, president and CEO of the Plibrico Company. "ELYSIS' disruptive technology has the potential to transform the way the aluminum sector — and the world — is addressing the climate crisis. Plibrico refractory materials will now literally 'touch' all users of Apple IPhone SE and Audi e-tron GT sports cars.

"For decades Alcoa has relied upon Plibrico durable nonwetting refractories to protect its furnaces and aluminum thermal processing equipment. We are honored that when Alcoa's lead engineers needed refractory advice for this bold, ambitious project, they approached Plibrico for the answer."

ELYSIS technology is on track to be commercially available by 2024, both as a "drop-in" replacement to retrofit existing aluminum smelters and in the building of new units.

Seco/Warwick furnace speeds up screw production

Solvera Gawel Technology S.A., a supplier of fasteners, chose Seco/Warwick as its vacuum furnace supplier.

The equipment on order is a Vector® vacuum furnace because the partner's previous experience with Seco/Warwick's solutions was with atmospheric furnaces. The new furnace will be used for vacuum heat treatment and high-pressure gas hardening of tools for fastener production. As a result, the company will significantly shorten the production process cycle for screws.

The ordered Vector vacuum furnace has a compact design, which makes it an ideal solution for manufacturing companies that need to create their own small in-house hardening plants. The heating chamber is equipped with a compact hot zone (400x400x600) that

is large enough to enable efficient heat treatment of many elements at the same time. Solvera Gawel Technology selected this solution as an addition to its facility due to the Vector's unique features, including a round heating chamber with very good temperature distribution, an efficient and ergonomic pumping system, as well as the cooling system based on a gas blower ensuring a maximum hardening pressure of up to 15 bar abs. The very structure of the furnace is reliable and refined in every detail.

"We are glad that Seco/Warwick's longterm partner has purchased a system from a different product and technology segment. Our proven vacuum device, the design of which ensures long-term and reliable operation in industrial operating conditions, will show the great advantage of this technology. The product advantage is the ability to carry out very efficient hardening processes thanks to the utilization of high-pressure cooling gas," said Maciej Korecki, vice president vacuum segment, of Seco/Warwick Group.

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UPDATE /// HEAT TREATING INDUSTRY NEWS

Solvera Gawel Technology S.A. is a global manufacturer of fasteners such as screws for wood, metal or plastic. This is also a very innovative manufacturer with many patents in its portfolio. For further development, they needed a vacuum furnace that would allow the heat treatment of tools for fastener production. Until now, this process has been outsourced. This resulted in numerous limitations related to timeliness and partners' production availability. The pandemic situation further intensified this need, and eventually prompted Solvera Gawel Technology to purchase its own device, which would ensure independence and high quality.

"Our own vacuum furnace means better control over the quality of heat-treated elements and reducing the risk of delays. The lack of tools necessary for production cannot only slow down but even completely block the production of fasteners," said Tomasz Gaweł, President of Solvera Gawel Technology S.A. "The new furnace (Vector) gives us the comfort of production planning as well as great flexibility and independence. Having your own equipment for heat treatment in the tool shop also means savings in transportation to and from external companies. This is the third time we have cooperated with Seco/Warwick. We have a similar philosophy contained in three words: quality, innovation, and development. Having a common denominator, you always cooperate better, because you can be sure of dialogue and understanding."

This compact device can be a response to the challenges that arise during production processes related to the availability of external partners, the timeliness of their work, or the quality of services. Independence from external entities is one of the major benefits of such an investment.

MORE INFO www.secowarwick.com

AWS Foundation launches YouTube series

To highlight unique careers and companies in the welding and metal fabrication industries, the American Welding Society launches Metal America, a new video series streaming exclusively on YouTube.

From roller coaster fabrication to auto-



AWS' Stephanie Hoffman as she visits fabricators across the country to explore some of the industry's most unique careers in the YouTube series Metal America. (Courtesy: American Welding Society)

mated welding robots, each episode, ranging from 10-15 minutes, follows AWS' Stephanie Hoffman as she visits fabricators across the country to explore some of the industry's most unique careers. Viewers will get a peek inside metal fabrication shops, schools, shipbuilders, and more.

"The American Welding Society Foundation promotes the incredible career opportunities available in the welding industry, but until a person sees it for themselves, it's hard to envision what it's like to be in a metal fabrication shop or large manufacturing facility," said Monica Pfarr, executive director of the AWS Foundation. "With this series, we hope to peel back the curtain to show what it's like to work in various careers within the welding industry."

First stops of the series include Fire & Safety Services – Plainfield, New Jersey; Arc+Flame School – Rochester, New York; Trident Precision Manufacturing – Webster, New York; Path Robotics – Columbus, Ohio; Clermont Steel Fabricators – Batavia, Ohio; Mill Mechanical – Monroe, Ohio; and Philly Shipyard – Philadelphia, Pennsylvania. During each episode, Hoffman joins fabricators as they work on their projects, getting a behind-the-scenes look and crash course into their methods and procedures.

"It has been amazing to visit each one of these companies, where people come to work each day with a huge smile on their faces and then get to work building some of the most rad machines and products on the planet," said Hoffman. "They are an inspiration and proof that manufacturing in America is not only making a comeback but thriving."

New episodes on AWS' YouTube channel began in April.

MORE INFO www.aws.org www.careersinwelding.com

Cook Induction, Super Systems team up for heat treatment

Cook Induction, Los Angeles, California, began in 1945 and continuously explores ways to improve its customer experience and capabilities. This has grown into today's Nadcap-approved facility offering both heat treating (including induction case hardening, localized hardening, localized annealing/stress relieving, heat treatment of BeCu, localized annealing of BeCu, and hydrogen annealing and tempering) and brazing and soldering services (including silver, copper, nickel, and precious metals, induction, torch and furnace brazing, and atmosphere induction brazing).

In 2020, Troy Doolittle, quality manager, decided the next step in Cook's evolution was partnering with Super Systems (SSi) to implement a fully electronic SCADA package. "Having the ability to track and recall furnace data from our desks has made life so much easier. The new system has improved our ability to stay on top of scheduling and production," said Doolittle.

Neither party anticipated this would be the first of many projects between the two companies. Zach Morgan, SSi's engineer who managed the latest project, said, "Most recently, Cook's engineers mentioned problematic combustion burners on a couple of their furnaces. With prices and lead times for new burners both astronomical, we collaborated and came up with a burner redesign which improved reliability, added ability to isolate burners, and complied with the latest NFPA86 requirements. Historically this level of engineering has originated from our Cincinnati, Ohio, main office but this gave us the opportunity to bring that to our West Coast customers." &

MORE INFO www.supersystems.com www.cookinduction.com



NORTH AMERICA'S LEADING ADVANCED CERAMIC INDUSTRY EXPO AND CONFERENCE

AUGUST 29 - 31, 2022 // HUNTINGTON CONVENTION CENTER OF CLEVELAND, OHIO, USA *AUG 29: EXHIBITOR AND VIP NETWORKING RECEPTION | AUG 30-31: EXHIBITS AND CONFERENCE

Ceramics Expo brings together engineers, decision makers, end-user OEMs and buyers from across the globe to source new materials, components and technologies, network with like-minded professionals, and discuss the challenges and opportunities in the ceramics industry.

Running concurrent to the exhibition is the free-to-attend Ceramics Expo Conference, where industry leaders will share their technical expertise in ceramics and provide real-world case studies, new technologies and materials, along with information on industry trends.

Discover the exhibition and sponsorship opportunities, the conference program, the full exhibitor list, and how to secure your free visitor pass at:

ceramicsexpousa.com

In partnership with









Ceramics Expo has been joined at the Huntington Convention Center of Cleveland by two co-located events: Thermal Technologies Expo and High Performance Plastics Expo. This exciting new partnership gives Ceramics Expo visitors the opportunity to discover the very latest thermal management technologies and innovations, plus the latest high performance plastics and polymers solutions. Your free Ceramics Expo 2022 pass gives you access to both Thermal Technologies Expo 2022 and High Performance Plastics Expo 2022.



INTERNATIONAL FEDERATION OF HEAT TREATMENT AND SURFACE ENGINEERING

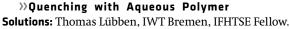


90-plus authors submit abstracts for European heat treat conference

o far, more than 90 authors from 22 countries have provided abstracts to the 27th IFHTSE Congress and ECHT2022. The contributions cover a wide range of heat-treatment and surface-engineering topics including:

- >> Furnace equipment and process control.
- >>Thermal processing of non-ferrous alloys.
 - >> Quenching technology.
- »Carburizing/carbonitriding and nitriding/nitrocarburizing.
 - >> Modeling and simulation.
 - >> Energy and the environment.

The conference will also feature a symposium honoring Sören Segerberg. This special symposium is dedicated to the late Swedish researcher who passed away in 2021. The talks in the symposium include:



- >>> Comparison of high-severity quenchants for low-carbon steels. Lauralice Canale, University of São Paolo.
- >> Quenching for the future In memoriam of Sören Segerberg. Eva Troell, RISE, Gothenburg, IFHTSE Past President.
- >> Current Investigations at Quenching Research Centre. Boz idar Matijevic , University of Zagreb.
- >>> **Birth of SmartQuench** In memoriam of Sören Segerberg. Imre Felde, Obuda University Budapest, IFHTSE Treasurer.
- »Advanced developments in the field of liquid quenchants; State of technique New Requirements Technical Perspectives. Rainer Braun, Burgdorf KG, Stuttgart.
- >> Characterization of Polymer Quenchants Influence of Agitation.

 D. Scott Mackenzie, Quaker Houghton, USA, former IFHTSE President.
- >> Overview of Researches and Standardization Activities on Test Systems for Quenchant Characterization in Japan. Kyozo Arimoto, Arimotech, Osaka, IFHTSE Fellow.

As previously announced, an additional five keynote lectures will highlight important aspects and trends in the different fields of heat treatment and surface engineering.

In the meantime, also the portal for sponsoring and exhibition has opened: ifhtse-echt2022.org/downloads/IFHTSE_ECHT-2022_



The European Conference on Heat Treatment/IFHTSE 27th Congress will cover a wide range of topics.

EUROPEAN CONFERENCE ON HEAT TREATMENT/IFHTSE 27TH CONGRESS

- >> September 5-8, 2022
- >>> Wyndham Grand Salzburg Conference Center, Salzburg, Austria
- >> Sponsored by ASMET, the Austrian Society for Metallurgy and Materials
- >> www.ifhtse-echt2022.org

ApplicationForm.pdf

After a long hiatus, we are looking forward to bringing together scientists, suppliers, customers, and industrial specialists to this event. We hope to see you in Salzburg.

MEMBERS IN THE NEWS

Bernard Kuntzmann – New IFHTSE Executive Committee Member

Bernard Kuntzmann was born in Strasbourg, France, in 1963. He first studied heat treatment and surface engineering at Saint-Louis

University, Brussels, and then graduated to CNAM engineer in metallurgy in Belfort, France, from 1981 to 1986.

His professional career started at SCR in Switzerland where he was responsible for the optimization and development of atmosphere control systems, in particular the development of oxygen probes.

He has been involved with furnace engineering, developing a



Bernard Kuntzmann

short-time nitriding process, and optimization of heat treating in fluidized-bed furnaces. Moving to the vacuum furnace manufacturing at Schmetz, he developed the previously unknown process of heat treating austempered ductile iron in a vacuum furnace.

He joined Bodycote as a process engineer and developed the combined process consisting of gas nitriding, plasma nitriding, and polishing (Corridur®) for the heat treatment of transmission parts.

He is presently managing director at Listemann AG in Winterthur, where he is responsible for development of heat-treatment process, high-temperature brazing, and electron-beam welding for the medical, aerospace, and energy industries.

He is currently the president of the Swiss Heat Treatment Association.

SPOTLIGHT ON MEMBERS

IMP Institute of Precision Mechanics (Instytut Mechaniki Przecyzyjnej)

The Institute of Precision Mechanics (IMP) conducts high-quality research, development, and implementation activities relating to surface treatment of metallic products and improvement of mechanical properties, durability, and corrosion resistance of tools, machine parts, and structures. The primary goal of the Institute is to transfer developed technologies — including the equipment required to use them, measuring and testing instruments, and know-how — into all branches of the industry and to provide services. During the many years of its activity, the Institute has become a recognizable brand, and the effects of its research are in common use.

