Technologies and Processes for the Advancement of Materials

Thermal processing

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COMPANY PROFILE ///

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DEPARTMENTS ///

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FROM THE EDITOR ///

The name changed, but the quality won't

A lot of things are happening this year with our publishing organization. Change is often a part of life, and it's definitely a part of business.

The umbrella group, Media Solutions, Inc., responsible for publishing our three magazines — *Gear Solutions, Thermal Processing,* and *Wind Systems,* has relinquished control of those publications, and they are now the intellectual property of MMSC Group LLC. The name may have changed, but the quality has not and will not. The editorial and advertising staff at MMSC is the same staff that has been bringing you the latest coverage in your industrial sectors for years now, and we will continue to do so. These important industries are a vital part of both the U.S. and global economy, and MMSC is just as dedicated to reporting and sharing the latest information as its predecessor.

We all know a lot of recent events have made doing business in these industries a challenge at best and a deep frustration at worst. For that reason, it's even more important that a mechanism for information on these sectors not only exists, but thrives.

That being said, we are still here for a vital service: To make sure we get your story to industries that need your expertise — whether that's displayed as an editorial feature or in an eye-catching ad. Our team stands ready and is excited to share your story and experience with our thousands of readers.

If you're looking for a vehicle to disseminate your expertise to the industry or you're wanting to put on full display the very products and services that make you vital to your customers, then this publication remains in the ideal position to make either — or both — of those a reality.

Bottom line: Let us help. Our company may have changed names, but the publications you have come to trust — *Gear Solutions, Thermal Processing,* and *Wind Systems* — will continue to be here to shine a spotlight on the company components important to you and the business community at large. If you're looking for a home for a feature article, contact me at the email below. If you're looking to advertise, contact ben@thermalprocessing.com for more information. Come be a part of our community.

And as always, thanks for reading!

KENNETH CARTER, EDITOR
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Teresa Cooper
PRESIDENT

Parts entering Abbott Furnace's seven-zone continuous belt sintering furnace at Metco Industries in St. Marys, PA. (Courtesy: Abbott Furnace Company)

Abbott Furnace delivers 7-zone sintering furnace

Abbott Furnace Company has successfully delivered and commissioned a seven-zone continuous-belt sintering furnace for Metco Industries. The system incorporates Abbott's latest generation of fully digital atmosphere control technology, engineered and manufactured in-house.

The system is designed to deliver tighter process control, improved repeatability, and real-time visibility into furnace performance. Fully digital flow control, advanced monitoring, and data-driven diagnostics allow Metco to optimize sintering conditions of the furnace, supporting higher quality parts and more consistent results.

Abbott Furnace Company applauds projects such as this that reflect a shared commitment to process control, operational consistency, and long-term manufacturing performance within the powdered metal industry.

Abbott Furnace Company designs and manufactures continuous-belt furnaces for sintering, brazing, annealing, and other controlled atmosphere heat treatment applications. With decades of experience in thermal processing innovation, Abbott delivers engineered systems built for performance and longevity.

MORE INFO www.abottfurnace.com

AHT in Alabama adds nitriding, induction hardening equipment

Advanced Heat Treat Corp.® (AHT), a recognized leader in heat-treat services and metallurgical solutions, has invested in two additional pieces of equipment at its Cullman, Alabama, location. The equipment will expand capacity for induction hardening and gas nitriding, supporting increased production volumes, faster turnaround times, and more complex part geometries.

The Alabama location recently installed a larger induction hardening unit to support continued growth in customer demand. The new system accommodates parts up to 60 inches in diameter and more complex part geometries. While earlier systems were primarily suited for cylindrical components such as shafts, gears, and pins, the new unit enables induction hardening of more intricate part designs, opening the door to a broader mix of applications and industries.

AHT has also expanded gas nitriding capacity with the addition of another nitriding unit, enhancing the site's ability to support high-volume nitriding programs while maintaining quick lead times and consistent quality.

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.

Advanced Heat Treat Corp.® employees with the new induction hardening unit in Cullman, Alabama. (Courtesy: Advanced Heat Treat Corp.)

"These investments allow us to scale with our customers," said Tim Garner, AHT plant manager. "We are well-positioned to handle a wide range of part sizes, geometries, and production volumes without compromising turnaround time."

Advanced Heat Treat Corp. operates four locations: one in Cullman, Alabama; two in Waterloo, Iowa; and one in Monroe, Michigan. Across these locations, AHT offers more than 20 surface treatment processes, including ion nitriding, gas nitriding, ferritic nitrocarburizing, UltraOx®, induction hardening, stress relieving, and more.

MORE INFO www.ahtcorp.com

Bodycote adds ADM surface hardening to N. America services

Surface treatment specialist Bodycote has announced the addition of S^{3}P ADM® (austenitic, duplex, martensitic) to its range of services in the United States.

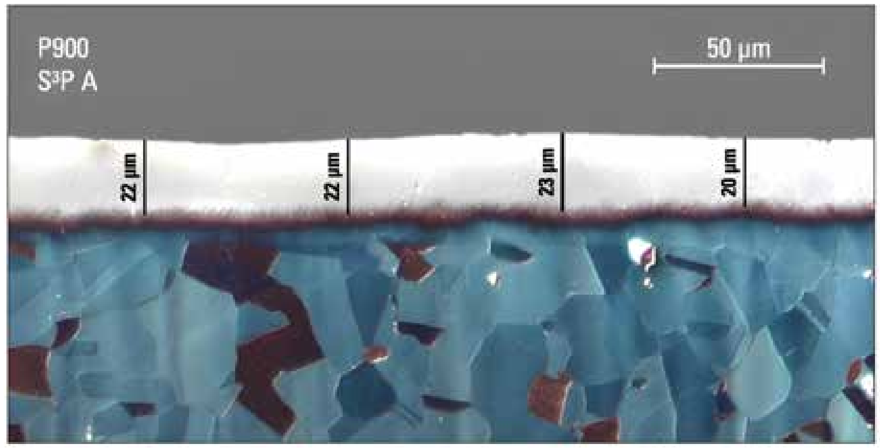
It expands the company's specialty stainless steel processes (S^{3}P) portfolio and brings advanced stainless steel surface hardening capability closer to North American customers. The new U.S. capability helps reduce transportation costs and tariff exposure for North American customers, while strengthening Bodycote's global S^{3}P network and adding operational resilience across its facilities.

The investment in ADM marks a significant expansion of Bodycote's S^{3}P offering at its facility in Mooresville, North Carolina. The new treatment vessel can accommodate components up to 79 inches (2 meters) in length and 47 inches (1.2 meters) in width, enabling the surface hardening of larger and heavier stainless-steel parts than previously possible in North America in industries such as oil and gas, food and beverage, and medical technology.

In addition to increased component size capability, ADM can treat martensitic alloys which are widely used in load-bearing and high-strength applications. “Demand is growing for stainless steel components that can deliver longer service life in harsh operating environments and to demanding standards, without introducing the risks associated with coatings,” said Temitope Oluwafemi, Bodycote’s S^{3}P technical manager, North America. “Bringing ADM capability to the U.S. allows us to support customers locally, reduce lead times, and expand what’s possible for larger stainless-steel components across multiple industries.”

ADM is a low-temperature, diffusion-based surface-hardening process that significantly improves the surface hardness of stainless-steel components. Performed below 500°C, it helps maintain the corrosion resistance that makes stainless steel the material of choice for many demanding applications, while improving surface hardness and tribological performance.

Unlike coatings and plating, ADM does not create a separate layer on the surface of the component. Instead, it forms a hardened diffusion zone within the material itself, meaning there is no risk of cracking, chipping, or delamination in service. The process is also designed to preserve dimensional stability, enabling treatment of finished components without affecting part geometry or



Microstructure of surface hardened stainless steel AISI660 (1.4980)

The addition of S^{3}P ADM® (austenitic, duplex, martensitic) to Bodycote’s range of services will deliver optimum performance for larger stainless-steel components and martensitic alloys. (Courtesy: Bodycote)

tolerances. Bodycote has established expertise in ADM, based on more than a decade of delivering the process in Europe.

MORE INFO www.bodycote.com/s3p

Can-Eng becomes FANUC authorized system integrator

Can-Eng Furnaces International Ltd. (Can-Eng) announced it has been certified as a FANUC authorized system integrator (ASI), expanding its capabilities in robotic automation for industrial furnace systems and thermal-processing equipment. This certification recognizes Can-Eng's advanced training and expertise in FANUC robot integration, supporting manufacturers worldwide with custom automation solutions for heat treatment and thermal processing applications.

As a FANUC authorized system integrator, Can-Eng is part of a global network of trusted robotic system integrators specializing in industrial automation solutions. This partnership provides customers with direct access to FANUC industrial robots, advanced automation technologies, and technical support delivered through Can-Eng as a single-source provider. Can-Eng works closely with manufacturers to select, design, and integrate robotic automation systems that deliver high performance, reliability, and operational safety and efficiency.

Can-Eng's engineers have been trained and certified directly by FANUC, ensuring expert application of robotic automation in thermal processing systems, including heat-treatment furnaces, material handling automation, and high-volume industrial furnace operations. With strong in-house engineering and on-site support, Can-Eng helps manufacturers modernize production through high-performance industrial robotics.

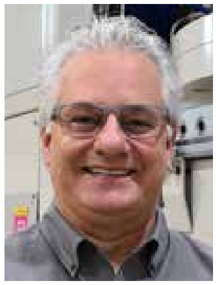
Can-Eng's rugged furnace designs are recognized for innovation, durability, and efficiency, incorporating energy-saving furnace technology, automated material handling, and advanced industrial robotics to improve production flow, throughput, and facility performance. (Courtesy: Can-Eng Furnaces International)

This collaboration reinforces Can-Eng's role as a single-source automation partner for industrial furnace projects. By offering a unified approach from industrial furnace design and in-house manufacturing to robot programming, system integration, and long-term support Can-Eng simplifies project execution and delivers reliable turnkey automation solutions for demanding industrial environments.

MORE INFO www.can-eng.com

ECM USA names senior sales engineer for western U.S.

ECM USA has appointed Marco Möser as senior sales engineer for the western U.S., reinforcing its dedication to meet increasing demand for advanced vacuum furnace technology across the United States.



Marco Möser

With more than 25 years of experience in the heat-treatment industry, Möser brings extensive expertise in supporting OEMs on large-scale automotive programs (ex. 8/9/10-speed transmission programs). His strong technical expertise and analytical approach position him to play a key role in advancing ECM USA's sales strategy and enhancing customer success.

Prior to joining ECM USA, Möser held senior leadership roles, including sales director and vice president, for specialized alloy fixturing and foundry organizations across Europe and the Americas.

Throughout his career, he has demonstrated a consistent ability to drive sales growth, optimize performance, and strengthen team collaboration.

Möser's professional background includes multiple executive-level positions, as well as, completion of an executive development program at The Wharton School in Philadelphia, further underscoring his leadership capabilities and strategic insight.

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

Gasbarre chosen for custom thermal processing system

Gasbarre Thermal Processing Systems (Gasbarre) has received an order for a custom-engineered box furnace and loading system to be installed at a U.S.-based manufacturing facility, marking a new customer relationship and demonstrating Gasbarre's ability to deliver solutions tailored to highly specific operational requirements.

The project required a furnace design that could meet strict space, access, and installation constraints while supporting a non-standard thermal application. Gasbarre worked closely with the customer to develop a solution that fit within the available footprint and complied with facility limitations that had previously restricted equipment options.

Gasbarre was selected based on its ability to respond quickly, collaborate closely throughout the approval process, and engineer a system specifically aligned with the customer's needs — rather than adapting an off-the-shelf design. The project progressed under a tight timeline, with Gasbarre providing consistent engagement from initial inquiry through final authorization.

"Some applications don't allow for compromise, whether due to space, schedule, or process requirements," said Patrick Weymer, business development manager for Gasbarre. "This project reflects our ability to engineer practical, reliable solutions when standard equipment simply won't work."

The system supports a specialized high-temperature thermal operation that was previously validated at a smaller scale and is now being expanded to meet increased capacity requirements. The direct-fired furnace is designed to operate in an air atmosphere up to 2,100°F and represents the largest configuration that can be accommodated within the facility's constraints.

MORE INFO www.gasbarre.com

Wisconsin Oven ships batch oven for adhesive curing

Wisconsin Oven Corporation announced the shipment of one custom electrically heated six-tier batch oven with a dedicated cool-down chamber to a manufacturer of glass products. This industrial curing oven will be used to cure adhesive in glass assemblies.

The adhesive curing oven is designed to heat 960 pounds of product from 21°C to 140°C and has a maximum operating temperature of 150°C (302°F). The oven and cool-down chamber include six tiers for processing the assemblies. Each tier is equipped with an independently operated pneumatic vertical hinged door to allow for efficient loading and unloading. A carbon steel rack is provided in both the oven and cool-down for supporting product loads in each tier.

The curing oven features a top-down, bottom-up airflow configuration distributed through adjustable louvers to ensure uniform temperature across each load. Guaranteed temperature uniformity of ±5°C at 140°C (±9°F at 284°F) was verified through a 30-point profile test prior to shipment.

The control system includes an Allen-Bradley CompactLogix PLC with 10" color touchscreen for starting and shutting down the oven, adjusting setpoints, viewing system status, and trending key process variables. A Watlow F4T controller provides temperature control, recording capabilities for data logging, adaptive tuning, and Ethernet communications.

The oven is also equipped with Wisconsin Oven's DataSense® industrial IoT system which enables remote monitoring of equipment performance to help prevent unexpected downtime. "This curing oven was designed with six independent tiers, each equipped with its own pneumatically operated door so operators can load and unload the product assemblies individually," said Tom Trueman, senior application engineer. "This configuration improves handling efficiency during the customer's production process."

Unique features of this adhesive curing oven include:

- Temperature uniformity of ±5°C at 140°C (±9°F at 284°F).
- Insulated floor for additional structural support.
- Independently operated doors for each tier.
- Removable carbon steel rack.
- Allen-Bradley CompactLogix PLC for advanced controls.
- DataSense® industrial IoT performance monitoring system.
- Installation supervision, startup, and operator training.

The adhesive curing oven and cool-down chamber were fully factory tested and adjusted prior to shipment from the Wisconsin Oven facility.

MORE INFO www.wisoven.com

Rodrigo González appointed president of Nutec Bickley


Rodrigo González

Nutec Group chairman Genaro Cueva and CEO Daniel Llaguno announced that, effective immediately, Rodrigo González has been appointed president of Nutec Bickley, the internationally renowned manufacturer of furnaces, kilns, ovens, and leading-edge combustion and control systems.

González has been with Nutec Bickley for 24 years and has served in a number of senior positions, most recently as vice president, engineering and project operations.

"I'm honored to be appointed president of the company," said González. "I want to thank Genaro Cueva and Daniel Llaguno for their trust and for the opportunity to take on this responsibility.

After more than two decades with the organization, working across engineering, operations, projects, and commercial roles, I know this business deeply and believe strongly in our people and our capabilities.

"My focus will be on serving our customers, executing with excellence, and continuing to build a strong, committed team that delivers sustainable results.

I'm grateful to work alongside such a talented group of people and I look forward to the next chapter together."

"Given his capabilities, commitment, and adherence to Nutec's values, I am certain that Rodrigo will successfully lead Nutec Bickley into the future," said Llaguno.

"He is completely aligned with our ethos, which sees our continued strong commitment to our mission and our business philosophy.

My sincere congratulations go to Rodrigo — I am confident that he has everyone's full support in achieving the objectives we have set."

MORE INFO www.nutecbickley.com

A message from the new IFHTSE vice president

(Courtesy: Cathay Pacific (www.cathaypacific.com/cx/en_TW/inspiration/travel/travel-guide-chengdu-china.html)

Jianfeng Gu

It is a great honor to serve as your new vice president. I take on this role out of deep passion for our field and a commitment to advancing the collaboration that has defined IFHTSE since its founding in 1971. For decades, this federation has been a vital bridge connecting global professionals, and I am eager to carry forward its mission of knowledge sharing.

In the coming years, I will focus on three key priorities: First, I will strengthen our international conferences and congresses, ensuring they remain premier forums for exchanging cutting-edge ideas. Second, I will promote deeper synergy between researchers and industry, especially through initiatives focused on sustainability. Third, I will expand our outreach to nurture the next generation of professionals.

To our members: You can expect enhanced opportunities for connection and knowledge dissemination. I will listen closely to your needs, advocate for our field's impact, and work to make IFHTSE an even more inclusive and supportive community.

Let us continue to collaborate, innovate, and drive progress together. Thank you for your trust — I am excited for the journey ahead.

With sincere regards — Jianfeng Gu

Gu is the deputy president of IFHTSE'S member organization Chinese Heat Treatment Society (CHTS), a professor at the School of Materials Science and Engineering of Shanghai Jiao Tong University (SJTU), and the director of Institute of Materials Modification and Modelling (IMMM) at SJTU.

MEMBERS IN THE NEWS

Korean Society for Heat Treatment appoints new president

IFHTSE member association KSHT recently appointed Dr. Sang-Gweon Kim as its new president. He works at KITECH Research Institute. KSHT was founded in 1988 and has been a member of IFHTSE since then.

Dr. Sang-Gweon Kim

CONFERENCE UPDATES

7th Asian Conference on Heat Treatment and Surface Engineering
September 18-21, 2026
Chengdu, China

The 7th Asian Conference on Heat Treatment and Surface Engineering of Materials (7ACHTSE2026) will be in Chengdu, Sichuan Province, September 10-12, 2026. The conference will focus on the latest research progress, technological frontiers, and future trends in the field of material heat treatment and surface engineering and is committed to promoting deep integration and collaborative innovation in this field in the Asian region.

The Asian Conference on Heat Treatment and Surface Engineering of Materials (ACHTSE) is an important series of international conferences jointly initiated by China, Japan, South Korea, and other countries. It focuses on the latest research and developments in surface engineering and heat treatment.

DEADLINES

Extended Abstracts/Full Papers submission: July 31, 2026.
Notification of Acceptance: August 5, 2026.
Early Bird Registration: August 31, 2026.

31st IFHTSE World Congress
October 13-15, 2026
Cologne, Germany

Organized by AWT – Arbeitsgemeinschaft Wärmebehandlung + Werkstofftechnik e. V., the 31st IFHTSE World Congress will be October 13-15, 2026, in Cologne, Germany, at the International Conference and trade fair. It will include three events: HK 2026, ECHT 2026, and the 31st IHTSE World Congress.

The largest European congress on topics of heat treatment and materials technology, manufacturing and process engineering in 2026 is organized in cooperation with the International Federation for Heat Treatment and Surface Engineering (IFHTSE) as well as the European heat treatment associations from France, Austria, Switzerland, the Czech Republic, Slovakia, and the Benelux countries. Due to the expected number of lecture registrations, this will be a three-day event. The language of the conference will be English.

In addition to the extensive scientific and technical programs, attendees will have the unique opportunity to experience a major international exhibition and trade fair with about 150 exhibitors. Leading companies from around the world will present their latest developments in equipment, services, operating materials and other relevant technologies essential for the heat treatment and surface engineering industries. The exhibition will provide invaluable networking opportunities and foster collaborations between academia and industry.

DEADLINES

Notification of abstract acceptance: May 15, 2026.
Deadline for proceedings manuscript (extended abstract 2-4 pages): July 15, 2026.

MORE INFO www.hk-awt.de

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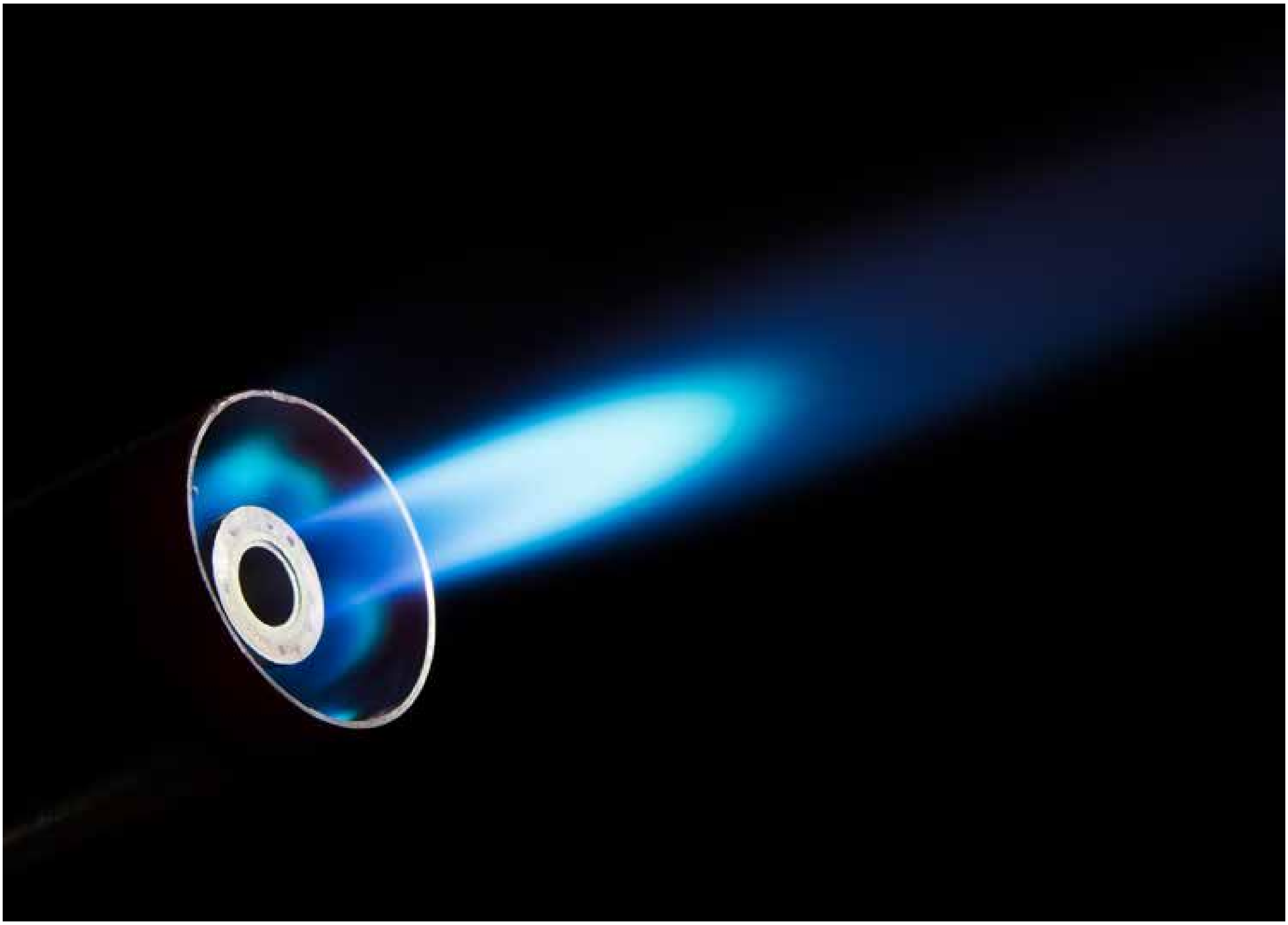
ONLINE www.ifhtse.org | **EMAIL** info@ifhtse.org

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

Stowe & Sons provides energy engineering services to a diverse range of sectors



In the fall of 2025, after 24 years in industrial manufacturing plants followed by 14 years in the energy engineering business, owner and principal engineer Michael L. Stowe started Stowe & Sons PLLC, an energy engineering consulting firm in North Carolina. As the sole owner and principal engineer, Stowe continues to provide industrial and energy consulting to serve a wide variety of clients.

The focus of Stowe & Sons PLLC is to "make more with less."

For example, if a client is manufacturing bricks, then the company works to help them reduce its total energy consumption and total greenhouse gas (GHG) emissions per brick produced. If a client is a dairy farmer, then Stowe & Sons helps reduce the total energy consumption and GHG emissions per gallon of milk produced. If the client is a hospital, then the company helps them reduce the total energy consumption and GHG emissions per patient or per square foot of building space.