IFHTSE UPCOMING EVENTS

MAY 11-13, 2022

International Bosphorus Heat Treatment Symposium

Milan, Italy I www.sct-2020.com

JUNE 19-23, 2022

6th International Conference on Steels in Cars and Trucks

Salzburg, Austria I www.sct-2020.com

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 | www.htsindiaexpo.com

APRIL 21-24, 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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INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

IHEA MEMBER PROFILE

Gasbarre Thermal Processing Systems

asbarre, headquartered in DuBois, Pennsylvania, was founded in 1973 to design, manufacture, and service a complete line of powder compaction and sizing presses for the powder metallurgy industry. Since that time, Gasbarre has earned a worldwide reputation as a full-service supplier to the powder metallurgy, particulate materials, and thermalprocessing industries. With 180 employees in five locations, Gasbarre stands alone in the ability to offer equipment and services for all applications related to powder compaction and thermal processing. Today, with 20 percent of Gasbarre products being exported, there are thousands of Gasbarre presses, furnaces, and other equipment in operation all around the globe that service the automotive, aerospace, commercial heat

treating, energy, industrial equipment, lawn and garden, military, and medical industries.

Through the acquisitions of Sinterite (1989), C. I. Hayes (2003), and J. L. Becker (2011), Gasbarre Thermal Processing Systems now operates in three locations and offers a broad range of products including air, atmosphere, and vacuum-furnace equipment; associated auxiliary equipment; and never-ending aftermarket support.

Gasbarre is dedicated to serving its customers by providing products and services that combine value and design flexibility through knowledge and understanding of their process. For each piece of equipment, Gasbarre takes a 360-degree approach. From sales and applications engineering to equipment design, manufacturing, commissioning, and never-ending aftermarket support, the company's team of engineers, metallurgists, and technicians understand their process from all angles. Gasbarre's technical capability and commitment to service will ensure its customers' success today and into the future.

PRODUCTS MANUFACTURED/SERVICES PROVIDED

Gasbarre has a broad range of products and core competencies in multiple areas. Gasbarre's continuous atmosphere line includes mesh belt furnaces for annealing, brazing, and sintering. The continuous atmosphere line also includes pusher furnaces for applications requiring processing above 2,050°F (1,120°C). The flexible batch atmosphere product line includes integral quench furnaces with associated companion equipment, large box, car bottom and tip-up



GASBARRE THERMAL PROCESSING SYSTEMS

- >>> Main location: 310 State St.; St. Marys, Pennsylvannia, 15857.
- >> Offices: Livonia, Michigan, and Cranston, Rhode Island.
- >> Phone: 814-834-2200.
- >>> Web: www.gasbarre.com

furnaces, and top-of-the-line nitriding and ferritic nitrocarburizing systems. Finally, Gasbarre's line of modular vacuum furnaces offers the ultimate versatility for low- to high-volume production. The modular design allows for efficient processing for a wide range of thermal processes. All equipment can be designed to meet the strictest of standards such as AMS 2750 and CQI-9 requirements.

Gasbarre also provides a full range of aftermarket services. This includes replacement parts, alloy and custom fabrications, rebuilds, and upgrades. Gasbarre is ISO 17025 certified and has technicians available to perform calibrations, maintenance, equipment moves, troubleshooting, and equipment evaluations.

Gasbarre designs and manufactures a wide range of continuous atmosphere products that include mesh belt and pusher furnaces. The company's product line covers a wide range of different processes including sintering, brazing, annealing, glass-to-metal sealing, inert atmosphere processing, normalizing, stress relieving, tempering, and drying. These products are energy efficient and can be gas-fired

or electrically heated. Gasbarre can provide the ideal product to process specific parts based upon a customer's process, temperature, atmosphere, and throughput requirements.

Gasbarre's multi-chamber vacuum furnaces are designed for a wide range of thermal processing applications. Gasbarre's design allows for faster floor-to-floor times, superior material properties, energy efficiency, and elevated temperatures, all while being environmentally friendly. Systems can be configured for both batch and continuous processing and can use both oil and gas quenching.

Gasbarre Thermal Processing Systems' precision gas nitriding and ferritic nitrocarburizing furnace uses the latest in

controls technology for automatic K_N and K_C control to AMS 2759/10 & 2759/12 specifications. The furnace is designed to meet AMS 2750 Furnace Class 2 requirements, which allows it to be used to perform nitrogen tempering and stress-relieving processes. For cycletime improvements and consistent process control, the furnace is equipped with a vacuum pump for purging, is capable of pre- and postoxidation, and incorporates accelerated air and atmosphere cooling systems. This product delivers top-of-the-line control, repeatability, and quality on every cycle. Gasbarre Thermal Processing Systems is proud to say this complete system is engineered, manufactured, and serviced out of its U.S. locations solidifying the company's position as a leader in equipment for the nitriding and FNC process.

Gasbarre's continuous flow vacuum furnace systems take vacuum processing, energy efficiency, and furnace performance to a new level. The unique continuous vacuum furnace system offers many advantages over batch vacuum furnaces and conventional atmosphere furnace systems. Gasbarre discusses this in terms of the four Es:

>> Effects on material properties due to the pure environment of the furnace.

>> Energy efficiency due to its ability to be turned on and off when not in use, limited furnace conditioning, and focused heating system.

>> Environmentally friendly as there are little-to-no emissions, either zero or more efficient atmosphere consumption, and no atmosphere burn-off requirements.

>> Elevated temperatures can be achieved supporting more process flexibility and improved cycle times.

THE PEOPLE AT GASBARRE

At Gasbarre, it all starts with the people. One of the company's core operating principles is ensuring the staff is motivated, professional, and has a high level of technical expertise. Gasbarre works to ensure it has personnel who have been in the customers' shoes and have dealt with the same challenges. This allows Gasbarre to understand the customers' needs and supply effective solutions.

Through a strategy of acquisition, Gasbarre has built a unique and diverse product offering, all while ensuring it maintains core competencies in each product line. It's not a "one size fits all" supplier. With offerings of batch or continuous equipment and both atmosphere and vacuum technologies, the company can go into each situation objectively and offer the best solution for each customer's need.

Gasbarre has taken a two-fold approach over the last couple years. First, there has been the evolution of its Thermal Processing Systems' organization to improve efficiencies and ultimate service to customers. Gasbarre has consolidated manufacturing into a



single location in St. Marys, Pennsylvania. It has restructured the responsibilities of key leadership to drive market growth and develop new technologies, and increased the capacity and capability of its field service department. Second, the company developed Gasbarre Automation Solutions that is now a division of Gasbarre that offers automation and robotic systems for press and furnace and other processes such as quality and inspection. These changes are not only positioning the company to be better for customers today, but into the future as well.

Speaking of the future, expect to see details from Gasbarre about expansion of its manufacturing facility in Pennsylvania; the

completion and growth of its technical center in Livonia, Michigan; and additional advancements in its product offering and automation packages. While Gasbarre doesn't have immediate acquisition plans, the company does keep its ears open for opportunities that fit its strategy and can grow the business. Gabarre is certainly excited about the position it has put itself in and the opportunities it has.

In the end, what drives Gasbarre is supporting its customers in their initiatives as they grow and business conditions change. Gasbarre will continue to evolve to ensure it is supplying the latest and best solutions to its customers.

IHEA 2022 CALENDAR OF EVENTS

JUNE 15-16

Process Heating & Cooling Show

The inaugural show will focus on industrial heating and cooling processes. This event will bring together numerous industries in the process industries including oil & gas, electronics, pharmaceuticals, food, beverages, packaging and plastics, to name a few.

Donald E. Stephens Convention Center | Rosemont, Illinois

IUNE 28-30

Electrification 2022 International Conference & Exposition

This event will bring together the most diverse group yet of innovators, decision makers and stakeholders in the electrification of vehicles, buildings and industry. Keep at the forefront of our decarbonizing society with immersive pre-conference workshops, executive-level plenary sessions, content-rich breakout sessions in multiple tracks and an exhibit hall showcasing the latest technology.

Charlotte Convention Center | Charlotte, North Carolina

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

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

P.O. Box 679 I Independence, KY 41051 859-356-1575 I www.ihea.org





Determining the appropriate heat transfer coefficients is critical for simulation accuracy.

Characterizing equipment using simple modeling tools

ften, the terms "digital twins" or ICME (Integrated Computer Materials Engineering) are used when talking about computer modeling of actual parts or the behavior of materials in industry. There exists a big push to collect as much data as possible and convert these data to computer models that accurately predict the process parts go through from billet to final product. All this collection of data begs the question: "How can all these data be used?" In heat treatment modeling, there exists a need to accurately represent the boundary conditions of the furnaces and quenching systems used. High thermal gradients that exist in heat treatment have a significant effect on phase transformation timing, the overall strain in the part, and the in-process and residual stresses. Lab tests with carefully controlled environments and probes are great for base data that can be used in general cases, but the experimental conditions in the lab rarely correlate to commercial furnaces or quench systems running real parts. Thus, the use of thermocouples, embedded in actual parts, and data collection systems have become the gold standard in data collection for heat treatment.

For this article, time-temperature data from a salt bath heating and high-speed water quench process will be examined. A utility tool originally developed internally at DANTE Solutions and now

available to the public, called HTCFit, is used to determine the Heat Transfer Coefficient (HTC) that the part surface experiences during heating and quenching. HTCFit uses a forward finite-element (FE) method to quickly execute a series of FE models, having different heat transfer boundary conditions based on the input parameters, to find the best fit to the time-temperature data using an optimization function. This forward method is preferred because it can capture the effects of latent heat due to phase transformations and capture the different thermal properties of individual phases.

The quench probe for this experiment was a cylinder made of AISI 304 stainless steel, with a 60 mm diameter and a 100 mm height, as shown schematically in Figure 1. A 50 mm threaded hole, 25 mm deep, was countersunk in the top of the cylinder, and from there five holes were drilled to insert thermocouples. One thermocouple

was placed on the centerline of the cylinder, representing the core, and four thermocouples spaced radially from the center to measure the temperature near the surface. The top of the probe was sealed with a 50 mm NPT threaded cap and rod to allow an egress for the

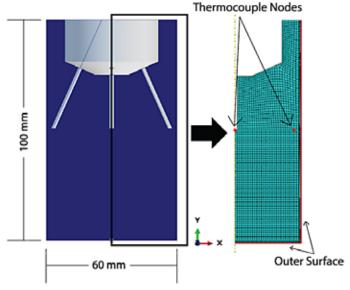


Figure 1. Schematic showing the dimensions of the probe and the paths of the core and near-surface thermocouples. The axisymmetric mesh of the FEA model is on the right.

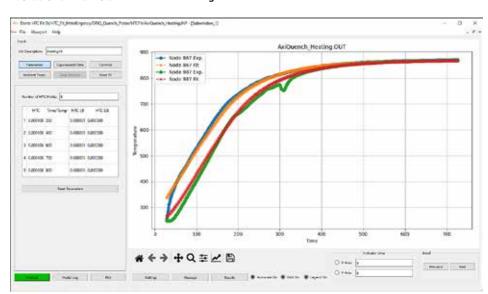


Figure 2. Measured and predicted temperature histories for the near-surface and core thermocouple locations during heating in the salt pot.

thermocouple leads. The experiment was performed by submersing the probe in a bath of molten salt at 870°C until fully soaked. Then, the probe was quickly transferred to a highly agitated water bath where it was quenched to room temperature. The time-temper-

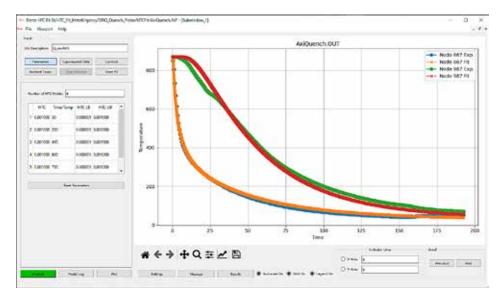


Figure 3. Measured and predicted temperature histories for the near-surface and core thermocouple locations during quenching in highly agitated water.

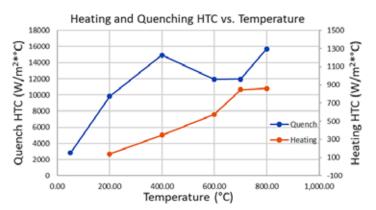


Figure 4. HTC values determined for salt pot heating and agitated water quenching as functions of part surface temperature.

ature data for heating was collected every second while the quench data was collected every 30 milliseconds to capture the rapid quench. Data from the core thermocouple and one near-surface thermocouple were used to fit the surface convection coefficient experienced by the probe for the heating and quenching process. A complication was discovered when viewing the collected data and the probe after the experiments. Some molten salt had entered the cap and housing, causing a slight ripple in the core thermocouple data between 700°C and 800°C. Despite this anomaly, the HTCFit algorithm could ignore this noise and the fit was largely unaffected. Often, when dealing with raw data there is some level of cleanup that is required before processing. Other than separating these data into heating and quenching, no other data cleanup modifications were required.