ENGINEERING ENERGY EFFICIENCY!

The company symbol is E3 which is the three key "E's" that describe what Stowe & Sons is about: Engineering Energy Efficiency! = E3. Whatever an organization is doing, Stowe & Sons can make processes, facilities, and buildings more efficient. This saves energy, reduces energy costs, and reduces GHG emissions.

IHEA is a great connecting point for Stowe and Sons PLLC. Stowe has been a member of IHEA since 2011 and was the IHEA president in 2019-2020. He continues to work on the board of directors and the Sustainability and Energy Management committee.

"IHEA membership is a great match for my new company, and I look forward to providing energy management, energy efficiency, and sustainability knowledge to IHEA members and their customers," Stowe said.

DIVERSE SECTORS

Stowe & Sons PLLC provides energy engineering services to a diverse range of commercial and industrial (C&I) business market sectors including: K-12 schools, colleges and universities, city government, hospitals, retail, restaurants, warehouses & storage, primary metals, fabricated metals, machinery and electrical manufacturing, transportation equipment, furniture, textiles, pulp and paper, chemicals, plastics, food & beverage, agriculture, water and wastewater treatment, and others.

WIDE RANGE OF SERVICES

Stowe & Sons PLLC provides engineered energy efficiency, which is persistent and will provide ongoing savings.

The company can help improve the energy efficiency of processes, facilities, and buildings, and help build an energy management system (EnMS) to deliver continual improvement.

Stowe & Sons PLLC provides a wide range of technical engineering services for improving energy efficiency and energy management including:

- Commercial and industrial site energy assessments.
- Energy efficiency evaluations for the following systems: compressed air; boilers, steam, hot water, and combustion; chillers, cooling towers, and heat exchangers; HVAC; lighting; motors and variable frequency drives (VFDs); fans and pumps; water and wastewater treatment systems; all types of industrial processes; renewable energy systems; and more.
- Commercial and industrial maintenance programs including predictive maintenance methods.
- Application of process heating technologies such as infrared, induction, electrical resistance, ultraviolet, radio frequency, microwave, and electron beam.
- Utility energy efficiency and incentive programs.
- Implementation of strategic energy management (SEM) programs.
- ISO 50001 Energy Management Standard — consulting for third-party certification.
- ISO 50001 internal auditing of the EnMS.
- ISO 50001 internal auditor training.
- DOE 50001 Ready Program — Cohort Lead Coach.
- Commercial and industrial energy mapping and energy modeling.
- Commercial and industrial GHG emission accounting and reduction.
- Beneficial electrification technologies and implementation.
- Lean manufacturing and continuous improvement methods.
- Research and development of energy management strategies and technologies, and delivery of this information in the form of coaching, teaching, presenting, writing, and implementing.
- Other customized energy services as needed.

Stowe & Sons has the ability to map out and improve energy consumption and then relate this energy consumption to its related onsite GHG emissions and to build systems to ensure the continual improvement of energy consumption and its related GHG emissions.

U.S. ISO TECHNICAL ADVISORY GROUP

Stowe is a member of the U.S. ISO Technical Advisory Group (TAG) to ISO technical committee (TC 301) for energy management and energy savings.

The U.S. ISO Technical Advisory Group (TAG) is the American National Standards Institute's (ANSI) sanctioned body to develop and advance the official U.S. position in the International Organization for Standardization's (ISO) Technical Committee 301, which developed the ISO 50001 Energy Management Systems standard and the related series of international energy management documents.

Just recently, TC 301, working group one (WG1) worked to produce ISO 50100, a new standard for Energy management systems and energy savings — decarbonization — requirements with guidance for use. This new standard provides guidance on setting up and tracking energy related GHG emissions reduction goals and provides a pathway to validate and verify meeting these goals.

STOWE & SONS CAN HELP

Stowe is a U.S. Navy veteran who served in the Navy on submarines from 1982 to 1987.

"If you have specific energy and GHG emission reduction goals, if you need to get ISO 50001 third-party certification, or if you just want to get started on improving your energy and GHG emission tracking systems, Stowe & Sons PLLC can help," Stowe said. "We are flexible and can meet you where you are on your energy journey and help you get from your Point A to your Point B. If any of this is of interest of you, please reach out."

For more information, contact Stowe at 919-904-0279 or michael@stoweandsons.com.

D. SCOTT MACKENZIE, PH.D., FASM
SENIOR RESEARCH SCIENTIST–METALLURGY, RETIRED

Titanium alloys are used in a variety of applications, ranging from aerospace and biomedical to automotive and sporting equipment. These applications require an excellent strength and a high strength-to-weight ratio.

Titanium and its alloys

In this column, I will discuss the different types of titanium alloys and review their physical metallurgy.

INTRODUCTION

Titanium alloys are widely used in aerospace, chemical, and biomedical applications. They are increasingly used in automotive applications, because of the unique strength-to-weight ratio, chemical resistance, and heat resistance. The low creep rates at elevated temperatures make it an excellent alloy for turbine blades and discs in the low and intermediate stages of compressors.

Titanium is widely used for biomedical applications, such as bone and joint implants, as well as dental implants. This is due to the excellent corrosion resistance of titanium, and its biocompatibility.

Automotive applications include exhaust systems for exotic cars and titanium valves used by Toyota [1]. Titanium suspension components, and springs are used in motorcycles and racing cars. Titanium is also used in bicycle frames and sporting equipment.

PHYSICAL METALLURGY

Titanium has only two crystal structures: the low temperature structure, alpha (α) titanium, which is a close packed hexagonal structure (HCP), and beta (β) titanium, which has a body-centered-cubic (BCC) structure. Alpha titanium, in pure form, is stable from room temperature to about 882°C (1,620°F). After being heated to about 885°C, the alpha titanium transforms to beta titanium by allotropic transformation, which is stable up to the melting temperature of pure titanium (1,668°C or 3,034°F) [1].

Allotropic transformation is a reversible reaction, where the pure material changes its crystal structure at a specific temperature. This is like pure iron (ferrite or α-iron) at room temperature (body-centered-cubic or BCC) transforming to austenite (γ) with a face-centered-cubic (FCC) structure. Alloying element additions can change the temperature of the β-transus (temperature where α transforms to β). Alloying elements are classified as α stabilizers (Al, O, N, C, Sn, Zr) that raise the β transus and extend the stability field of hcp α, and β stabilizers (Mo, V, Nb, Ta, Fe, Cr, Mn, Ni, Cu) that lower the β transus and expand the bcc β field. It is the balance between the alloying elements that determines the microstructure.

Titanium alloys are conventionally divided into three main classes: alpha(α), alpha–beta (α + β), and beta (β), depending on the predominant phase present [2].

The behavior of these alloys is controlled by the allotropic α⇆β transformation of titanium and the division or partitioning of alloying elements between these phases.

The physical metallurgy and properties of these alloys is, in large part, governed by how alloying elements shift the β transus and change the α (hcp) or β (bcc) ratio [3].

ALPHA ALLOYS

Alpha alloys at room temperature have a single-phase microstructure of HCP α, with a distribution of fine interstitial solutes (oxygen, nitrogen, and carbon) and substitutional elements (aluminum, tin and zirconium) that strengthen the matrix by solid solution [4].

Aluminum is a primary substitutional α stabilizer. It contributes significantly to strength but can reduce ductility and creep resistance if the aluminum content is too high. Aluminum content is generally limited to approximately 7 percent to prevent the precipitation of $Ti^{3}Al$, which can lead to severe embrittlement [5]. Sn and Zr further strengthen α and improve creep resistance through size misfit and stacking-fault energy effects.

Alpha alloys only have three different microstructures. The first equiaxed alpha, which is the result of recrystallization after deformation and heating. The second microstructure is Widmanstätten alpha, which occurs as the alloy is cooled moderately slowly from above the β-transus (Figure 1). This is the familiar "basket-weave" pattern and microstructure. Lastly, there is martensitic alpha (α') which forms upon rapid cooling from above the β-transus.

ALPHA-BETA ALLOYS

These α–β alloys contain sufficient β stabilizers (V, Mo, Fe, Cr, etc.) that both phases are present at room temperature over a useful compositional range. The prototypical alloy is Ti–6Al–4V, which contains roughly 6 wt.% Al as α stabilizer and 4 wt.% V as β stabilizer.

In these alloys, the primary transformation path involves β decomposing to α+β upon cooling. Different microstructures can result, depending on the cooling rate and composition. At moderate cooling rates (such as air cool from the β field), Widmanstätten or basketweave α plates can nucleate on prior β grain boundaries and grow inward, with retained β located between the α plates. At higher cooling rates, a martensitic transformation can occur, resulting in the hexagonal α'. This martensite is supersaturated with alloying elements and decomposes on subsequent aging into fine α+β mixtures, greatly strengthening the alloy [4] [3] [1] [5].

BETA AND METASTABLE-BETA ALLOYS

In these alloys, the physical metallurgy is controlled by precipitation reactions from supersaturated β [6] [7] present at room temperature. These alloys are predominantly composed of β stabilizers such as vanadium and molybdenum, with limited α stabilizers. These alloys give up mechanical strength to improve ductility. Because of the very high concentration of β stabilizers, even air cooling is sufficient to retain β in a metastable or stable condition [3].

In metastable β alloys, containing 10-15 percent of β stabilizers,

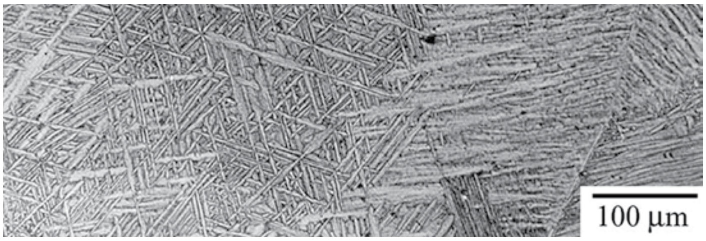


Figure 1: Ti-6Al-5Zr-0.5Mo-0.25Si heat treated to 1,050°C and slowly cooled to ambient temperature. Showing Widmanstätten α within prior β grains [1].

β is metastable at room temperature. This metastable phase can be aged to produce a very fine Widmanstätten α in a β matrix. Aging the metastable structure in the range of 425–600°C produces fine, coherent, or semi-coherent α precipitates within β, such as the precipitation hardening in aluminum alloys [8]. As aging progresses, α coarsens and strength falls while ductility improves. These alloys have an excellent balance of high strength, toughness, and ductility over a wide range of temperatures.

If very large additions of β stabilizers are present (30+%), then β is stable at room temperature. These alloys exhibit poor ductility [1] and are used for highly specialized corrosion resistance applications [6].

CONCLUSION

Titanium alloys are used in a wide variety of applications ranging from aerospace and biomedical, to automotive and sporting equipment. These applications require an excellent strength and a high strength-to-weight ratio. By controlling the alloying composition, the temperature of the β transus can be controlled, yielding the three different types of titanium alloys. Should you have any comments on this article, or suggestions for further articles, please contact the editor or the author.

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TONY TENAGLIER
QUALITY MANAGER /// ALCUMET

A technician who gets "into the flow" at work performs optimally and with a feeling of investment in the job.

Keeping the momentum going

One of the challenging things about manufacturing is the need to continually stay motivated each day. This is because in the manufacturing world of processing parts for aerospace — unlike in sports — there are no finish lines. A soccer game is done after two 45-minute halves. The marathon is complete when the athlete crosses the finish line after 26.2 miles of running. But the industrial "athlete" who works in heat treatment continually needs to find ways to stay motivated to get the required work done. Author Simon Sinek talks about the difference between a finite game and an infinite game. Sports are finite games as they are played within finite rules and boundaries. Business (and life), on the other hand, are infinite games. The rules keep changing as the world keeps evolving. New technologies. Years ago, the technology to perform a TUS wirelessly was not available. Now, companies can integrate this recent technology into their practice. So, in order for the heat-treat athlete to stay motivated each day, they need to redefine how they look at their work.