With the experiments performed and the data collected, an FEA model of the probe is constructed. An axisymmetric CAD model was created and meshed with 3,217 nodes and 3,075 elements, with finer elements near the surfaces to capture the steep thermal gradients present during heating and quenching, as shown in to Figure 1. Nodes, correlating to the positions of the thermocouples on the actual probe, and the outer surfaces were named and defined in the FEA model. The model information was passed to DANTE Solutions' MatSim software, along with the time-temperature data, the initial guess for the HTC values, and an HTC range to search. For this exercise, the HTC is fit by part surface temperature because the

probe is being quenched with water. HTC vs time can also be fit for processes such as gas-quenching, where the HTC and ambient quenchant temperature can vary with time. The heat-up fitting took three minutes to process six design variables while running 77 FEA simulations. The quenching fitting took 2.5 minutes to process seven design variables while running only 40 FEA simulations, despite having significantly more time-temperature data, due to the frequency at which quench data were saved: 6,419 data pairs for the quench vs. 699 pairs for heating.

RESULTS

Results for fitting are shown in Figures 2 and 3. The heating and quenching fit is good overall. The near-surface fit, shown in blue and orange, is the best fit of the two data sets. The core fitting, shown in green and

red, is off in the higher temperature range where the salt entered the probe housing and skewed the data, but otherwise the predicted core temperature follows the heating and cooling data trend reasonably.

The HTC results from HTCFit, shown in Figure 4, reveal that the expected vapor blanket stage, typical of water and oil quenches, is absent for the high-speed water quench. The high agitation quickly removes heated water and replaces it with fresh quenchant so no stable vapor blanket forms. The peak value determined by HTCFit was 15,700W/(m2*°C). This value dipped slightly early in the quench until the surface dropped below 400°C, where the HTC value drops off as convection forces take over in the quench tank.

The HTC value was found to be $140W/(m2^{*\circ}C)$ at the start of heating and steadily increased to a final value of $860W/(m2^{*\circ}C)$ at higher temperatures. The HTC for the salt bath increased almost linearly as the part heated until about $600^{\circ}C$, when radiation begins to play its part in the heat transfer.

CONCLUSION

The need to process time-temperature data into useful heat transfer coefficients for modeling has been fulfilled using HTCFit. The quench probe designed for this application successfully captured the rapid temperature changes present during heating and quenching. The process of determining relevant HTC values is not limited to this probe, or to this particular heating and quench process, and is robust enough to handle virtually any part geometry and quenchant where time-temperature data is collected with embedded thermocouples. The derived heat transfer coefficients can now be used in finite element simulations to accurately simulate the convection boundary conditions present during the heat treatment process. Accurately representing the boundary conditions leads to more accurate models, especially where stress and strain are considered, providing an accurate "digital twin," and shedding light on the black box that is heat treatment.

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.



//// SENIOR RESEARCH SCIENTIST-METALLURGY /// QUAKER HOUGHTON INC.

While it is possible to increase the mass/quenchant ratio beyond 1:1, it comes at a cost of shortened oil life, increased furnace maintenance, cleaning costs, and fire risk.

Revisiting the 1:1 Rule for oil quenchants

he rule of thumb "one gallon of oil to one pound of parts and fixtures" has been in the literature for a long time. The earliest reference I have been able to find is Derby [1] from 1921. In this paper, it described general practice as "one gallon of oil for every pound quenched per hour."

The temperature rise in an uncooled tank can be calculated from the basic equation:

$$M_m C_{p_m} \Delta T_m = M_q C_{p_q} \Delta T_q = \rho_q V_q C_{p_q} \Delta T_q$$

Where M_m is the mass of the metal, C_p is the specific heat of the metal, and ΔT_m is the decrease in the temperature of the metal being quenched. For the quenchant, ρ_q is the density of the quenchant, and V_q is the volume of the quenchant. Similar values of the quenchant are also needed.

Typical values for specific heat (C_n) at 20°C are as follows:

- >>> Steel 0.17 cal/gm/°C (0.17 BTU/lb/°F).
- » Aluminum 0.23 cal/gm/°C (0.23 BTU/lb/°F).
- >> Quench oil 0.45 cal/gm/°C (0.45 BTU/lb/°F).
- >> Polymer quenchant 0.95 cal/gm/°C (0.95 BTU/lb/°F).
- >> Water 1.0 cal/gm/°C (1.0 BTU/lb/°F).

Using the rule of thumb "one gallon of oil to one pound of parts and fixtures" will produce about a 38°C (70°F) temperature rise under nominal conditions. Rearranging the above equation to obtain the temperature rise of a quenchant:

$$\left(\frac{M_m}{V_q}\right)\left(\frac{C_{p_m}\Delta T_m}{\rho_q C_{p_q}}\right) = \Delta T_q$$

We can now look at the effect of the mass-to-quenchant ratio on the temperature rise of the quenchant. Using the values above, and ρ_q of 8.3 pound per gallon, we can now examine the effects of M_m/V_q on the temperature rise of a quenchant. This is illustrated in Figure 1. Several caveats must be mentioned with this calculation. The specific heat (C_p) for steel and the quenchant varies as a function of temperature. For instance, the specific heat for oil increases as a function of temperature (Figure 2), while the specific heat for steel increases slightly as a function of temperature (Figure 3), except for phase changes. The net effect of the increase of specific heat for oil and steel as a function of temperature is that it will decrease the temperature increase upon quenching.

While the use of the fixed ratio of weight of parts of "1 pound of parts to 1 gallon of quenchant" has been disputed [2], the use of the general guideline is conservative for good reason. While an increased temperature rise for oil quenchants may not influence metallurgical properties (especially for higher hardenability alloys), it can affect operation of the system.

Proper design of the quench tank requires that the tank be sized to limit the temperature rise of the quenchant during quenching. This is for several purposes. First, it is one of safety. The load size of

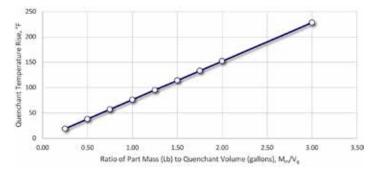


Figure 1: Temperature rise of an oil quenchant as a function of part mass (pounds) to quenchant volume (gallons) ratio.

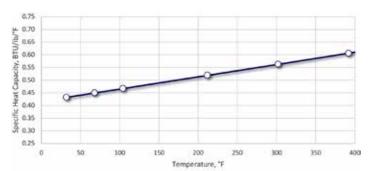


Figure 2: Change in specific heat of oil as a function of temperature.

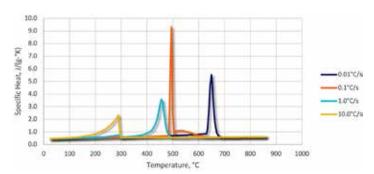


Figure 3: Change in specific heat of 4340 as calculated by JMatPro, as a function of quench rate.

a quench tank is limited to prevent the quench tank from exceeding the flash temperature, plus a suitable margin. From NFPA 86 Standard for Ovens and Furnaces [3], the quench tank should be designed and sized to quench a maximum gross load such that the maximum quenchant temperature is not less than 28°C below the flash point of the quenchant.

However, increasing the part/volume ratio, increases the peak temperature of the oil. While this may allow an increase in production load sizes, it also increases the risk of fire. While the criteria of



NFPA 86 [3] establishes a maximum temperature rise, based on the quenchant flashpoint, it does not provide for any additional safety factor for partially submerged (hung) loads. Further, smaller parts give up heat more rapidly than larger parts. The peak load temperature is achieved more quickly. An additional safety factor is needed. Typically, this safety factor for many specifications is an additional 28°C (50°F).

Lastly, besides the important safety reason, is to minimize oil oxidation. Since the kinetics of oil oxidation approximately double with each 10°C [4], it is very important to minimize the temperature rise. While the use of a larger temperature rise does not generally affect metallurgical properties, it does affect the life of the oil. Since increasing load sizes would result in an increase of the peak oil temperature, oxidation will increase, and the life of the oil would be reduced. It would require the oil to be replaced at a greater interval, costing the heat treater.

The original intent of the 1:1 rule of thumb was to provide a simple (and conservative) rule of thumb for quench tank designers and operators to prevent fires, and to make sure of adequate quenching capacity in the tank. It was not designed to establish quenchant volume for metallurgical properties.

Anecdotally, a customer had a series of large integral quench furnaces, each with a quench capacity of approximately 3,000 gallons. He was using a martempering oil (nominal flash point of 445°F) at quenchant temperature of 250°F and quenching 6,000-pound loads. The customer's temperature rise during quenching was approximately 140°F, to approximately 390°F. Prior to increasing the load size, they were getting approximately three years (36 months) of life from their quench oil. After increasing the load size, the oil life decreased to 18-20 months, with increased staining from oil oxidation. They also experienced increased mechanical maintenance. While the customer was able to increase his throughput in his furnaces, they experienced increased cost due to increased cleaning and grit blasting toward the end of life for the quench oil. They also experienced increased furnace down time due to the increased loading to the

quench elevator. Their oil budget doubled. The customer also experienced some rather close calls with fires due to heat exchanger pump failures and hung loads. I am not sure the increased production rate justified the increased cleaning, maintenance, and oil cost, as well as the increased fire risk.

CONCLUSION

In this column, I have tried to relate the issues with increasing the mass/quenchant ratio beyond the historically accepted "one gallon of oil to one pound of parts and fixtures." While it is possible to increase the mass/quenchant ration beyond 1:1 ratio, it comes at a cost of shortened oil life, increased furnace maintenance, increased cleaning costs, and increased fire risk. A detailed cost-benefit analysis should be performed to understand all the ramifications of allowing the peak oil temperature during quenching to increase.

Should you have any questions regarding this column, or suggestions for additional columns, please contact the editor or myself.

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QUALITY COUNTS ///

/////////////// TONY TENAGLIER | HEAT TREAT PROCESS ENGINEER /// |/////// HITCHINER MANUFACTURING



Heat-treating processes are complex and sometimes confusing. Teaching operators to recognize where the system goes beyond the customer requirements is only one aspect of improved training.

The 'why' in heat treating is important to operators

uality is in the details, but what details need the most attention? A good contract review, starting with the purchase order, then the drawing, then the related customer specifications — whether they be material specifications or specific heat-treat specifications — is considered a good first step and is required for aerospace work. Those steps provide the rules for heat treating the parts and are important.

Companies also put in place work instructions and travelers to keep traceability and control the details of nonconformances and process details, also requirements and ways to maintain control for the process. However, along with these specific parameters it is equally important to understand the "why" from a theoretical metallurgical perspective.

Classroom training is important to realize that what is going on in the furnace is making some serious changes to the microstructure internally. Solution temperatures are designed to be in one phase regions on simple binary equilibrium phase diagrams, but selection of this setpoint must be care-

ful to be above the solvus and below the solidus temperatures. Ramp rates are designed to eliminate chance for overshoot and/or thermal shock to not create any undesirable melting. The time at temperature provides the necessary time for the atoms to diffuse to their positions in the part for the properties needed. Atmospheres are reviewed for carburizing, nitriding, or even protection against vaporization and/or oxidation of elements at the surface of parts. Then design of the quench rate ensures that the certain microstructure is obtained after review of the TTT curve (time, temperature, transformation curves).

CYCLE UNDERSTANDING

The old saying "measure twice and cut once" in the context of heat treat could be interpreted as "learn the theory and fact check twice" to ensure quality of the cycle being run. First, check customer requirements. Second, check theoretical considerations, then hit go!

Customer specifications tell the heat treater to take parts along the process to cook much as you would follow a recipe for cookies in your kitchen oven, so they come out at their best. The parts satisfy the customer's requirements. However, anyone can press the temperature up and down buttons and start a timer and bake the cookies or even obtain the mechanical properties in a specific component that is housed in the combustible section of the jet engine. But the heat-



Heat-treat operators are not necessarily designing and developing the process, but as key components to the process they need to be adequately trained to understand the impact of heat-treat cycles on parts.

treat operator is more than just a mechanized set of limbs pushing buttons and pulling loads.