Most people will define "work" as what they do for a living. What earns money for them. However, work is beyond that narrow definition. Instead, if work is viewed from the perspective of the physics definition of an object being displaced in space by a force, that is "work". Thus, people showing up each day are being subjected to the force of gravity as they move their hands and bodies on the factory floor. But there are psychological forces that we need to contend with as well.

HOW TO KEEP YOUR TEAM MOTIVATED

People want challenges that are manageable. Telling them to work for 40 years and then they can retire is a goal, but that isn't a strong way to motivate them on the day-to-day or hour-to-hour or even minute-to-minute basis of those 40 years. Perhaps surprisingly, throwing more money their way isn't the answer. Sure, it helps these things. But what is needed most is kindling an intrinsic desire to do something. And to do that, you need to identify the clear challenge presented and align that with both the overall goal and the respective skills of that employee.

Here is an example. A pyrometry technician has been running the TUS for months now. It has now been extended to a periodic schedule based upon the compliance of AMS 2750. The technician is doing their job, but they seem disengaged. They have done this so many times. They understand the importance of doing it and why it's necessary to uphold compliance to the requirements of Nadcap, but they are having a hard time getting motivated. In this instance, you might recognize several things with this employee. Maybe they are very skilled with knowledge of the TUS and good with hands-on types of tasks. In this case, maybe you present a relative challenge for them to find ways to save on the length of the expendable thermocouple wire you use for the TUS (assuming the requirements of this TUS are one and done and the parameters for the cycle are adequate for this type of wire). Now, this slight challenge can incentivize the technician to use their skills and overcome an immediate challenge and succeed in a relatively more attainable goal.

The formula used here is one that I apply in all the "work" I do. It is derived from the antecedents of getting into flow states. In psychology, flow states have been correlated to optimal performance, well-being, optimal states of consciousness, and — in my practical and personal experiences — how some of the best work can get done. Flow is the state in which you are "in the zone." You are so engrossed in your work that time can become distorted. That tedious TUS setup with nine thermocouples placed perfectly seems to take only minutes, but an hour or so has gone by with the setup to get the cycle running.

We want employees to be in flow, just like athletes wanting to be in flow states to play their best game. Industrial athletes need to be given opportunities to find flow states on the job and in their work. Doing that requires a clear understanding of the goal. Assessing the relative goals that need to get done each day and thinking in terms of short-term goals rather than long-term helps to keep the team motivated.

With clear goals, there is then the need to recognize the challenges and skills with respect to the task at hand. In the case of the TUS setup, there is the challenge to now use the optimal amount of expendable TC wire. The skill is the technician's ability to navigate the AMS2750 requirements and physical setup to get this done. Then, there is the immediate feedback. This can come in various forms. There is the feedback from the setup itself. That is, the wire is either too short or too long when you close the furnace door and plug the thermocouple wires into the field test instrument. There is also the feedback from you as the manager or engineer encouraging their efforts and guiding them toward success.

Feedback to the industrial athlete is often overlooked these days. People lose motivation because they lose the feedback that keeps them on track. Feedback extends beyond annual reviews and passing/failing pyrometry tests. It comes from the "small talk" the heat-treat people have among themselves. One of the best things to do is to ask the technicians how they prefer feedback. One person might say, "to tell it like it is." Others may prefer a report, or even just a simple high five or encouragement on the job itself.

Remember, the industrial athletes and the work of organizations today require a longer-term vision of the game they are actually playing. But companies need to stop motivating with just long-term rewards and focus more on the daily scale of how to get their team into these flow states. Provide that consistency and support, and they will be motivated to show up and perform their best each day.

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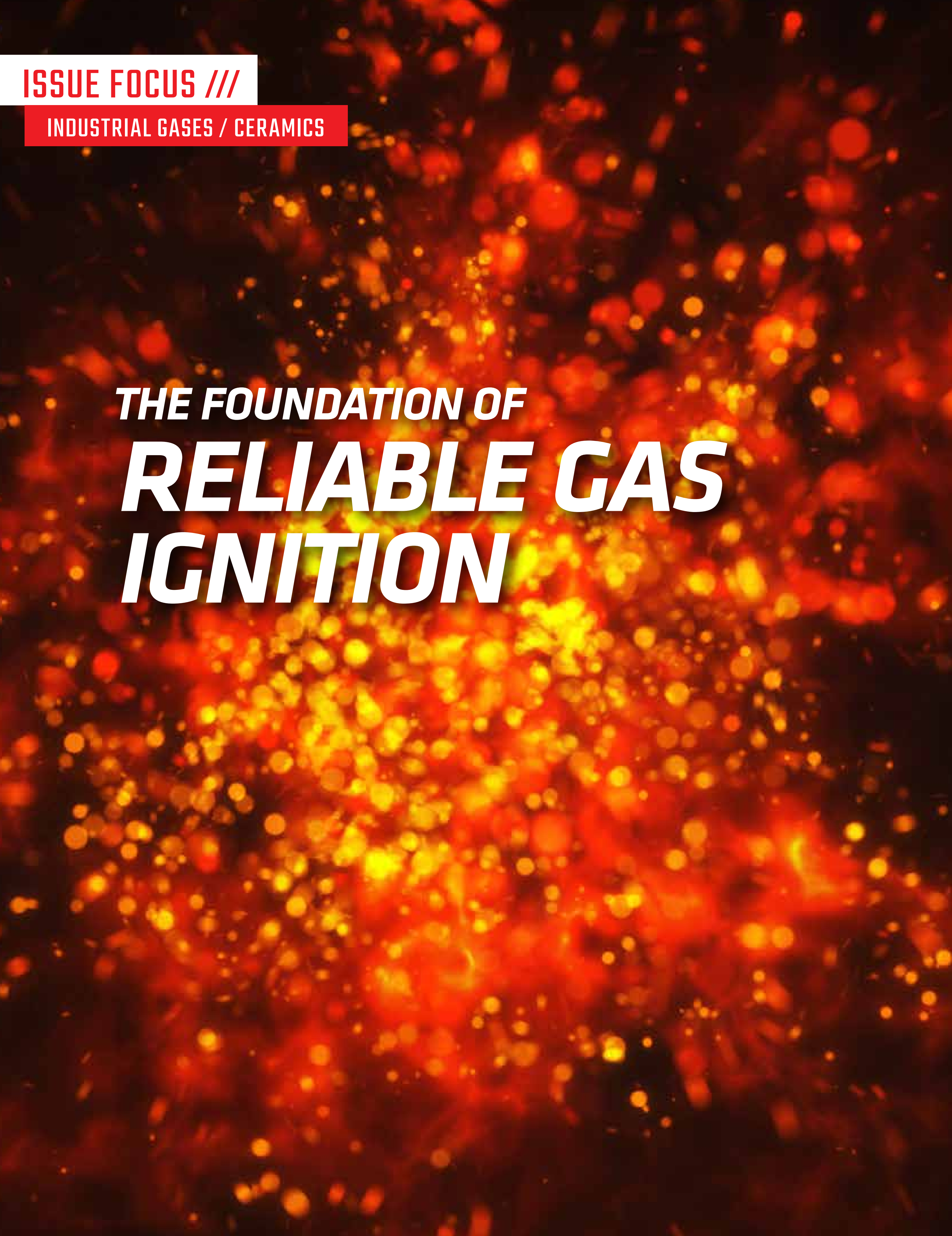


THE FOUNDATION OF RELIABLE GAS IGNITION

Why silicon carbide remains the gold standard for gas ignition.

By IAN BROWN

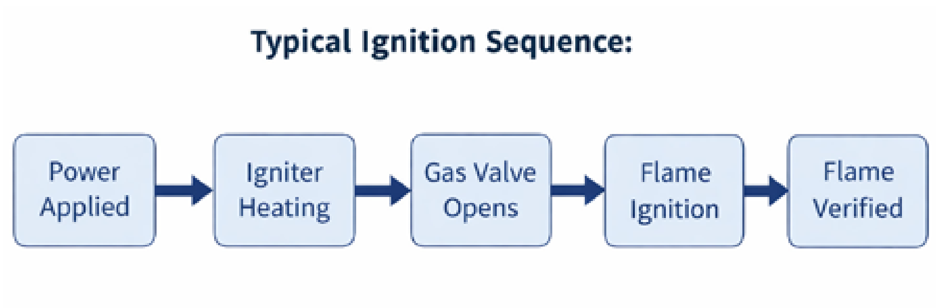
Silicon carbide hot surface ignition has been used in gas-powered equipment for decades because it delivers consistent ignition in environments defined by heat, thermal cycling, and combustion byproducts. In appliance applications — where ignition must be repeatable, safe, and manufacturable at scale — silicon carbide remains the baseline material against which other igniter technologies are often compared.

The history of silicon carbide ignition is closely tied to the development of early commercial igniter geometries, most notably the double-helix form that helped standardize hot surface ignition in gas appliances. Today, silicon carbide igniters remain widely used across cooking equipment, laundry appliances, and HVAC systems because they are practical to design around, produce, and support through both OEM production and replacement channels.

HOW A HOT SURFACE IGNITER WORKS IN A SAFETY CRITICAL SEQUENCE

A hot surface igniter functions as part of a controlled ignition system rather than as a simple heating element. In many gas-fired appliances, the ignition process follows a defined sequence: The igniter is energized first and allowed to heat before the gas valve opens. This approach ensures a reliable ignition source is already present when fuel is introduced.

Technical guidance on gas appliance design often describes these systems as "self-proving." Electrical current heats the igniter and, after a timed delay, signals the gas valve to open — a method widely used in ovens and other gas-fired equipment. Manufacturer documentation typically reflects a similar sequence: purge, igniter energizing, gas release, and flame verification.



A hot surface igniter operates within a timed, self-proving ignition sequence to help ensure safe, reliable burner light-off. (Courtesy: Surface Igniter)

Because of this controlled sequence, hot surface ignition is considered safety-critical. Ignition is not a chance event but a deliberate, timed process designed to minimize mis-ignition and support reliable burner light-off across repeated operating cycles.

WHY SILICON CARBIDE PERFORMS WELL AS AN IGNITION MATERIAL

Silicon carbide remains an effective ignition material because it can be formed into elements that heat quickly and predictably. When energized, silicon carbide igniters typically reach ignition-ready temperatures above 2,000°F (1,100°C) within roughly 15 to 60 seconds, depending on design and operating voltage. This predictable behavior allows system designers to coordinate ignition timing with gas flow for consistent burner operation.

Published specifications for hot surface igniters commonly describe performance in terms of time-to-temperature behavior. Silicon carbide elements consistently achieve the thermal output required for gas ignition in real-world appliance environments. Specifications also include controlled room-temperature resistance ranges used by engineers and service technicians to verify proper operation during design, testing, and maintenance. Beyond heat-up performance, silicon carbide is valued as a technical ceramic capable of withstanding harsh operating environments. It maintains strength at high temperatures and resists degradation from combustion byproducts and repeated thermal cycling. These properties help explain why silicon carbide continues to be used in demanding high-temperature applications where durability and consistency are critical.

While alternative ignition technologies — such as spark systems and silicon nitride igniters — are used in certain applications, silicon carbide remains widely adopted due to its predictable resistance characteristics, established manufacturing processes, and long history of field performance across millions of appliances.

DURABILITY IN PRACTICE: FROM MANUFACTURING PRECISION TO FIELD HANDLING

Silicon carbide igniters can withstand high temperatures and repeated thermal cycling, but long-term reliability depends on more than material properties alone. As a ceramic component, an igniter must be properly supported, mounted, and handled to perform as intended throughout its service life.

Service guidance consistently emphasizes handling the igniter by its ceramic base rather than the heating element itself, reducing the risk of microfractures during installation or maintenance.

These considerations extend upstream to design and manufacturing decisions. Mounting geometry, lead attachment, and mechanical support all influence how well the igniter withstands vibration, thermal stress, and handling once it leaves the factory. In real-world service environments — where installation conditions are not always ideal — these details can significantly affect performance and longevity

Ignition reliability also depends on manufacturing consistency. Even with a well-understood material, hot surface ignition systems require tightly controlled performance characteristics across large production volumes. Specifications commonly define acceptable ranges for parameters such as time-to-temperature behavior, room-temperature resistance, and minimum operating temperatures. These controls allow engineers to design ignition sequences that behave predictably from unit to unit.