The operator doesn't need to defend a Ph.D. thesis on thermodynamic and kinetic principles of metallic alloy phenomena when performing a heat-treat cycle, but providing the knowledge and empowering them to know why they are making the furnace do what it needs to do is important to building a sense of belonging and ownership to the process. This promotes the overall quality of the process because the operator feels they are an integral component to what they might otherwise think of as just being a spoke in a wheel. Sometimes, employees who have offices forget that one of their roles is to support the employees who move the product along.

Having some understanding of theory helps in troubleshooting as well. When the power goes out and a load needs to be cooled, the first

question should be "what happened to the microstructure?" rather than simply looking at the answer of what the customer requires. Knowing the "why" gives more clarity on what to do and hopefully the customer specification has taken the same approach.

THERMODYNAMIC CONSIDERATIONS

In thermodynamics, systems go from a state A to a state B under certain variables. So, operators take parts from A to B by loading, running the cycle, and unloading the parts to the next step. However, it's important to educate them on what is actually going on in the microstructure from state A (e.g. as cast microstructure) to a state B (e.g. solution range allowing eutectic phases to dissolve into the matrix). Often this as-cast microstructure is not desirable for end use properties in service and heat treat is required to improve these properties for practical reasons, not just because the customer says to do it. From alloy segregation to controlled precipitation of particular phases that yield mechanical properties, heat treat with carefully designed times, temperatures, ramp rates, and even atmospheres achieve desirable properties from the material.

Studying simple binary phase diagrams provides the tools for the operators to recognize potential eutectic reactions and setup baskets and parts accordingly. The work becomes a form of play when the operator begins to learn the jargon and use it in their conversations around heat treat. Problem solving becomes easier as the engineer can now discuss the process and potential issues in the same language with the entire team.

KINETIC CONSIDERATIONS

Helping operators know where the system goes beyond the customer's requirements is only one aspect for training. Production is always concerned with how fast things can get produced on the floor, so studying the kinetic reactions within the part being heat-treated is beneficial for understanding the time it takes for the atoms to properly diffuse.

One example we recently used was solving the Arrhenius equation in determining the diffusivity of a particular solute atom from the interdendritic region to a secondary dendrite (distance was obtained from a micrograph) to then calculate diffusion time for the solution cycle.

Allowing the operators to see the equation and the math and the assumptions made with the calculation actually confirmed the time the customer had required in their specification. There was no way to speed up this particular process.

A term came up recently calling the heat-treat operators "pseudo-engineers." In a way, there is some truth in that. They are not necessarily designing and developing the process, but as key components to the process they need to be adequately trained to understand the impact of heat-treat cycles on parts. But this does not make them fake engineers. If anything, they are making the entire train move forward. They actually heat treat the parts.

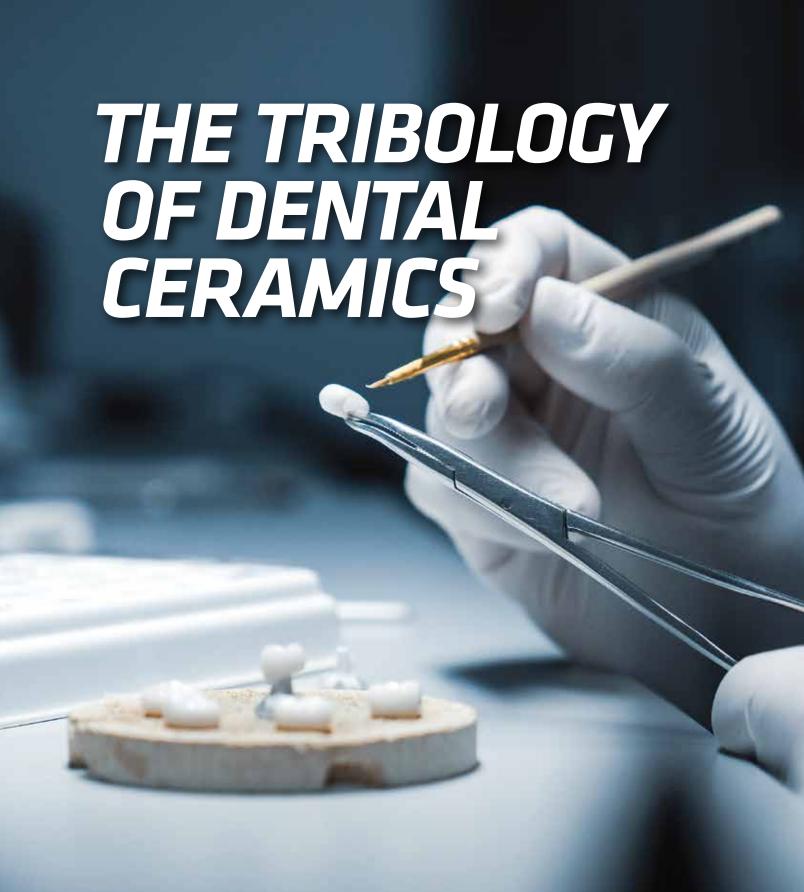
Again, those in offices who make decisions would do well to remember that every team benefits from having players who cooperate and respect each person's role in the process.

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MEDICAL APPLICATIONS / THERMOCOUPLES



Wear factors influence the development of materials and the design of restorations.

By JEANNA VAN RENSSELAR

eramics are widely used in dentistry due to their ability to mimic the optical characteristics of enamel and dentine, as well as their biocompatibility and durability. They include a wide array of materials.

There are three main classes of dental ceramics: predominantly glassy materials, particle-filled glasses, and polycrystalline ceramics (See Figure 1). In general, the higher the proportion of polycrystalline components, the higher the strength of a ceramic.

Conventional production involves blending the minute particles of raw material, forming the mixture into a green body, and firing it at a high temperature. This process is referred to as sintering, which fuses the individual grains to produce a hard, durable, corrosion-resistant product.

Tooth tissue loss is caused by caries or traumatic injuries and might be prevented. However, surface loss due to aging is unavoidable. It is the result of tooth interaction with an opposing tooth, the food that is being chewed, and even the toothbrush and toothpaste. Besides numerous advantages of dental ceramics such as superior aesthetics, favorable physical and mechanical properties, and biocompatibility, these materials might be a factor in additional toothsurface loss. The quantity of surface reduction depends on the ceramic material (chemical composition and microstructure), final procedures before cementation (glazing, finishing and/or polishing), and the restoration type (inlay versus overlay or full crown).

TOOTH SURFACE LOSS

Tooth surface loss most often results from natural tooth-to-natural tooth and/or natural tooth-to-restoration contact (See Figure 2). It is often accelerated by restorations — this is especially true with opposing ceramic restorations. The reduction of surface might lead to a variety of problems. These include loss of enamel, loss of dentine, teeth fracture, hypersensitivity, compromised aesthetics, misshapen teeth, loss of tooth vitality, and problems in chewing and possible jaw problems as a result of reduced facial vertical dimension in patients with generalized tooth surface loss (See Figure 3).

This tooth surface loss can be categorized as:

- >> Erosion (loss due to acids).
- >>> Attrition (loss due to tooth-to-tooth contact).
- » Abrasion (loss due to contact with a foreign object such as a toothbrush).
- >> Abfraction (loss due to flexure, i.e., fatigue cracking).

Tooth surface loss is usually a result of a combination of these factors — with abfraction often instigating the process.

Lab tests reveal that the following factors have a strong influence on the extent of wear:

- >> Configuration (more wear of flat surface).
- >>> Surface treatment (more wear of glazed versus polished restorations).

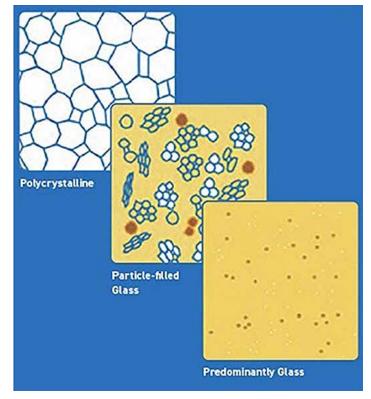


Figure 1: Three types of ceramic materials. (Courtesy: J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health)

- >> Antagonist system (more material wear and less antagonist wear for ceramic versus enamel) [1].
 - >> Enamel thickness (more wear with thinner enamel).

The surface finishing and contouring of ceramics does have a significant effect on the rate and extent of wear (See Figure 4). However, ceramic restorations when polished are hard on opposing enamel and on opposing natural teeth that have restorations. Ceramics, while aesthetically favorable and very wear resistant in themselves,

are even more abrasive than gold, amalgam and composites. This is one of the reasons dental professionals don't favor ceramics in all applications (See Figures 5 and 6).

"In general, the wear of brittle materials, such as dental ceramics, occurs primarily due to crack growth mechanisms rather than plastic deformation," said Dr. Paulo Francisco Cesar, associate professor, department of biomaterials and oral biology, School of Dentistry, University of Sâo Paulo. "Factors that influence the wear behavior of dental ceramics include ceramic type, microstructure, fracture toughness, surface



Figure 2: Tooth surface loss in anterior maxilla. (Courtesy: European Journal of Dentistry and U.S. National Institutes of Health.)

quality/roughness, contact load, environment, and the number of cycles. Wear facets in dental ceramics usually present a series of superficial microcracks forming a zone of quasi-plastic deformation." [2]

Cesar goes on to explain that, under higher contact loads and high friction, subsurface crack propagation (brittle fracture) results in the formation of large wear particles due to delamination. Delamination wear of glass ceramics is associated with the presence or formation of microcracks. Because of this, ceramic materials that possess higher fracture toughness, such as zirconia, are able to resist delamination wear better than low-fracture toughness ceramics, such as porcelain, that possess lower fracture toughness [3].

In vitro wear studies have revealed partially detached wear particles and/or subsurface cracks running parallel to the sliding surface in both dental ceramics and enamel. These indicate that the wear particle formation can occur gradually with a lateral crack extending due to cyclic tensile loading by the sliding antagonist (i.e. delamination wear controlled by a fatigue process). The delamination process can, thus, result in relatively low wear or high wear, for example, when considering enamel opposing polished zirconia under low load or enamel opposing rough zirconia under high load, respectively.

"Overall, lower ceramic and/or opposing enamel wear is generally noted when the ceramic material possesses high flexural strength or fracture toughness, the ceramic material, particularly for feld-spathic porcelains or leucite glass ceramics, contains a high fraction of small, uniformly distributed crystals, when the ceramic contains fewer internal defects (e.g., cracks, pores) or the surface roughness of ceramic is reduced (e.g., by polishing)," Cesar said.

MAXIMIZING DURABILITY

"Efforts to understand clinical failure of single crowns and multiunit prostheses (bridges) has involved studying fracture surfaces from clinically failed prostheses (using fractography), finite-element analysis modeling, and developing clinically valid laboratory tests," said J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health. "These all demonstrate that the main mechanism of bulk failure of single ceramic crowns does not involve damage from wear facets but stresses on the cementation surface due to occlusal loading."

According to Kelly, there are four clinical techniques for maximizing durability:

- **1.** Providing maximum occlusal thickness for the ceramic (strength increases with the square of the thickness).
- **2.** Using the highest elastic modulus (stiffness) substrate possible (i.e., metal or ceramic versus resin-based composite).

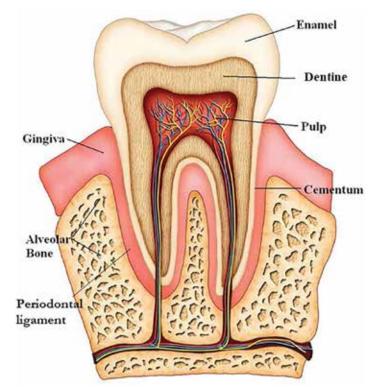


Figure 3: Structure of a tooth. (Courtesy: Dr. Mahdiyyah Baig, University of Southampton)

- **3.** Bonding the restoration, ceramic cement, and cement tooth (or substructure).
 - 4. Developing broad, not pinpoint, occlusal contacts.

ADVANCEMENTS IN CERAMICS

"Dental ceramics is a unique family, not only due to the varieties in the physical and mechanical properties but also due to the variation in the production methods and uses," said Dr. Ahmed Hussain, assistant professor in prosthodontics at the College of Dentistry, University of Saskatchewan. "Initially, dental ceramics were composed mainly from materials that exist in nature such as silica, potassium, sodium and others—glass-based ceramics. Although they are still in use due to their high aesthetic characteristics, they have low flexural strength, which makes them unsuitable for use in the high loading areas of the mouth. That is why their use is usually limited to the anterior part of the mouth."

"Later on, high-strength ceramics such as zirconia were introduced," he said. "Although zirconia has a high flexural strength,

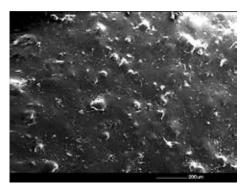


Figure 4: Scanning electron microscope image of an unglazed, unpolished ceramic surface. (Courtesy: European Journal of Dentistry and U.S. National Institutes of Health.)

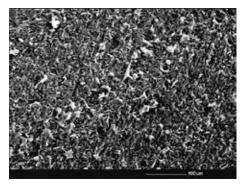


Figure 5: Scanning electron microscope image of an abraded/adjusted ceramic surface. (Courtesy: European Journal of Dentistry and U.S. National Institutes of Health)

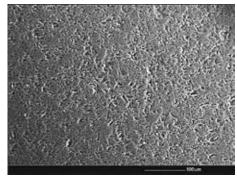


Figure 6: Scanning electron microscope image of an adjusted, polished surface of a ceramic. (Courtesy: European Journal of Dentistry and U.S. National Institutes of Health)

TRIBOLOGICAL TESTING OF DENTAL CERAMICS

The most common tests used in dental research to simulate wear are:

- >>> **Toothbrush abrasion:** The simulation of the toothbrush abrasion uses specimens with defined size and load for simulated tooth brushing of the dental restoration.
- >> **Pin-on-block test:** The antagonist (e.g., steatite, alumina, zirconia) with a defined load hits the specimen.
- >> Two-body abrasion: In a two-body test arrangement, according to the principle of the two-medium abrasion, like a chewing simulator, a direct contact between antagonist and a tooth-shaped sample surface exists.
- >>> Three-body abrasion: The main difference between the two-body abrasion and the three-body abrasion is that a medium is used between the two bodies.

Material attributed to Dr. Paulo Francisco Cesar, associate professor, department of biomaterials and oral biology, School of Dentistry, University of Sâo Paulo.

FRACTURE TOUGHNESS

The following conclusions by J. Robert Kelly, DDS, MS, DMed-SC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health, are drawn from a recent analysis, using published failure data to explore the predictive value of ceramic fracture toughness.

- **1.** Fracture toughness in the research lab does provide a significant correlation with clinical behavior.
- 2. The annual failure rate for ceramic materials has plateaued, implying that manufacturers are not advised to spend research time and funds on tougher ceramics. "It is apparent that further progress will more likely come from learning how to make current parts to a higher quality," Kelly said. "Future dental ceramics restorations will derive from enhanced engineering with current materials."
- **3.** There is better than predicted clinical success with certain ceramics with actual failure rates much less than the regression predicts for that toughness. "This is likely the 'bonding effect' since this is a very etchable ceramic," Kelly said.

its aesthetic characteristics are not close to that of the glass-based ceramics. So, the dentist sometimes uses a combination of ceramic materials to address the functional and the aesthetic needs of the patient."

All ceramic materials have excellent aesthetic qualities that rival healthy natural teeth. However, ceramics tend to be brittle and fracture under high stress. To offset that, the current trend is to reinforce ceramics with crystalline materials. There are three basic categories of dental ceramics:

- >> Predominantly glassy (also called porcelains).
- >> Particle-filled glasses.
- >> Polycrystalline.

Kelly explains these three categories as follows:

>> Predominantly glassy ceramics are based on feldspar, are resistant to crystallization (devitrification) during firing, have long firing ranges (resist slumping if temperatures rise above optimal) and are extremely biocompatible. In feldspathic glasses, the 3D network of bridges formed by silicon-oxygen-silicon bonds is broken up occasionally by modifying cations such as sodium and potassium that provide charge balance to non-bridging oxygen atoms.

» Particle-filled glasses have filler particles that are added to increase the strength and fracture toughness of the ceramic. Commonly used fillers include aluminum oxide, leucite, and lithium disilicate. These particles can decrease the natural flaw size of the ceramic and make crack initiation and propagation more difficult. They also generally increase the opacity of the ceramic as well by increasing light scatter.

>> Polycrystalline ceramics have no glassy phases; all of the atoms are densely packed into regular arrays that are much more difficult to drive a crack through than atoms in the less dense and irregular network found in glasses. Hence, polycrystalline ceramics are generally much tougher and stronger than glassy ceramics. Well-fitting prostheses made from polycrystalline ceramics were not practical prior to the availability of computer-aided manufacturing.

According to Kelly, the dental ceramics that best mimic the optical properties of enamel and dentin are predominantly glassy materials (see Tribological Testing of Dental Ceramics).

PROCESSING

Porosity in dental restorations is undesirable because it increases the roughness of the surface and can lead to increased wear. Sintering reduces porosity. During the sintering process, high heat causes the ceramic particles to consolidate. This leads to a reduction in the porosity of the surface and, to some degree, the rest of the material. The extent of porosity depends on the length of time and the degree of temperature during the sintering process.

Porcelain can be fortified via a process called "dispersion strengthening" during which the material is reinforced with magnesia and alumina. Zirconia also can be added to strengthen the porcelain in a process called "transformation toughening." When the zirconia is further stabilized with yttria (yttrium oxide), it has increased strength, thermal shock resistance, and fracture toughness. The downside is that it is less translucent. Because of this, copings are usually veneered to achieve better aesthetics.

Glass ceramic restorations are developed in a non-crystalline state and then converted into a crystalline material. To fabricate glass ceramic restorations, wax patterns are made using a dental wax. The liquefied ceramic is cast into the empty space in the investment material after the wax has been burned out. Then the glass is heated again for six hours. This leads to the formation of tetra-silicic fluoromica crystals. The resulting crystals improve strength and fracture toughness and increase abrasion resistance and chemical durability (see Fracture Toughness).

"The ceramic material itself does not affect the price of the dental restoration significantly," Hussain said. "The major factor that would affect the price is the time required to fabricate the restoration, the experience of the ceramist and (the more the experienced the ceramist, the higher the fee) if it is going to be fabricated either partially or completely by computer-aided manufacturing or if it will be fabricated the conventional way."

Most dental professionals are aware of not just these and other recent advancements in ceramic restorative materials but also the importance of finishing and polishing these materials before finalizing the patient's procedure.

"In dental prosthodontics, the surface finish is a key factor," Cesar said, "Finishing and polishing can be carried out intraorally or in the laboratory. Intraoral polishing is a difficult task and demands good operator skills and a variety of intraoral instruments to achieve an acceptable result. The final aim in dentistry is to achieve the lowest surface roughness possible, as rough surfaces result in more wear, more biofilm accumulation and discomfort for the patient."

ADVANCEMENTS IN MANUFACTURING

The development of computer-aided design/manufacturing (CAD/CAM) methods for the creation of restorations such as inlays, crowns, and bridges has enabled cutting-edge machinable ceramics. Because they can be created while the patient is still in the chair, they eliminate at least one additional visit. The downside is that CAD/CAM technology is expensive, and the process requires more than a little expertise.

"Technological improvements have come from both design/processing and materials enhancements (See Figure 7)," Kelly said. "Understanding how to maximize durability by design and processing flows from understanding clinical failure and the factors influencing the stress state at failure that are within our clinical control. (See Figures 8 and 9)

CAD software sets the parameters for the dimensions and shape of the restoration; CAM software defines and governs the manufacturing process. CAD/CAM has

been used for restorations by dental professionals for three decades. Prior to that, the alternative was slip-casting, which resulted in more defects/cracks in the restoration.

CAD/CAM systems are continually producing better restorations, for not only ceramics but also metal alloys and resin composites. CAD/CAM techniques for producing restorations involve:

- >> Machining the prosthetic restoration from a mass of sintered material.
- >> Machining a partially sintered mass that then requires final sintering.
 - >> Additive manufacturing technique (AMT).

The first method results in a more precise restoration and also takes less time. However, with some materials, it can lead to defects, be hard on the machining unit, and actually take more time.

The second method has the advantage of healing defects that occurred in the machining process during the subsequent sintering process. This final sintering, however, can misshape the restoration and create a misfit in the patient's oral area. One of the issues with CAD/CAM for dental restorations is that the machining process wastes about 90 percent of the material, which cannot be reused. New technologies are being developed to mitigate this such as AMT [4].

"Usually dental ceramics can be produced either conventionally or digitally," Hussain said. "In the conventional method, the quality of the final restoration is highly dependent on the technique, the material used, and the experience of the dental technician. The conventional method is usually time consuming, and it is getting less common in dental labs because of the advances in digital technology. More dental offices are getting digital scanners to scan the prepared teeth. Then they send the digital files from the scanners to the lab. In the lab, a dental technician, with the help of special software, can fabricate a restoration that will not only fit the prepared teeth but provide function, aesthetics, and comfort for the patient."

Hussain believes digital restoration design software is an essential part of any dental lab because more dental clinics are sending their impressions digitally—today many restorations are completely designed and fabricated digitally. This includes anything from a single restoration up to a full mouth restoration. Hussain said digitized

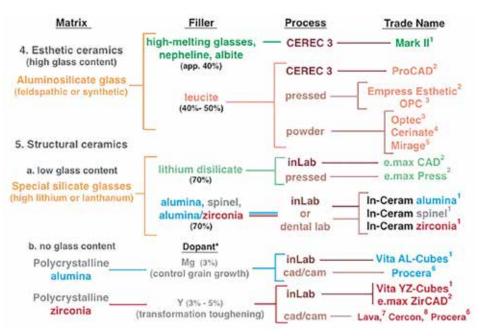


Figure 7: Types, composition, processing, and trade names of dental ceramic materials. Figure courtesy of J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health)

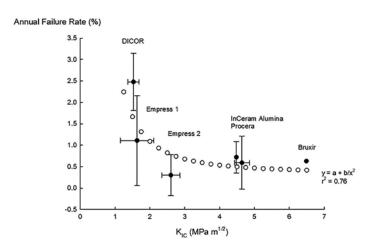


Figure 8: Failure rates for various dental ceramic materials. (Courtesy: J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health)



Figure 9: Clinical failure typically involves two pieces, no subsurface damage at the wear facet and patient reports of "chewing something soft." (Courtesy: J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health)



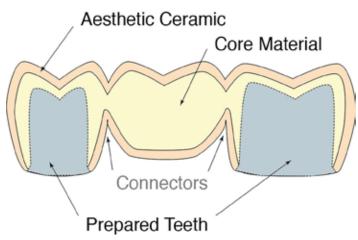


Figure 10: Cross-section of the anatomy of three-unit prostheses for a bi-layered ceramic system (outline form would be identical for a monolithic ceramic system). (Courtesy: J. Robert Kelly, DDS, MS, DMedSC, professor of prosthodontics and dental materials science, School of Dental Medicine, University of Connecticut Health)

 $manufacturing\ has\ improved\ dental\ ceramics\ in\ the\ following\ ways:$

- >> It has reduced the time of dental restoration production.
- >> It has reduced the cost.
- >> It has led to better quality consistency since the material is supplied by the manufacturer in the processed or green stage.
- >> There are better physical and mechanical properties of the materials.
- >> The production of such materials as high-strength ceramics is much easier.
- >> A replacement restoration can be fabricated because the file for the restoration manufacturing is already stored digitally.
- >>> There is less possibility for error since there is less of a human factor involved in production.

"The digital revolution has radically changed the workflow in dental clinics around the world, and some dental ceramics like zirconia are only produced via CAD/CAM," Cesar said. "Gradually, prosthodontic procedures are changing to a completely digital workflow, beginning with the planning steps that include printing test-drive smiles in a 3D printer, with subsequent planning of the rehabilitation in an advanced CAD software and final steps involving milling the ceramic restoration in specialized CAD units. By using

this workflow, a full-mouth rehabilitation with ceramics can be performed in two or three days."

AESTHETIC CONSIDERATIONS

There are several factors that affect the aesthetics of the dental restoration such as optical properties, surface texture, polish ability, resistance to staining, and color stability. The missing tooth structure is usually composed of two layers (dentin and enamel). The combination of these two layers affects the tooth value, color, and chroma.

"A closer look at the complex light interaction with these two layers makes us wonder if there is a single ceramic material that can have aesthetic properties similar to the natural tooth structure," Hussain said, going on to explain that the dentist usually faces one of the following two scenarios:

>> The dentist is trying to restore a nondiscolored tooth for a patient who does not want to change the color of the tooth but to improve

its shape or restore the missing tooth structure. "In this scenario, the dentist should try to use a ceramic material that has a high translucency so that the light can pass easily through the restoration to interact with the natural tooth structure, which, in turn, will show the natural color of the tooth," Hussain said.