For appliance OEMs, this repeatability is essential. Systems must

Durable hot surface igniters rely on sound design, consistent manufacturing, and proper handling to deliver reliable ignition over time. (Courtesy: Surface Igniter)

Spiral silicon carbide hot surface igniters from Surface Igniter are engineered to match OEM electrical characteristics, supporting consistent ignition performance across gas appliances. (Courtesy: Surface Igniter)

ignite reliably across thousands — or even millions — of appliances while supporting aftermarket replacement scenarios that require drop-in compatibility and predictable performance.

APPLYING PROVEN IGNITION TECHNOLOGY IN MODERN GAS APPLIANCES

Across gas-fired equipment, silicon carbide remains a foundational ignition technology for applications that demand consistent performance, long service life, and compliance with regulatory requirements. Manufacturers must balance multiple constraints: ignition systems must integrate into original equipment designs while also supporting service and replacement scenarios where compatibility, safety approvals, and installation readiness are essential.

Surface Igniter operates within this framework as a long-standing manufacturer of hot surface ignition solutions based on silicon carbide technology. Its igniters are engineered to meet OEM material and performance expectations while addressing the practical realities of service and repair environments.

In applications such as gas ranges, igniters are often specified as direct replacements aligned with established part numbers, allowing technicians to restore equipment quickly without altering system behavior or compromising safety. This focus on compatibility and installation-ready design helps reduce downtime and deliver predictable results in the field.

Surface Igniter further differentiates itself through a focus on quality, compliance, and durability. Its ignition components are produced to meet recognized safety and environmental standards, including CSA approval and RoHS and REACH compliance. These certifications help ensure reliable performance while aligning with broader industry expectations for safety, materials, and responsible manufacturing.

As gas appliance designs continue to evolve — driven by changing control strategies, regulatory requirements, and supply-chain pressures — the fundamental requirement of ignition remains unchanged: Systems must light reliably and safely across thousands of operating cycles. Silicon carbide's long history of proven performance, predictable electrical behavior, and compatibility with established appliance architectures ensures it remains a dependable ignition solution for modern gas-fired equipment.

ABOUT THE AUTHOR

Ian Brown is president of Surface Igniter, LLC.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HEAT TREATMENTS FOR SPRAYED LEAD-FREE PIEZOELECTRIC CERAMIC COATINGS

High-quality piezoelectric coatings can be achieved by the P-HT method, which is promising for scaling up the fabrication of piezoelectric ceramic coatings using for SHM.

By HAOJIE YUE, KAILING FANG, ZHICHAO GONG, KUN GUO, SHIFENG GUO, HONGFEI LIU, KUI YAO, AND FRANCIS ENG HOCK TAY

The piezoelectric ceramic coating, $[0.94(Bi_{0.5}Na_{0.5})TiO_3\text{-}0.06BaTiO_3]_{0.98}\text{-}(LiNbO_3)_{0.02}$ (BNBTLN), was fabricated by thermal spray process on stainless steel substrates with thermal barrier coating (TBC) as an intermediary layer. The morphology, structure, and electrical properties of the thermal-sprayed BNBTLN coatings after furnace heat treatment (F-HT) and plasma torch heat treatment (P-HT) were studied, respectively. The BNBTLN coatings after F-HT and P-HT both had the coexisting rhombohedral and tetragonal perovskite phases and exhibited excellent electrical properties, with an effective piezoelectric coefficient d_{33} of 68 p.m./V and 40 p.m./V, respectively. These results reveal that high quality piezoelectric coatings can be achieved by the P-HT method, which is promising for scaling up the fabrication of piezoelectric ceramic coatings.

1 INTRODUCTION

The Internet of Things (IoT) demands have led to a rapid expansion of the structure health monitoring (SHM) market in recent years. Rapid prototyping and integration of sensors and electronics on engineering structures and parts are desired in smart systems with SHM, which have inspired the research and development efforts on the revolution of smart materials fabrication. Piezoelectric materials have been widely used in sensors, transducers, and actuators [1-8]. The traditional piezoelectric ceramic coating fabrication methods, such as screen-printing [9-11], physical vapor deposition (PVD) [12,13], chemical solution deposition (CSD) [14, 15, 16], and aerosol deposition (AD) [17] cannot meet the on-site engineering practical operation requests, such as operating in the open air, large scale, high productivity and substrates with complicated shape. Air plasma spray (APS) is a well-developed technique for coating fabrication [18, 19, 20], which has been widely used in the aerospace and oil and gas industry [21]. In the past 30 years, efforts have been made to prepare lead zirconate titanate (PZT)-based piezoelectric ceramic coatings by a scalable deposition method — thermal spray. However, a large number of secondary phases were formed in the obtained PZT-based coatings, which resulted in much lower electrical properties compared to the PZT-based ceramic bulk counterpart [22, 23, 24, 25]. In previous studies [26,27], a single perovskite phase was achieved in thermal sprayed bismuth sodium titanate (BNT) lead-free piezoelectric ceramic coatings. Furthermore, the obtained effective piezoelectric coefficient d_{33} of heat-treated BNT coatings is close to that of BNT bulk ceramic.

The heat treatment can significantly improve the crystallinity and electrical properties of thermal sprayed coatings. Researchers have investigated the effects of heat treatment on the quality of PZT thick film, obtaining a single PZT phase after a 700°C calcination treatment. At an adequate heat treatment temperature, not only to avoid a large number of secondary phases but for better crystallization during the transformation of the precursor to crystalline PZT [28]. Some efforts have been made to prepare barium titanate-based piezoelectric coatings on carbon steel by plasma spray and investigating their electrical and mechanical properties after heat treatment. During the plasma spray process, the coating formed by the rapid melting and cooling of barium titanate contains a large amount of amorphous phase. Heat treatment was found to transform the amorphous phase into a crystalline one, while also yielding a high dielectric constant and low dielectric loss [29]. Potassium sodium niobate based ceramic coating with single perovskite phase and dense morphology were successfully prepared by thermal spray, and heat treatment at 1,150°C was carried out to improve the crystallinity and electrical properties. The results show the effective piezoelectric coefficient d_{33} is more competitive than other thermal sprayed lead-free piezoelectric coatings [30,31]. However, the high temperature of F-HT limits the applications of the piezoelectric coatings on metallic substrates, as oxidation occurs when some metallic substrates are heat treated for a long time at high temperatures. In addition, since some engineering structures and parts can be large in dimension, scale-up fabrication or direct in-situ production of piezoelectric ceramic coatings requires thermal treatment on-site implementable instead of conventional thermal treatment in a furnace. To date, no studies have been conducted with a focus on the different on-site heat treatments of piezoelectric ceramic coatings, except for a few reports on heat treatment in the furnace. A novel and effective heat treatment method is desired for the on-site processing of piezoelectric ceramic coatings.

The Internet of Things (IoT) demands have led to a rapid expansion of the structure health monitoring (SHM) market in recent years. Rapid prototyping and integration of sensors and electronics on engineering structures and parts are desired in smart systems with SHM, which have inspired the research and development efforts on the revolution of smart materials fabrication.

In this work, the plasma torch was innovatively used for the heat treatment of piezoelectric ceramic coatings. $LiNbO_3$-doped

$0.94(Bi_{0.5}Na_{0.5})TiO_3$-$0.06BaTiO_3$ (BNBTLN) piezoelectric ceramic coatings were fabricated on a 316L stainless steel substrate by thermal spray process after introducing TBC as an intermediary layer. Thermal analyses of the melt-recrystallization process of BNBTLN ceramic coatings were conducted. The crystallization behaviors of the thermal sprayed coatings during heat treatment in a furnace (F-HT) and by plasma touch heat treatment (P-HT) were investigated. The comparison between F-HT and P-HT of thermal sprayed BNBTLN coatings was presented, including morphology, structure, and electrical properties.

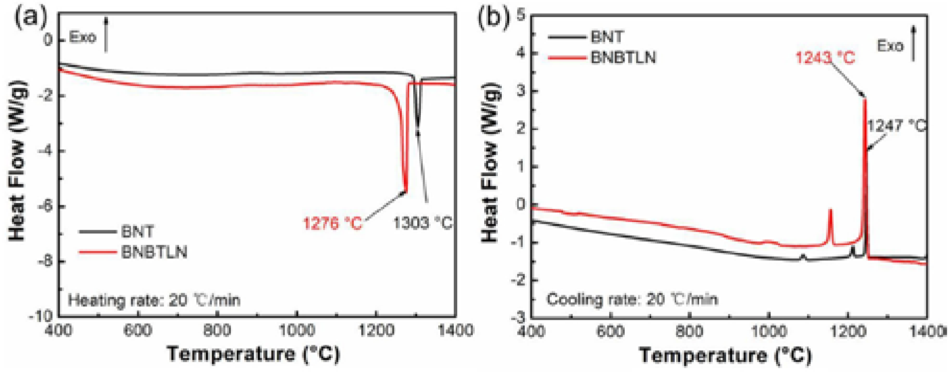

Figure 1: (a) Heating and (b) cooling DSC curves of BNT and BNBTLN ceramic powders.

2 EXPERIMENTAL PROCEDURE

BNBTLN ceramic powders were prepared by conventional solid-state ceramic processing using Bi_2O_3 (99.99 %), Na_2CO_3 (99.5 %), $BaCO_3$ (99.95 %), Li_2CO_3 (99.998 %), Nb_2O_5 (99.9 %), and TiO_2 (99.90 %) powders (Alfa Aesar, Karlsruhe, Germany) as the starting materials. As the carbonate powders were moisture sensitive, they were dried first at 120°C for 24 hours prior to use. All the starting materials were weighed to get the stoichiometric composition of $[0.94(Bi_{0.5}Na_{0.5})TiO_3$-$0.06BaTiO_3]_{0.98}$-$(LiNbO_3)_{0.02}$. 10 mol% excess Bi was introduced to the feedstock to compensate for the volatile loss. The weighed materials were wet-mixed in ethanol for 24 hours by a planetary ball mill machine. Then, the slurry was dried and compacted before it was put into an alumina crucible and calcined in a furnace at 850°C for 2 hours and then at 1,000°C for 5 hours.

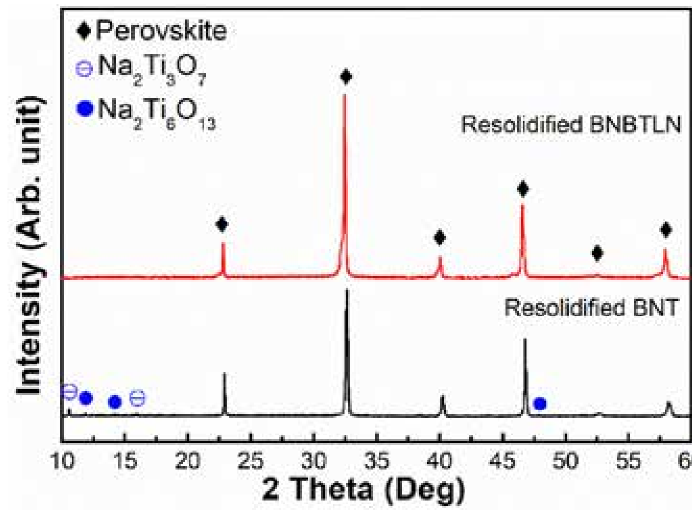

Figure 2: XRD patterns of resolidified BNT and BNBTLN.

The feedstock powder was prepared by crushing and sieving the calcined coarse agglomerates to obtain desired particle size. The melting and crystallization behaviors of BNBTLN calcined powder were studied by thermogravimetric analysis combined with differential scanning calorimetry (TG-DSC, STA 449 F1 Jupiter, Netzsch GmbH, Germany), up to 1,400°C in the air in Pt crucibles, with both heating and cooling rate of 20°C/min. In order to identify the phases formed in the cooling process of the DSC test, the final product after the STA test (i.e., the resolidified BNBTLN ceramic) was examined by X-ray diffraction (XRD).