>> The dentist is dealing with discolored teeth that the dentist and the patient both think are undesirable. In this scenario, the dentist should use a high opacity (low translucency) dental ceramic to block the undesired color of the tooth and to establish a new natural color.

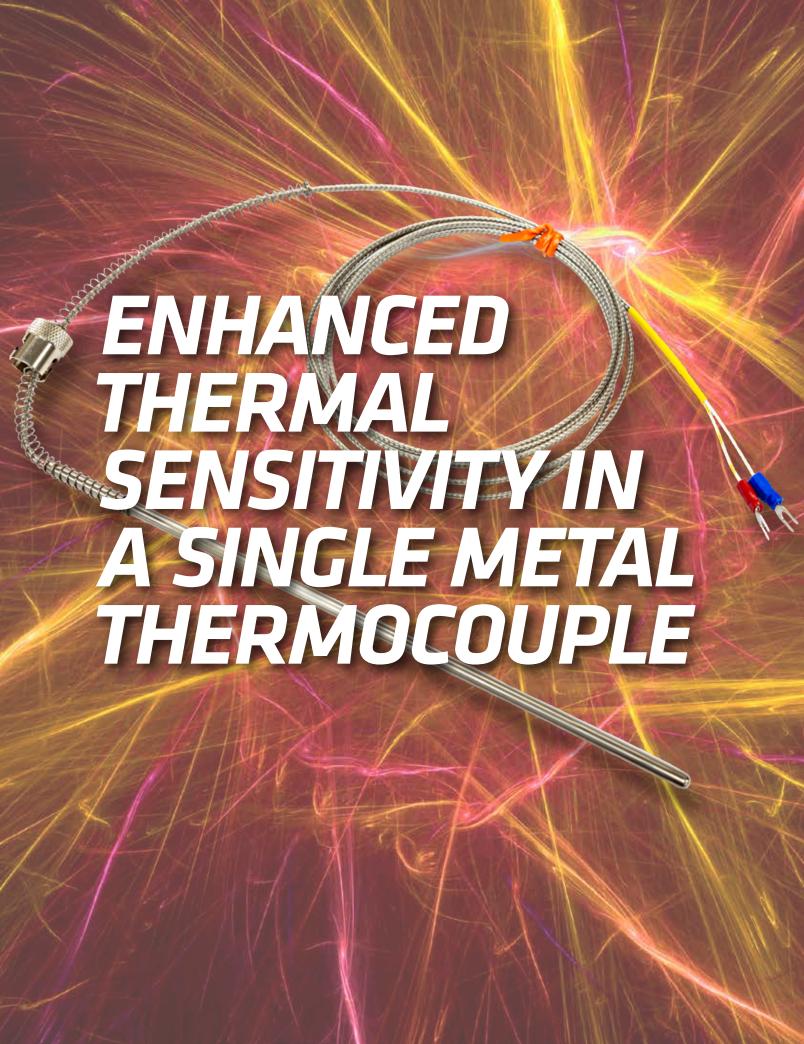
As ceramic materials and processes continue to develop, aesthetics, wear resistance, and patient convenience will improve (See Figure 10). "Twenty years ago, I would not have predicted the use of engineering failure analysis of clinically failed prostheses and the increased use of clinical longevity studies to improve the performance of dental ceramics," Kelly said. "However, design details, such as crown thickness and connector dimensions of multi-unit prostheses, have derived from these investigations."

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Noting a significance of thickness-engineering of the metal layers, this article introduces an alternative method to achieve higher thermal sensitivity from single metal thermocouples (SMT).

By RAFIQ MULLA and CHARLES W. DUNNILL

ingle metal thermocouples (SMTs) have recently been developed with a new design concept of widthengineering of metal segments. In such designs, two segments of different micro-width are formed to obtain different levels of Seebeck effects. The variations in the Seebeck effect achieved from dissimilar segment width are small. In addition, the fabrication of such micro-width patterns requires special fabrication facilities such as photolithography or electron-beam lithography. In this article, an alternative method is presented that has the potential to give high thermal sensing SMTs and requires no sophisticated facilities to fabricate. The method is based on thickness-engineering instead of width-engineering, and thus devices can be obtained from commonly available thin film deposition techniques. Constructing better thermal sensing SMTs is possible with this approach as thickness can be easily and conveniently varied down to nanoscale range, which is necessary to achieve significant changes in the Seebeck effects from effectively using size effects. As a result, a high thermal sensing bismuth based-SMT has been fabricated with a sensitivity of as high as $31\mu VK^{1}$, one of the highest values reported for SMTs. It is straightforward, more convenient over width-engineering approach and thus SMTs can be easily developed.

1 INTRODUCTION

Thermocouples, a universal type of thermometer, are typically made up of two dissimilar metals [1, 2]. These devices work on the principle of the Seebeck effect and, therefore, the use of two metals of dissimilar Seebeck coefficients is a basic requirement to observe a voltage signal from these sensors [1]. When two dissimilar metals/conductors of different Seebeck coefficients (S_1 and S_2) are joined to form a thermocouple junction, an open circuit voltage signal can be observed by heating or cooling the junction. The magnitude of this voltage (ΔV) is directly proportional to (i) temperature difference (ΔT) between the junction and open ends of the metals and (ii) difference between the Seebeck coefficients (S_1 and S_2) of metals, which can be expressed as [1]:

$$\Delta V = (S_1 - S_2) \Delta T$$
. Equation 1

where S_1 and S_2 are the Seebeck coefficients of metal 1 and 2, respectively.

Alternatively, researchers have come up with a new concept of "single metal thermocouple" (SMT) in which a single metal layer with two segment patterns of different widths are used, as illustrated in Figure 1a [1–4]. In these width-engineered patterns with at least one of the segments of narrow width, the Seebeck coefficient can be modified with respect to the wider segment to obtain a net voltage from the sensor. As they need micrometer wide patterns, the construction of the width-engineered thermocouples requires special fabrication techniques such as photolithography or electron-beam lithography [1, 2, 5, 6]. Further, due to the limitations of reducing the width down to the sub-100nm range, the thermoelectric changes

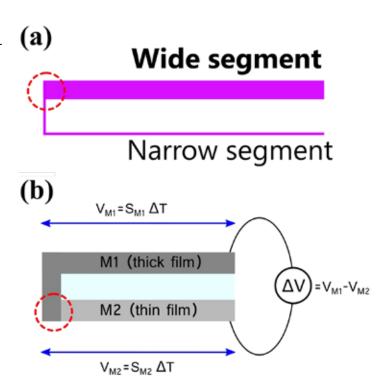


Figure 1: Schematic of (a) width-engineered thermocouple constructed from the single metal having wide and narrow segments and (b) is the proposed thickness-engineered thermocouple constructed from the single metal having thick (M1) and thin (M2) segments. The terms S_{M1} and S_{M2} are the Seebeck coefficient of M1 and M2, respectively; V_{M1} and V_{M2} are the voltage generation from M1 and M2 segments, respectively when the junction is maintained at a temperature gradient of ΔT with respect to surroundings or the open ends of the metal segments. The red dotted circles show junction region of the sensors.

between the wide and narrow segment are also limited. As a result, most of the reported width-engineered SMTs have low thermal sensitivity of about 1-5 μ VK⁻¹. Here, an alternative and straightforward method to fabricate SMTs has been developed that overcomes the above difficulties, enabling the construction of SMTs with better thermal sensitivity. The method is based on thickness variation of the metal patterns instead of width, as the thickness of the patterns can be easily and conveniently varied or controlled in the nanoscale range with common thin film deposition techniques (Figure 1b). As a proof of concept, a bismuth-based thickness-engineered SMT has been designed and developed that shows a high thermal sensitivity of 31μ VK⁻¹, one of the highest values reported in SMTs.

2 EXPERIMENTAL DETAILS

2.1 Thin film fabrication

For initial thermoelectric testing, bismuth (Bi) thin films of different thickness (t ~ 500nm, 200nm, 100nm, 50nm, 20nm) on

glass substrates have been deposited by the sputter coating method (Model: Quorum Q150T S coater) using a bismuth target (99.9% purity, PI-KEM Ltd). For every deposition run, the sputtering chamber was evacuated to 10^{-4} mbar and films were deposited at room temperature under an argon atmosphere (10^{-2} mbar). A sputter current of 20mA was used for all the films and thickness was controlled using the film thickness monitor accessory of the instrument.

2.2 Fabrication of single metal thermocouple (SMT)

The SMT device consisting of two Bi layer strips/segments of t ~ 20nm and 500nm was patterned on a microscope glass slide (size: 75mmÅ~25mm). To fabricate this device as illustrated in Figure 1b, first, a thin metal layer strip (t ~ 20 nm, width: 8mm) was deposited and then an L-shaped thick metal layer (t ~ 500 nm, width: 8mm) using a mask. Another SMT device having two junctions was fabricated by patterning a thin metal layer (t ~ 20 nm) between the two thick metal layers (t ~ 500 nm).

2.3 Measurements and characterization

The Seebeck coefficient measurements on Bi thin films of different thickness were performed using a standard method with a homemade setup [7]. The thermoelectric voltage (ΔV) produced from the thin film samples have been recorded at different temperature gradients (ΔT), and the Seebeck coefficients were estimated using the expression, $S = -(\Delta V/\Delta T)[8, 9]$. The electrical resistivity of the films was obtained from the standard four-probe method. The output characteristics of the SMT sensors were performed by heating the junction to different temperatures and recording the output voltage signal. The junction heating was achieved from a small resistive heater (size: 5mmÅ~5 mm, thickness: 1 mm, resistance: 100Ω) [10] by supplying DC-power inputs. This heater and a K-type thermocouple were fixed on a thin copper plate (thickness ~ 0.5mm) of similar size as the heater using high-temperature glue; the resulting heating element was then placed on the junction area of the SMT. Good physical contact between the heating

element and junction was maintained by a pressing arrangement with a spring clamp set. All the thermoelectric voltages of the individual films and the output voltage signal of SMT sensors were measured with micro-voltmeters (Model:HMC8012DMM). The DC-voltage accuracy for this model of multimeter is 0.015% of reading +0.002% of range. So, for the most precise range of 400.000 mV, the best accuracy would be about 8 μ V. The surface morphology of the junction area of a sensor was obtained by scanning electron

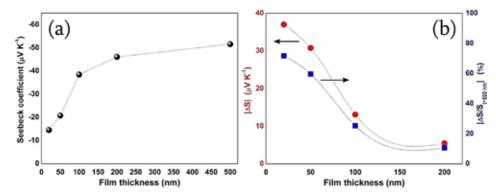


Figure 2: (a) Variation of Seebeck coefficient as a function of Bi film thickness, (b) dependence of the absolute value of Seebeck coefficient reduction, $|\Delta S|$, and relative reduction of Seebeck coefficient, $|\Delta S/S_{t=500nm}|$, on the films of thickness, t ~ 200nm, 100nm, 50nm, and 20nm with respect to the first film of t ~ 500nm.

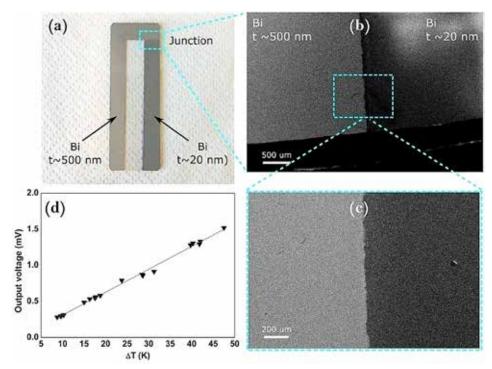


Figure 3: (a) Photograph of a dual strip Bi thin film SMT sensor fabricated on a glass substrate. (b), (c) Scanning electron microscopy (SEM) images of the junction region of the sensor, marked with a blue dotted frame on the real photograph. (d) Output voltage signal of the Bi SMT measured at different temperature differences (ΔΤ).

The fabrication of thickness-engineered SMTs is simple and does not require any special facilities, which makes the approach more preferable and economical.

microscopy (SEM) using a Zeiss Evo LS25 SEM.

3 RESULTS AND DISCUSSION

The proposed thickness-engineered design of a single metal thermocouple (SMT) based on different thickness metal layers is schematically displayed in Figure 1b. Bi metal has been chosen for the purpose due to its more prominent thermoelectric changes with respect to the changes in the material dimension, and, also, it is one of the

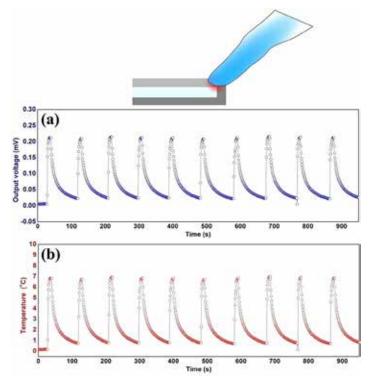


Figure 4: The sensing capability of the Bi SMT: (a) Typical output voltage response from the SMT when touching its junction with a gloved finger for 10 repetitive cycles with pressing time of 10 seconds at each cycle, (b) The data after converting voltage response into temperature response.

metals to display substantial thermoelectric effects, as compared to any other metal [11, 12]. The changes in the thermoelectric effects have been confirmed by measuring the Seebeck coefficient (S) of the individual Bi films of different thickness; the data is shown in Figure 2a. The observed room temperature S value of a 500nm thick film is -52μVK⁻¹, which has seen a decreasing trend with respect to reduction of film thickness; $-46\mu VK^{-1}$, $-39\mu VK^{-1}$, $-21\mu VK^{-1}$, and $-15\mu VK^{-1}$ are the S values of the films having thickness 200 m, 100nm, 50nm, and 20nm, respectively. The reduction in the Seebeck coefficient in thin films as compared to their bulk values has been observed in most of the metal films due to the increased electron scattering at the surface and theoretically described by the Fuchs-Sondheimer model [1, 13, 14]. The variation of resistivity as a function of film thickness is shown in Figure S1 (available online at stacks.iop.org/ ERX/3/035015/mmedia) (supplementary file); the resistivity of the thick film (t ~ 500 nm) is found to be 5.4Å~ $10^{-4}\Omega$ cm, which is slightly more than its bulk resistivity and consistent with previously reported values for Bi thin film [12, 15]. With the decrease in film thickness, it is found to increase as shown in Figure S1 (supplementary file). This increase is attributed to the fact that charge carriers in thin films undergo scattering at the film surface, which is more pronounced in the case of very thin films.

The dependence of absolute values of S reduction, $|\Delta S|$, on the films of thickness, t ~ 200nm, 100nm, 50nm, and 20nm with respect to the first film (t ~ 500nm) are shown in Figure 2b with an observed maximum $|\Delta S|$ for the film with t ~ 20nm. The change of S from $-52\mu VK^1$ to $-15\mu VK^1$ demonstrates a very high relative reduction of Seebeck coefficient $|\Delta S/St=500~\text{nm}|$ of about 70%, which is higher than values achieved in width-controlled segments. For illustration, a maximum relative reduction of Seebeck coefficients of about 30% to 35% was reported in Ta and Ti metals by decreasing the segment width from 100 μ m to $3\mu m[14]$. But in the case of Bi, the reduction of segment width to 3μ m has resulted in a less than 6% reduction

[14] . These data indicate that the thickness-engineered sensors can have better output signal or thermal sensitivity in contrast to the width-engineered sensors. The changes in the Seebeck coefficient with respect to material dimension can be understood through standard expressions, such as the Mott-Jones equation for S (in metals), which is expressed as [14, 16]

$$S = -rac{\pi^2 k_B^2 T}{3e} igg(rac{d \ln \sigma}{dE}igg)_{E=E_f}.$$
 Equation 2

where k_B , σ , e, T, E, and E_f are Boltzmann constant, electrical conductivity, the charge of the electron, temperature, electron energy, and the Fermi energy, respectively. As the electrical conductivity (σ) in metals can be expressed by [14]

$$\sigma = rac{e^2 \lambda A}{6 \pi^2 h}.$$
 Equation 3

where λ , A, and h are the mean free path of charges, Fermi surface area, and the Plank's constant, respectively, the equation for S can be divided into two parts [14]:

$$-\frac{\pi^2 k_B^2 T}{3e} \left(\frac{d \ln \lambda}{dE}\right)_{E=E_f} - \frac{\pi^2 k_B^2 T}{3e} \left(\frac{d \ln A}{dE}\right)_{E=E_f}.$$
 Equation 4

The variations to the S from the second term in the above equation are not expected as the term $(d\ln A/dE)_{E=Ef}$ can change in the case of atomic-scale material dimensions, hence the second term is approximately considered constant [14]. Therefore, the size effects on the S are in general dominated by the first term (related to λ). It is well-known that surface scattering is an additional mechanism that occurs in thin films in addition to the phonon, impurity, and defect-scattering mechanisms [13]. The surface scattering can influence the S and other transport properties when the thickness is comparable to the mean free path (λ) of the charge carriers (for most metals, the range of λ is about 40-100nm) [13, 14]. Therefore, the bulk S values can be changed by reducing at least one of the dimensions to nanoscale and significant changes in S can be expected in thin films of nanoscale thickness as compared to microscale width-engineered patterns.

The photograph of SMT displayed in Figure 3 has two segments of t = 500nm and 20nm as the maximum difference in the Seebeck coefficient $|\Delta S|$ can be obtained from this combination. The surface morphology of the films and the junction region are also given in Figure 3, which show the morphological differences between the thick and thin film. The open-circuit voltage (ΔV) as a function of temperature gradient (ΔT) is shown in Figure 3d; a linear increase in the ΔV with respect to the increase in ΔT has been observed with a slope value of $31\mu V K^{-1}$, one of the highest sensitivity values from the SMTs reported until now. The observed sensitivity is in near agreement with the estimated $\Delta S = 37\mu V K^{-1}$ from S values of the individual segments of t = 500nm and 20nm. The output signal data points are well aligned with linear fittings with a good R² value of 0.995, which suggests that the sensor has a nearly constant sensitivity factor and can be useful for thermal sensing applications around room temperature. These measurements were carried out at a room temperature of ~21± 2°C and the devices can be used up to ~80°C without any problems. The small decrease in the observed sensitivity of the thermocouple as compared to the estimated ΔS might be associated with the uncertainties in the junction heating temperatures. Previous work on a Pd thin film SMT with dual strips of widths 30µm-200nm has reported a maximum sensitivity of 2.2µVK⁻¹ and for a Ni film based SMT with strips widths 100μm-3μm, a maximum sensitivity of 1.1μVK⁻¹ has been reported [2, 5]. Recent studies suggest that the high thermal sensitivity values as compared to metal-based devices can be observed

in carbon or graphene-based devices [4, 17].

The sensing capability and reliability of the Bi SMT have been studied under a continuous and cyclic operation by touching the junction with a finger wearing a nitrile glove for 10 seconds and recording the generated signal from the SMT. As shown by Figure 4a, a sharp increase in the voltage signal is observed for each touching cycle and the observed maximum voltage is consistent. The observed voltage signal is then converted into temperature by using the thermal sensitivity value of $31\mu VK^{-1}$ in order to realize the temperature change before and after touching the sensor; the data of which is plotted in Figure 4b. The observed peak values from the 10 repetitive touching cycles are found to be in the range of 6.70°C to 6.96°C with an estimated average value of 6.85(±0.08)°C (the data scatter rang e±0.08°C was estimated from 10 peak temperature values of the heating cycles). Further, the reliability of this observed temperature change from the Bi SMT was confirmed by a similar procedure with a standard K-type thermocouple sensor; the rise in temperature was recorded by touching it with a gloved finger for a similar time period of 10 seconds. The recorded variation in the temperature is shown in Figure S2 (supplementary file); the temperature reading has changed from 21.3°C (room temperature) to 27.8°C before removing the finger after 10 seconds, which indicates a net change of 6.5°C. These measurements confirm that the SMT is giving reliable information, the small difference between the temperature data from the SMT and standard K-type thermocouple, which is about 0.3°C, could be due to the variations in the pressure applied by the finger or the pressing time. Further, the thermal response time of the SMT is very short, which is evident from the sharp rise of the voltage signal observed immediately after touching the sensor; a magnified single curve has been shown in Figure S3 (supplementary file).

The sensing reliability of the SMT under heating cycles was also studied by heating with a standard resistive heater fixed on the junction; Figure 5 shows data of two heating cycles. The heater was applied with a fixed DC power for ~1 minute and turned off, the output voltage variation of the SMT was recorded; a similar procedure was repeated to record sensing data for the second heating cycle. The sensor output voltage was then converted into temperature using its thermal sensitivity value (see Figure 5b). The temperature change

of ~15.5°C was observed from the SMT sensor whereas the temperature of the standard thermocouple attached to the heater changed from 21.7°C to 37.6°C resulting in a net change of 15.9°C. These results indicate that the present SMT sensors can produce reliable thermal sensing data.

The dissimilar Seebeck effects in Bi film segments of different thickness have also been observed and confirmed with a design of a two-junction (J1 and J2) pattern. For this, a thin film segment (t ~ 20nm) was deposited between two thick film segments (t ~ 500nm) as shown in Figure 6. When one of the junctions was heated using a small resistive heater placed on one of the junctions,

there was a voltage generation from the pattern and also, there was a change in the polarity of the output voltage when the hot junction was changed from J1 to J2 or vice-versa; the output voltage response is presented in Figure 6b. This confirms that the change in the direction of net flow of charges through the pattern made up

Heater 0.5 off Output voltage (mV) 0.0 0.0 1 0.0 Heater on 200 300 0 100 400 500 Time (s) (b) Temperature (°C) 200 100 300 400 500

Figure 5: The sensing capability of the Bi SMT: (a) Typical output voltage response from the SMT when a heater in contact with the junction was turned on and off, (b) the data after converting output voltage into temperature.

Time (s)

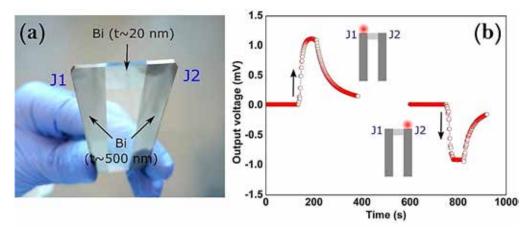


Figure 6: (a) A real photograph of two junction (J1 and J2) pattern fabricated on a glass substrate and (b) variation in the output voltage signal when a temperature gradient is created between junctions J1 and J2 by heating J1 (first curve) or J2 (second curve).

of Bi films of different thickness due to different levels of Seebeck effects in the segments. Overall, the present study demonstrates that the changes in thermoelectric powers of Bi metal are small in microscale and thus significant changes can be observed by going down to nanoscale, which can be easily and effectively achieved by

varying thickness instead of the width of the segments.

In addition, studies on Bi thin films and nanowires have reported a significantly decreased thermal conductivity in contrast to its bulk value [18–21]. Good Seebeck coefficient and good electrical conductivity added with reduced thermal conductivity can make this element a promising n-type material [22, 23] and can be used in combination with good p-type thermoelectric materials for low temperature heat conversion applications [24–29].

4 CONCLUSIONS

The present work introduces an alternative method to achieve higher thermal sensitivity from the single metal thermocouples (SMT). More prominent changes in the Seebeck coefficient can be observed by changing the metal film thickness instead of width and, as a proof of concept, high thermal sensitivity of $31\mu\text{VK}^{-1}$ has been achieved in thickness-engineered Bi-based SMT constructed from a combination of 500nm and 20nm thick segments. The fabrication of thickness-engineered SMTs is simple and does not require any special facilities, which makes the approach more preferable and economical.

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DATA AVAILABILITY STATEMENT

All data that support the findings of this study are included within the article (and any supplementary files).

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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Noble Industrial Furnace has been building and maintaining industrial furnaces for some of the biggest names in the industry.

By KENNETH CARTER, Thermal Processing editor

n the competitive world of heat treating, it's no small feat to make it to the half-century mark. In order to do that, a company has to stay innovative and in tune with the latest trends, as well as being there to ensure customers are getting the best quality equipment available.

To that end, Noble Industrial Furnace has shown that ability time and time again since it began in 1972.

"We build state-of-the-art robust gas-fired or electric furnaces in almost any configuration that's out there," said Dan Noble, vice president of Noble Industrial Furnace. "One of the things that we've always done is we overbuild, because it's such a demanding industry. We know what works and we know what makes our equipment last. We put our burners closer together; our furnaces have that outer channel iron skeleton; we go beyond code requirements. Bottom line, we overbuild, and we build it with good materials."

"Right now, in our shop, we have a 40-foot-long car bottom furnace that we're building; it's a real monster," he said. "That's for the oil industry down in Texas."

Also in production are two additional gas fired car bottom furnaces, along with high volume concurrent orders of multiple custom configurations of electric box furnaces, according to Noble.