A Pd/Ag bottom electrode layer (30/70, Gwent Group, Pontypool, U.K.) layer was first prepared by screen printing on the 316L stainless steel plate substrates with TBC. The BNBTLN feedstock was sprayed onto substrates using an atmospheric plasma spraying system (9 MC, Sulzer Metco Inc., Westbury, NY). The thermal spray process was conducted at ambient pressure using Ar plasma at a power of 18 kW. The crystal structure of the obtained samples was analyzed by X-ray diffraction analysis (XRD, D8 ADVANCE, Bruker AXS GmbH, Karlsruhe, Germany). The morphology of the coatings was examined with a field emission scanning electron microscope (FESEM, JSM6700F, JEOL, Freising, Germany). The microstructure of the samples was analyzed using transmission electron microscopy (TEM, JSM-6100F, JEOL, Ltd., Tokyo, Japan). A focused ion beam (FIB, FEI Helios NanoLab 600 DualBeam, Eindhoven, Netherlands) cutting was used for the TEM specimen preparation. Dielectric properties were measured with an impedance analyzer (HP4294A, Agilent Technologies Inc, Tokyo, Japan). The ferroelectric properties were studied at room temperature using a ferroelectric testing unit (Premier II, Radiant Technologies, Inc., Albuquerque, USA) at a frequency of 10 Hz. The thermal sprayed coatings were poled under an electric field of 60 kV/cm at room temperature for 10 minutes.

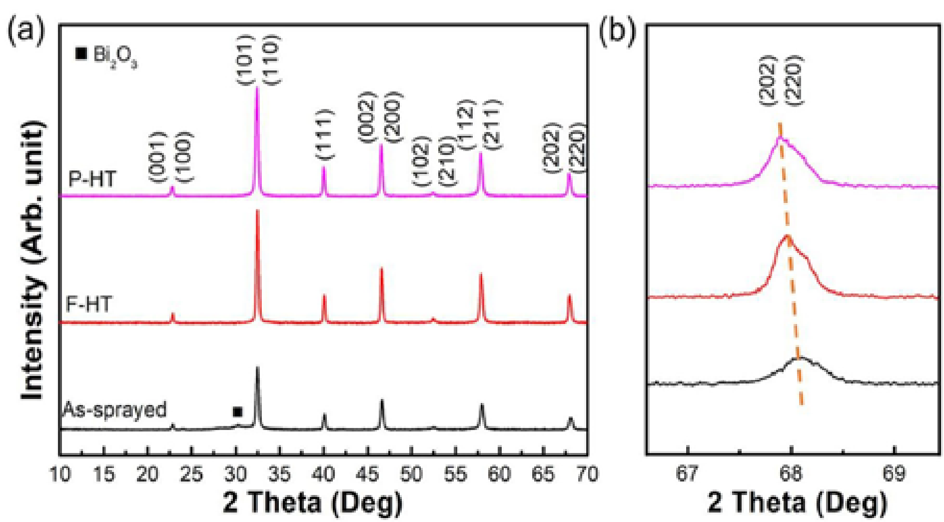

Figure 3: XRD patterns of thermal sprayed BNBTLN coatings before and after heat treatment.

The piezoelectric coefficient (d_{33}) was measured using a laser scanning vibrometer (OFV-5000, PolyTech GmbH, Waldbronn, Germany). BNBTLN bulk samples were also prepared for electrical properties testing as a control. The d_{33} of bulk ceramic was measured with a piezo-d_{33} m (ZJ-4B, Institute of Acoustics, Shanghai, China).

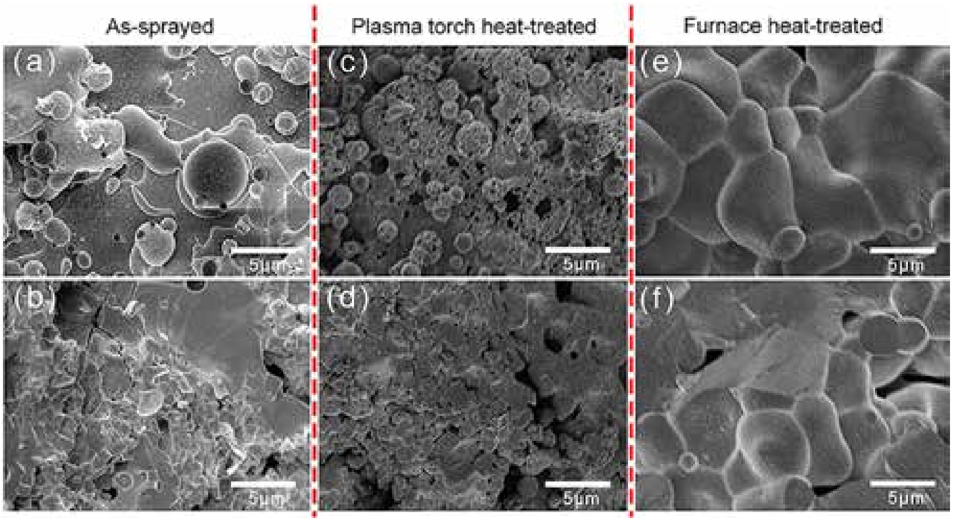

Figure 4: FESEM images of surface (a, c, e) and cross-section (b, d, f) for BNBTLN coating on 316L-TBC: (a) and (b) As-sprayed coating, (c) and (d) Plasma torch heat-treated coating, (e) and (f) Furnace heat-treated coating.

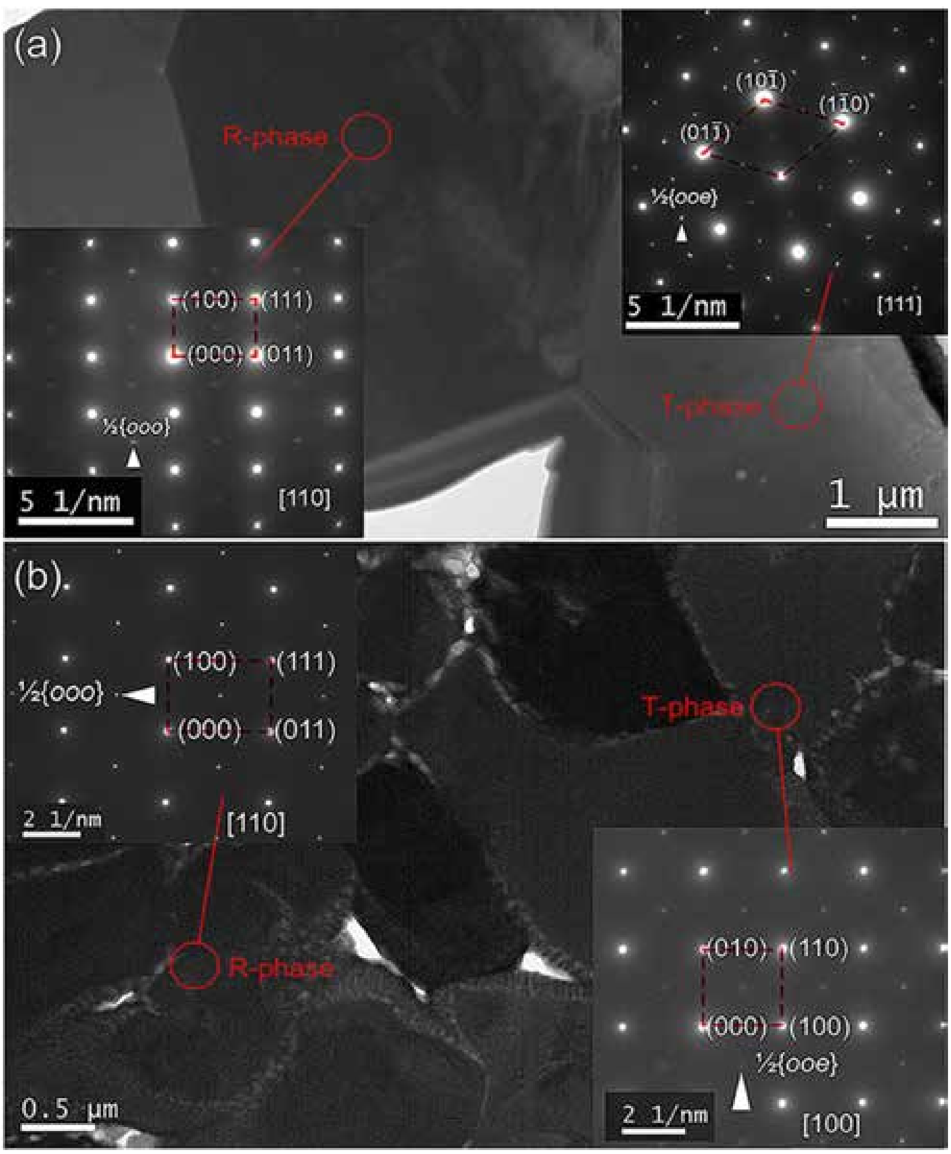

Figure 5: TEM image of BNBTLN coating: (a) F-HT, SAED patterns obtained from the [111] and [110] crystal axes, respectively, with ½{ooe} and ½{ooo} superlattice spots highlighted with white arrows. (b) P-HT, and SAED patterns were obtained from the [110] and [100] crystal axes, respectively, with ½{ooe} and ½{ooo} superlattice spots highlighted with white arrows.

3 RESULTS AND DISCUSSION

3.1 Melting-recrystallization behavior of BNBTLN coatings

Since the melting-recrystallization process was involved in the thermal spray process, the melting and recrystallization behaviors of BNBTLN ceramic powder were studied in comparison with BNT by the DSC test shown in Figure 1 BNT was reported to be a congruent melting composition [32,33]. The DSC curve of BNT in Figure 1a exhibited a single sharp melting peak at 1,303°C, and BNBTLN showed a similar melting behavior with a lower melting point at 1,276°C. The lithium niobate dopant in the BNT-BT system was believed to contribute to the lowered melting point [34,35]. In the cooling DSC curve of BNT, there was one major sharp peak at 1,247°C, followed by two small peaks on the lower temperature side. BNBTLN had one major sharp peak at 1,243°C, followed by one small peak on the lower temperature side. XRD patterns of the resolidified BNT and BNBTLN were shown in Figure 2. Both exhibit major perovskite phase, which could correspond to the major peaks in cooling DSC curves. In addition, minor Bi-deficient $Na_2Ti_3O_7$ and $Na_2Ti_6O_{13}$ secondary phases were detected in the resolidified BNT due to the more serious volatile loss of Bi than that of Na.

3.2 Structure and morphology of BNBTLN coatings

The XRD patterns of thermal sprayed BNBTLN coatings are presented in Figure 3. The as-sprayed coating exhibited a tiny hump of the amorphous phase. After heat treatment, all the BNBTLN coatings showed a single phase of perovskite structure with significantly increased intensity of diffraction peaks compared to the as-sprayed coating, indicating the heat treatment by both furnaces and plasma torch effectively enhanced the crystallinity. Additionally, the diffraction peaks shift to smaller angles after F-HT and P-HT (shown in Figure 3b), indicating a larger lattice space. This phenomenon could potentially be attributed to the presence of tensile stress [36].