Noble also builds thermal processing equipment used by the aerospace industry including VPA and VPC coatings, precipitation heat treat, bakeout, and heat-tint furnaces; however, aerospace is just one example of many industries that Noble serves.

CUSTOM-DESIGNED FURNACES

Designing and building a furnace is not a cut-and-paste venture. That's why almost all of the furnaces that come out of Noble's shop are custom made for each customer, according to Noble.

"We're always starting from scratch, really," he said. "Building to our customers' specifications almost always requires different furnaces. You really have to start with the work area and work your way out from there."

Although Noble said he's grateful for a simple customer request, he pointed out that his team is always ready for a challenge.

"One of the things that's nice is when you get to build a standard furnace — a 2-foot-by-3-foot air furnace — it's like a breath of fresh air; it's like, oh, something easy," he said. "As a manufacturer we always try to get a furnace design going where there can be some standardization, but, in reality, every shop seems to have their own specifics — they need this different temperature, different size, different configuration. We end up building more custom furnaces than the standard. But that's OK: it works for us."

COMPARTMENTALIZING REQUESTS

In order to properly address a customer's needs, Noble said it's important to compartmentalize and simplify things as much as possible.

"That's a specialty of ours, really," he said. "Everything that comes in — the phone calls, the inquiries — are complicated and challenging. So, the first thing we do is break it down and take it apart piece by piece. It simplifies the process. A lot of times our customers come



A 90 kW electric box furnace with rod-overbend elements and a circulation fan allowing for processing temperature range of 700-1,650°F. (Courtesy: Noble Industrial Furnace)

to us with a really long wish list, and they keep adding to it, and it's our job to help them whittle that down and balance out what they need from the product vs. financially what they can justify as a capital expenditure."

A large part of what keeps Noble's team of experts motivated — in addition to a work challenge — is that, since Noble started as a family business, the company wanted to make sure that family environment is integral to its employees, according to Noble.

"We all have to work, but we all like to go home at night, too," he said. "We keep it a family environment where we all care about each other. We work with each other."



Noble service crews provide onsite scheduled and emergency repairs on any brand of heat-treat equipment. (Courtesy: Noble Industrial Furnace)

And Noble added that family-oriented philosophy extends to Noble's customers as well.

"We keep that family environment with our customers, too," he said. "We do work together as a pretty competitive team, but with a family background and a family environment. We have worked with most of our customers for decades and have provided them with multiple new pieces of equipment and service as they expand processes and increase production."

CUSTOMER NEEDS

Having a special relationship with customers also helps when dealing with what those customers may need, according to Noble.

"Every single project you get is for a very specific customer need," he said. "Our philosophy is not to try to force the customer to pick one of our furnaces that will best match their needs. We start by asking, 'What are the customer needs?' And we're going to build them the best thing that fits with their process, facility, and budget. We design for the future, too, because it's robust, and it's going to last. We're always trying to think of tomorrow and next year."

BUILT TO LAST

Not just words as that expertise and reliability can be seen front and center upon entering prominent aerospace, tooling, and heat-treatment facilities located along the East Coast and beyond.

"We start by asking, 'What are the customer needs?' And we're going to build them the best thing that fits with their process, facility, and budget."

To drive home that point, Noble pointed out that the company has some of the longest running, 24/7 pieces of equipment in the industry.

"That's a big thing; it means less downtime so it keeps running," he said.

REBRICKING BOILERS

Noble Industrial Furnace was started by Noble's father, Raymond Noble, in 1972. About seven years before Raymond Noble began his company, he worked for a company that rebricked boilers. When someone asked him to rebuild one, it provided the perfect opportunity to start his own business. With Noble Furnace being located



A 20-burner 20M BTU 1,750°F construction car bottom furnace in production. (Courtesy: Noble Industrial Furnace)

in "aerospace alley" between Hartford and Boston, more and more customers began trickling in.

"It took a few years, but we build a good product, and so our name got out there and people were always asking for more," Noble said. "In this industry, it's word of mouth."

REINVESTMENT STRATEGY

To keep up with a changing industry, Noble said the company has recently reinvested resources into the facility, which includes new areas for fabricating tools and the addition of an overhead crane that can move throughout the building. Noble is also investing more in service road crews. Increases in new-build fabrication projects along with heightened demand for their 1-Stop program has required Noble to purchase storage facilities and hire new experienced personnel.

"We've put a lot of thought and actually a lot of money into that with tools and getting our crews out on the road," he said. "At our facility, we're restructuring offices, adding a new break room, and we have a big war room here where we gather as a team to go over prints and projects."

STILL GROWING

The industry and Noble have come a long way in 50 years, and many advances have helped take the company's products to the next level.

Noble expects that expertise to continue as the company moves into another half century of furnace production.

"We're still growing and improving our product," he said. "I don't honestly see the fundamentals of furnace design changing that much. I would like to see our name on the short list in every facility around the country when they're looking for a new product or looking for service. But I see furnaces, as far as they're still a box that keeps the heat in and the cold out, as a time tested, solid work horse of the manufacturing industry. Improvements come into play as we incorporate evolutionary materials and components, improving efficiency, longevity, and decreasing maintenance costs."

And those improvements will be used to continue to help Noble's customers operate and maintain their equipment, according to Noble.

"It's not only about fabricating the furnace, but it's also about predictive maintenance, preventative maintenance, and consumables and spare parts," he said. "We're going to help the customers figure that out and maintain that. Along with inventory recommendations and management of critical spare parts, we are also a resource for them as they use that piece of equipment providing training, troubleshooting, and offering our knowledge and experience. We're not going to just drop it off and expect them to figure it out."

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Q&A /// INTERVIEW WITH AN INDUSTRY INSIDER



TOM BALDOCK /// GUILL TOOL & ENGINEERING - AEROSPACE DIVISION

"We have pretty impressive machining capability, which lends itself to aerospace manufacturing."

What you do at Guill Tool?

My responsibilities here are for sales in the aerospace area. I've been in sales most of my adult life, in various capacities in different industries, most recently on the extrusion side of our business.

Guill Tool basically started out doing machinery for Electric Boat and other submarine manufacturers here in New England. And, of course, there's a lot of ship building here. This would've been after the original owner, Roger Guillemette, got out of the military and started this business. His background has been in precision machining, machining tooling and things like that his whole life. The opportunity was there when nuclear submarines were just beginning, and he got in on the ground floor and that was the basis of the company.

How has Guill helped support the aerospace industry?

It's an area we very recently got into. In the past, we occasionally would get an inquiry from an aerospace company, and be blessed with an order, but it was certainly nothing that we focused on. It was just something that happened occasionally. And our current owner, who's the son of Roger Guillemette, his name is Richard Guillemette, decided he wanted to put more focus and more resources toward the aerospace side of our business to build that up, so we could have another business line of machinery that we could rely on. He brought me along to try to do that, and that's what I've been working on since.

We have pretty impressive machining capability, which lends itself to aerospace manufacturing. There are a lot of parts that require very exotic materials, very precise machining, and that's where we fit in. There are not too many places that will focus on this.

You've recently announced the production of a new brass fitting. What makes it unique?

It was a fairly complicated part. It was something that we were asked to manufacture by one of our customers. This was nothing we invented; it was just manufacturing per our customer drawing. And it was turned on a Mazak CNC lathe, and then switched from there to a Mori Seiki 5-axis milling machine, and it was finished off there. It was just a two-step manufacturing process but with very fine finishes and very precise dimensions.

Does Guill work with any gear-manufacturing businesses?

We do have occasions where sometimes we make gears. We don't have Gleason gear cutters and stuff like that; that's not our thing really. But we have occasionally made a gear for some specific purpose; however, that's not our main manufacturing expertise.

Tell me about Guill's machine shop capabilities, and what that means for the industries that you work with.

It's a pretty impressive machine shop. We have numerous EDM

machines and milling machines. I think we've got about six or eight of them. We also have numerous CNC turning centers.

Downstairs in the manufacturing area we have two 5-axis machines. I think we have four or five 4-axis machines. We have precision grinding. And we have roomfuls of old manual machines. We have a whole roomful of Bridgeports and engine lathes and horizontal mills.

We have a good inspection department. We have a couple of CMMs. We have a Nikon measuring microscope. We have numerous Brown & Sharpe height gauges. We have a Taylor Hobson profilometer.

For a lot of our business, finishes are very important, especially on the extrusion side of our business. We have Rockwell hardness testers and granite surface plates, optical comparators, electronic height gauges, and more. Again, what we really offer is precision machining. We're used to doing exotic materials, various grades of stainless steel and titanium. And many, many, many kinds of materials others might be too anxious to get involved with.

Does Guill do anything that needs to be heat treated?

We do a lot of heat treating. A lot of stuff here goes out for heat treat. We don't do that internally as a company, just locally that we use.

Same with plating, especially on the aerospace side, there's a lot of exotic coatings and plating that needs to be done — dye penetrant inspection and X-ray. We don't do that in house. But because there's such a focus on aerospace in New England, there's plenty of places that do that. Actually, it's pretty easy for us to find those places.

What does Guill make that requires heat treatment?

Items that need to be hardened. Not so much on the government side, but things on the extrusion side. Dies and the parts of a die that would wear, like the actual tip in the die, not so much the die body polymer flow surface areas that are going to have polymer flowing through them, they need to be polished to a mirror finish, and they have to last a long time, so consequently they're hardened.

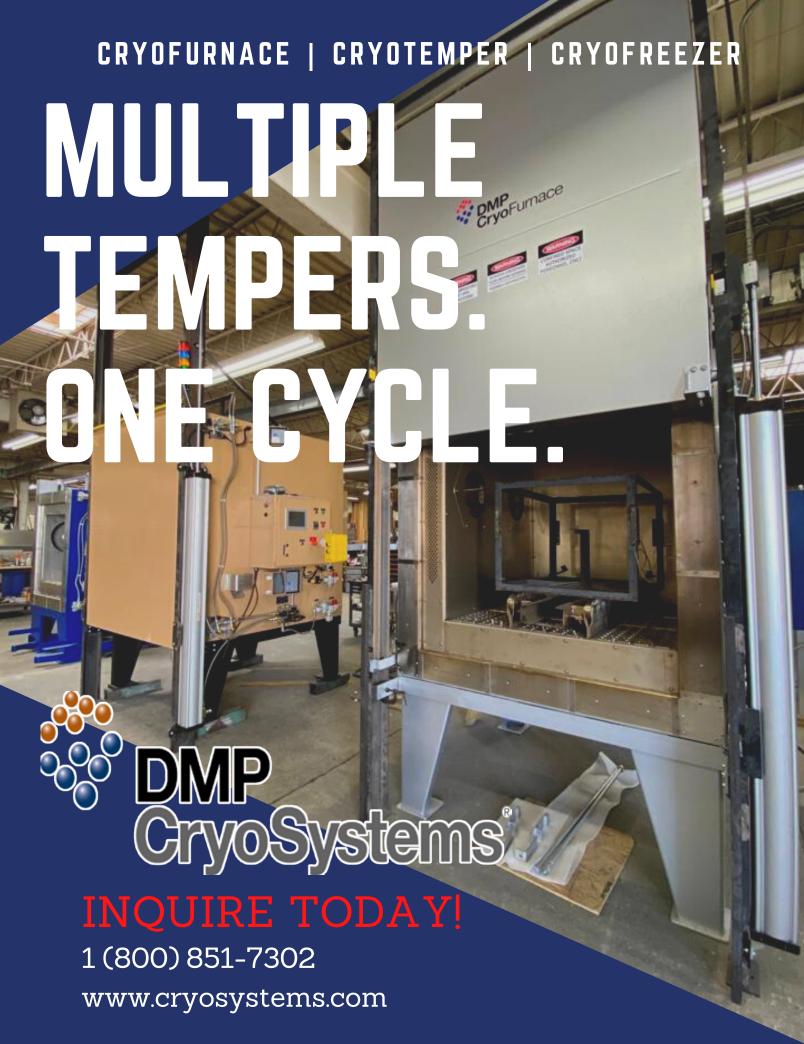
Anything else about Guill that you'd like to discuss?

Our efforts so far, specifically in aerospace, like I said, we're just getting started, we're just getting going. We've had some orders from some of the Tier 1 manufacturers. And I think as we continue on down that path, more and more often we'll be called upon to do some more.

The other challenge we have is, we're very busy, both on the extrusion side of our business, and on the defense side, particularly with work we're doing for the Department of Defense, the Department of Navy, Newport News shipyard, and General Dynamics Electric Boat.

But business has just been booming.

MORE INFO www.guill.com



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