Figure 4 presents the FESEM images of the surface and cross-section for BNBTLN thermal sprayed coating before and after the heat treatments. As shown in Figure 4a, the surface of the as-sprayed coating consists of a mixture of spherical and irregularly-shaped particles, which is a typical morphology resulting from rapid cooling and solidification after melting. The morphology indicate that the crystallization was not fully completed from the cool melt in the

BNBTLN	Substrates	Post thermal treatment	Dielectric constant	Dielectric loss	P_r ($\mu C/cm^2$)	d_{33} (pm/V)
Thermal sprayed coating	316L-TBC	As-sprayed	538	0.024	8	9
		F-HT	1154	0.044	29	68
		P-HT	648	0.038	16	40
Bulk ceramic	N.A.	N.A.	1720	0.050	34	180

Table 1: Dielectric and piezoelectric properties of BNBTLN coatings measured at room temperature (1 kHz).

as-deposited coating [37]. In addition, as presented in Figure 4b, it can be seen from the cross-section of the coating that the grains are uneven with irregular grain boundaries. After heat treatment, a significant increase in grain size and crystallinity was observed. As shown in Figure 4c, a large number of crystallized grains on the surface of the coating can be observed after P-HT. As presented in Figure 4d, the cross-section morphology of the coating after P-HT treatment is relatively dense with a more regular shape than the as-sprayed coating. Furthermore, the incompletely crystallized particles have also been recrystallized during the heat treatment, giving rise to the clear grain boundaries. Likewise, the morphology of the surface and cross-section recorded after F-HT is presented in Figure 4e and 4f, respectively. Due to the longer time and a more uniform heating process, the F-HT produced denser morphology and higher crystallinity than P-HT.

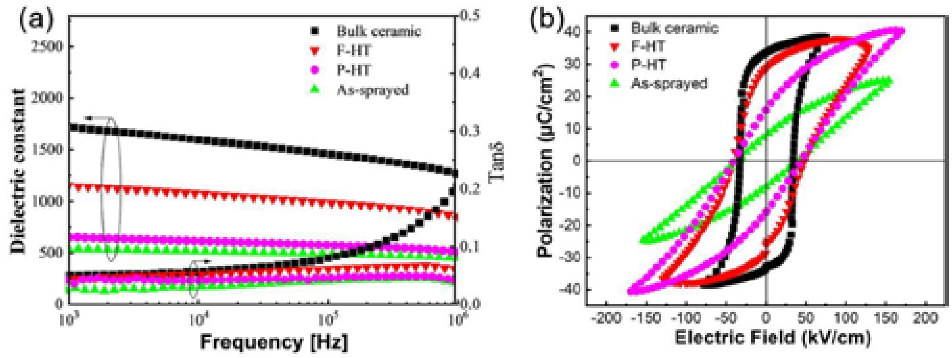

Figure 6: Thermal sprayed BNBTLN coatings: (a) dielectric constant and dielectric loss versus frequency, (b) polarization versus electric field at room temperature, at 10 Hz.

The bright field TEM image in Figure 5a revealed more details of the BNBTLN coating after F-HT, with the selected area electron diffraction (SAED) patterns obtained along [111] and [110] zone axes showing the presence of 1/2{ooe} and 1/2{ooo} superlattice reflections, respectively. The in-phase ($a^0a^0c^+$) tilting of oxygen octahedrons in the P4bm phase contributed to the presence of 1/2{ooe} superlattice reflections along [110] direction, indicating the perovskite phase had a tetragonal characteristic. The 1/2{ooo} superlattice spots along [110] indicated the antiphase ($a^-a^-a^-$) oxygen octahedral tilting in the R3c phase, which was not visible in *P4mm* and *P4bm* phases [38, 39, 40, 41]. These superlattice diffractions provided solid evidence for the coexistence of R-T phase in the same grain in thermal sprayed BNBTLN coatings after F-HT. The MPB of R-T phase was expected to enhance the subsequent electrical properties, similar to the effect observed in bulk ceramic.

Similarly, Figure 5b presents TEM images of BNBTLN coatings after P-HT, with SAED patterns obtained along [100] and [110] zone axes. The 1/2{ooe} superlattice diffractions in the SAED of [100] direction, in addition to the fundamental perovskite reflections, indicated a tetragonal characteristic of the perovskite phase. The alignment of the 1/2{ooo} superlattice spots along [110], revealed the presence of an R3c rhombohedral perovskite phase in the thermal sprayed BNBTLN coating. This indicated that the MPB of R-T phase also existed in the P-HT coating.

In addition, the measured reciprocal space vector $|G(111)|$ and $|G(1\bar{1}0)|$ in R-phase and T-phase for F-HT were 4.43 nm^{-1} and 3.70 nm^{-1}, respectively. The corresponding real space distances, calculated from the inverse of $|G_F(1\bar{1}1)|$ and $|G_F(1\bar{1}0)|$, were $d_F(111) = 2.26$ Å and $d_F(1\ \ 0) = 2.70$ Å, respectively. For P-HT, the measured $|G_P(111)|$ and $|G_P(110)|$ in R-phase and T-phase were 4.39 nm^{-1} and 3.61 nm^{-1}, respectively. The corresponding real space distances were $d_P(111) = 2.28$ Å and $d_P(110) = 2.77$ Å, respectively. The distances of $d_F(111)$ and $d_F(1\bar{1}0)$ were greater than $d_P(111)$ and $d_P(110)$, respectively, indicating that the lattice parameter of P-HT is larger than that of F-HT, which is consistent with the XRD diffraction peaks being shifted.

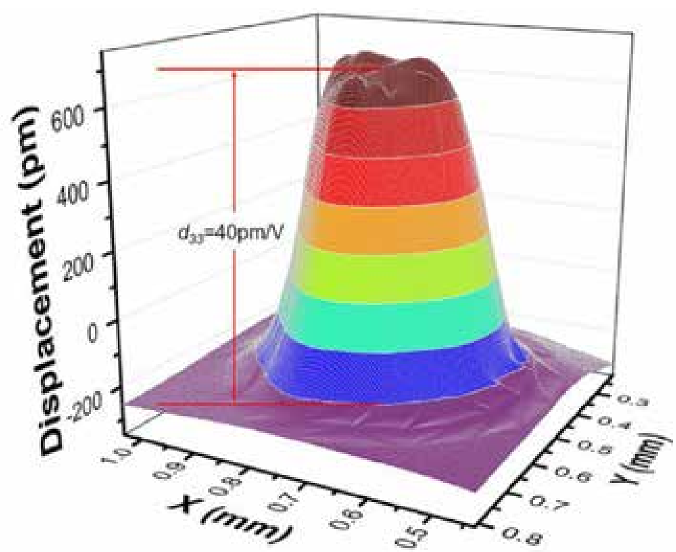

Figure 7: Three-dimensional plotting of instantaneous vibration data with the dilatation of the P-HT BNBTLN coating excited by an electric sine wave of 20 V (amplitude) at 1 kHz, measured with LSV under substrate clamping condition.

3.3 Dielectric, ferroelectric, and piezoelectric properties

The dielectric and ferroelectric properties of the heat-treated coatings were subsequently investigated and compared to those of bulk ceramics. Figure 6a shows heat treatment significantly enhances the dielectric properties of thermal sprayed BNBTLN coatings, which is mainly attributed to the improved crystallinity and densification of the coating. As presented in Table 1, at the measurement frequency of 10 kHz and room temperature, the dielectric constants of F-HT and P-HT samples are 1,154 and 648, respectively, with the former being significantly higher than the latter, yet still lower than 1,720 of bulk ceramics.

The dielectric loss of the coating after heat treatment is lower compared with the as-sprayed coating. Compared with the as-sprayed coatings, the P-E loop of the BNBTLN ceramic coating after heat treatment shows the remnant polarization increased significantly

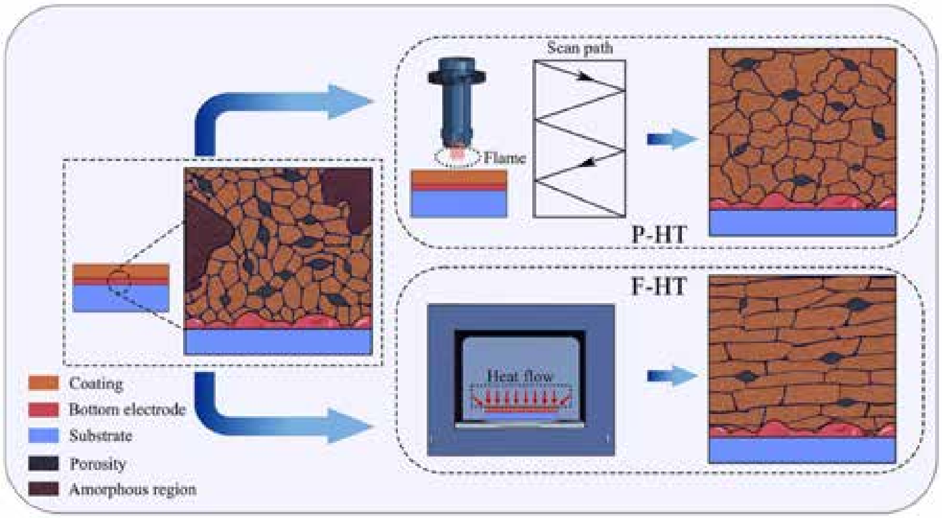

Figure 8: Schematic diagram of two heat treatment methods and the corresponding growth process of crystal grains.

with improved saturation. While both the F-HT and P-HT processes improved electrical properties of the as-sprayed coating, the F-HT processed coating still exhibited the best dielectric and ferroelectric properties.

After poling at room temperature under 55 kV/cm for 10 minutes, the effective piezoelectric coefficient d_{33} of the BNBTLN coatings was measured by the LSV method [42]. Figure 7 presents the displacement magnitude of BNBTLN coating after P-HT measured under the excitation of a sine wave of 10 V in amplitude at 1 kHz. Since the top (covered with the top electrode) of the 3D plotted data was uneven, the average value over the top area instead of the highest point was used to calculate the effective d_{33}. The thermal sprayed BNBTLN coatings after P-HT had the effective piezoelectric coefficient d_{33} of 40 p.m./V. In addition, Table 1 also compares the d_{33} of the thermal sprayed coatings and the bulk ceramic of BNBTLN. The as-sprayed coating shows effective piezoelectric coefficient d_{33} of 9 p.m./V, which reached 68 p.m./V after F-HT. The d33 of BNBTLN bulk ceramic is 180 p.m./V, which is relatively high compared with the BNBTLN thermal sprayed coatings.

3.4 Comparative analysis of F-HT and P-HT processes

Figure 8 illustrates the process of F-HT and P-HT and the associated grain growth details. The as-sprayed coating exhibits the presence of amorphous regions and a significant number of porosities along with a relatively small grain size. In the conventional F-HT, the workpiece with the thermal sprayed coating is heated to a high temperature through slow heating in the furnace, with the temperature in the furnace relatively stable and the heat flow emanating from all directions.

Prolonged heat flux leads to the gradual disappearance of the amorphous regions involved in the coatings, with the grain boundaries becoming increasingly distinct and the grain size becoming uniform, yet a small number of interlayer voids remained.

The P-HT uses a plasma torch as a heat source, which sprays a plasma flame of extremely high temperature directly onto the surface of the coating and scans the flame on the surface in a back-and-forth manner. At the high temperature of the plasma flame, the grains rapidly crystallize and grow. However, the heat from the plasma torch is directional with sharp interfaces and steep thermal gradients. The inhomogeneous heat source leads to irregular grain size and shape, which hinders the formation of regular layered grain morphology. The temperature change during P-HT of the sprayed coating along the scanning path was much faster, which may not favor formation of uniform nucleation and adequate grain growth. Although the density of the coating after P-HT is not as good as that of the coating after F-HT, the heat treatment time is greatly reduced, and the oxidation damage to the metal substrate is avoided, meanwhile, it is scalable for forming thermal sprayed piezoelectric ceramic coating in large engineering structures. These features are highly demanded for many practical applications, such as in ultrasonic structural health monitoring [43].

4 CONCLUSIONS

BNBTLN piezoelectric ceramic coating was deposited by thermal spray on stainless steel substrates with thermal barrier coating (TBC). Both the furnace heat treatment (F-HT) and plasma torch heat treatment (P-HT) significantly improved the crystallinity with R-T phase coexistence and enhanced the ferroelectric and piezoelectric properties of the BNBTLN coatings. F-HT provided gradual and uniform heating beneficial to more homogeneous grain morphology, higher density, and better electrical properties. P-HT offered a scalable, fast, and onsite processing method.

After P-HT, an effective piezoelectric coefficient d_{33} of 40 p.m./V was obtained. These results reveal that high-quality piezoelectric coatings can be achieved by the P-HT method, which is promising for scaling up the fabrication of piezoelectric ceramic coatings using for SHM.

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‘WE LET DEMAND DRIVE A LOT OF OUR DECISIONS’

Isembard works with customers who are developing a new product type or they’re in the prototype phase. (Courtesy: Isembard)

Isembard is a distributed manufacturing company using a franchise model to build a network of modular, software-enabled factories that scale production from prototype to factory-level output.

By KENNETH CARTER, Thermal Processing editor

Machine shops exist across the U.S. in all shapes and sizes; however, that "uniqueness" can sometimes cause customers to question consistency in the final product.

But what if machine shops could be franchised like a fast-food chain? In hindsight, it seems like a no-brainer, but it took the minds behind Isembard to make the franchising of machine shops a reality.

"We were incorporated in October 2024; the premise was that there wasn't any kind of unified effort up until that point to solve a diminishing supply as demand continued to increase for critical industries," said Justin Baucum, who leads U.S. Expansion at Isembard, from Dallas, Texas.

GLOBAL ENTERPRISE

Even though Isembard was founded in London — where it is headquartered — it was always intended to be a global enterprise tackling three manufacturing challenges: quickly creating more capacity, interconnecting a network of factories, and designing a franchise business model, according to Baucum.

"While we have what you could call corporate-owned factories, the primary growth mechanism for Isembard is going to be through a franchise model," he said. "We think that model works really well for the industry, because, historically, these privately owned machine shops have been distributed all around the country. The same applies in the U.K. and in Europe, but there are still all the benefits that come along with being part of or having partnerships, whether formal or informal, with a larger network."

To that end, Isembard has formalized that and is giving benefits to existing machine shops or with people who want to get into the industry, according to Baucum.

"In the past, the only way to do that was you either knew somebody or you knew how to program and operate CNC machines," he said. "There was no real pathway for outsiders. By doing a franchise model, we've thought through 80 to 90 percent of the process for them. We're making more new pathways into the industry."

BENEFITS OF CONSISTENCY

Franchising machine shops became a precedent when Isembard became aware of the large number of them across the U.S., according to Baucum.

"There are somewhere north of 20,000 machine shops with different manufacturing methods, and historically they've been decentralized," he said. "A lot of people look at that as a fragmented industry; however, the industrial base where most things are actually produced are spread across the country."

By taking advantage of a business model that has worked successfully within other industries — fast food, for example — customers get the benefits of consistency and working with a known brand, according to Baucum. "I think it's really interesting when you look at other industries and there is an immediate name that comes to mind — probably McDonald's," he said. "In manufacturing, there's not really a front-runner of where people may think of defense primes and things like that. But in order to have the reach and the brand focus, you have to have a model that fits within how the industry is historically operated. And these places are fundamentally doing the same process. Raw material comes in; you program it; you go through the quality steps, and you ship it. There is a lot of unification that can be done. Even though the franchising model hasn't historically been used, it actually fits really, really well."

5-AXIS CNC MACHINES

The equipment prominent in Isembard's locations consists of full 5-axis CNC machines capable of machining a wide variety of pieces, including gears. Much of what is made by Isembard is for defense, energy, and aerospace where a majority of the products go through different heat-treating processes as well, according to Baucum.

"A lot of those are just due to the use cases of those products," he said.Part of the integration of multiple locations into a franchise model is to have the machines controlled by software created specifically for the shops under the Isembard umbrella, according to Baucum.

"You can think of it as an ERP or MES on steroids," he said. "It's a modula r approach to how we designed the software. We started with simple things like supplier management in a really robust database. Then, we built out quoting, which is another really big pain point for the industry. We moved on to scheduling, and we'll continue to take that modular approach where we get a lot of value from a particular functionality. Long term, if you step into a factory, whether you're the general manager or a machinist, you'll be interacting with this one platform to do everything that you need to do."

'FORGE INDUSTRIAL ACCELERATION'

Isembard's dedication to its customers is captured in its mission statement: Forge industrial acceleration, according to Baucum.

"That could just sound like a bunch of words slapped together, but what it turns out to be, in reality, is that we bring a degree of intensity that I haven't seen in the industry," he said.

Recently, one of Isembard's factories worked all night on a large contract for a defense company customer with some immediate needs, according to Baucum.

"As soon as it was done, I had somebody on a plane to the West Coast to hand deliver those parts that we produced for them," he said. "We don't want to do that every time, but it's something that we were proud to do. We will move heaven and earth to make sure that we accomplish what is needed."

Isembard also takes that approach when setting up new factories while constantly revising its software, according to Baucum.

"The software of three months ago looks nothing like what it looks like today," he said. "That's the day-to-day of: 'Hey, here's a new idea.' There's an intensity to it. We know we need to be pretty fero-

Isembard's U.K. team. (Courtesy: Isembard)

cious with how we go about what we're doing. We let demand drive a lot of our decisions."

CUSTOMER COLLABORATION

With that in mind, Isembard works with customers who are developing a new product type or they're in the prototype phase, according to Baucum.

"What we want to do is not just be a shop or somewhere that they send some parts to; we want to be a true partner," he said. "We have a lot of folks that have design-for-manufacturing experience. We'll work with those customers and give them input from the material choices that they have, while we try to understand the end use case of what they're doing. We work closely with them. When we're going through the programming process, we'll identify things and give feedback. That way, we're saving the customer money, time, and effort, but we're also helping them calibrate what they're designing so that it's manufacturable."

Working closely with customers while also giving them options through a franchised machine shop has helped with the efficiency of those customers' needs, according to Baucum.

"Overarchingly, it's harder and harder to find reliable machining capability for these growing companies," he said. "Part of that's due to just the industry not having a lot of new people to get involved with it. And, at a lot of shops, the owners are starting to retire, or they're moving on to other things. I've also seen a pattern of when it gets to really complex things, there are fewer people who are actually able to produce them.

"We've heard that from a couple of our customers. They send us the hard stuff because nobody else wants to do it. In this industry, people want the 'rinse-and-repeat' sort of thing where it's just to keep the spindles cutting metal, but somebody has to do the hard stuff. And that's where we come in. We're the solution. We can do the easy stuff, sure, but we also are willing to do the really hard stuff and do it at scale."

TACKLING THE 'HARD STUFF'

Some of that "hard stuff" included the assembly for an anti-drone weapon system, according to Baucum. "One of the base housings for this took about a week to program; it required all this specialty tooling," he said. "Part of it was because of how it was designed, but it had never been machined before. It had only been designed. This was the first time it was being made in the real world. The machining time for this one part was 25 to 30 hours.

Most places wouldn't even take that on because they don't have the machines that could handle the tolerances required or they just don't want to undertake this beast of a part." Taking on those complex jobs while having the bandwidth to do it, at many locations, is just part of the enthusiasm that Baucum emphasizes as Isembard looks to the future.

"It's going to be harder and harder to find places that will do machining, heat treating, and do this full range of machined parts," he said. "In the movie *The Founder*, which tells the story of McDonald's, there is a scene where McDonald's founder Ray Kroc mentions that, in every small town in the U.S., there is a church, a school, and a McDonald's," he said. "Isembard wants to be the fourth business in that model. It's because it's something that's so fundamental to driving prosperity and creating livable jobs in our nation. It's something to take pride in because we're building something important."

And what continues to make Isembard's franchise model unique is that the machinists of today can be the franchise owners of tomorrow, according to Baucum. "At least half of our CNC engineers want to have their own businesses at some point, and so the franchise model base supports that," he said. "That's something that, even for myself, I could see a day where I have an Isembard factory as a franchise because I think it's a great model, and it's something that I'm super interested in."

BACKED FOR GROWTH

Isembard's momentum has also been reinforced by fresh capital. Isembard recently raised a $50 million Series A led by Union Square Ventures, signaling strong investor confidence in its model.

As demand for advanced manufacturing continues to grow, the company is actively seeking franchise partners, from experienced operators to first-time business builders, to join its expanding U.S. network.

MORE INFO www.isembard.com

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ANDREW TUCKER /// EXHIBITION DIRECTOR, SMARTER SHOWS /// CERAMICS EXPO AND THERMAL MANAGEMENT EXPO

"We're expecting over 2,000 visitors and 200 plus exhibitors representing companies across the global ceramics and advanced manufacturing supply chain."

With the growing demand for heat-treating processes across industries such as aerospace, automotive, electronics, and energy, advanced ceramics are playing an increasingly vital role in driving innovation and efficiency.

Thermal Processing talked with Andrew Tucker, event director of Ceramics Expo and Thermal Management Expo, to discuss this year's event, the decision to return to Cleveland, and what attendees can expect from the show's exciting new features. Ceramics Expo is May 5-6 at the Huntington Convention Centre.

Why is the Ceramics Expo integral to the ceramics and heat-treating sectors?

Advanced ceramics support numerous technologies, yet many people don't realize how much ceramics impact our daily lives — from cellphones and cars to household appliances like kettles and stoves. Thermal management solutions also play a key role in high-temperature materials and manufacturing processes, making the synergy between ceramics and thermal management essential.

The show brings together the entire advanced ceramics supply chain under one roof. Our conference serves as a meeting point for material scientists, engineers, manufacturers, and OEMs — supply chain leaders driving innovation across sectors such as aerospace, defense, electronics, automotive, semiconductors, and industrial manufacturing.

The Expo provides a platform for manufacturers and end users to connect, share knowledge, and explore performance improvements, efficiency gains, and new capabilities.

Through the conference program and technical sessions, attendees can exchange ideas, explore emerging research, and address key challenges like materials performance, sustainability, and manufacturing scalability.

The Ceramics Expo is returning to Cleveland this year. Why was it important to bring the event back to this city?

Cleveland is at the heart of the advanced manufacturing supply chain in the U.S., with the Midwest leading in material science and ceramics engineering. Hosting the Expo in Cleveland connects manufacturers, research institutions, and technology partners within this thriving ecosystem.

The aerospace, automotive, electronics, defense, and energy sectors have established their bases in the manufacturing belt, making Cleveland a natural hub for industry collaboration. Returning to Cleveland also strengthens local and regional partnerships, including the Greater Cleveland Partnership, which supports positioning Cleveland, Ohio, and the MEP network as key players in the manufacturing ecosystem.

This year, Ceramics Expo is introducing the Innovation Hub. What can attendees expect from this addition?

The Innovation Hub is an exciting new feature that will showcase cutting-edge research, emerging technologies, and next-generation ceramics applications. Leading universities and research institutions will present breakthrough advancements in material science, processing technology, and ceramics innovation.

Attendees will gain access to technologies that could transform production capabilities. The Hub also includes a startup zone, where businesses seeking mentorship or investment can connect with institutions in Ohio and integrate into the supply chain — a vital step for growth.

What should attendees mark on their show calendars this year?

This year's conference program features expert-led presentations on a variety of topics, here are some key sessions you won't want to miss:

- Welcome Address by The American Ceramic Society (ACerS) "Ceramics' Role in Supporting Thermal Management's Future."
- An opening panel discussion titled "Why Ohio? How the State Is Powering the Next Generation of Ceramic Manufacturing and Innovation." It will explore how Ohio is powering the next generation of ceramics manufacturing and innovation.
- Keynote Session by NASA – "Ceramics at Hypersonic Limits: Advancing Ultra-High Temperature Materials for Space and Aeropropulsion."

What kind of turnout are you expecting this year?

We anticipate over 2,000 visitors and more than 200 exhibitors from across the global ceramics and advanced manufacturing supply chain. Attendees will include engineers, R&D professionals, manufacturing leaders, procurement specialists, material scientists, and PhD students. The Expo is an opportunity to discover new technologies, strengthen supplier relationships, and explore innovative solutions for organizations.

What are you personally looking forward to at this year's expo?

Each Expo is a labor of love, and I'm particularly excited about the Innovation Hub. It's a chance to connect and nurture young talent in the industry, especially through partnerships with STEM communities and academic institutions.

I'm also thrilled to have Ceramics Expo back in Cleveland. The city has gone all out to support the event, highlighting why this niche sector of ceramics is so important to Cleveland, Ohio, and the broader manufacturing network.

MORE INFO www.ceramicsexpousa.com

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