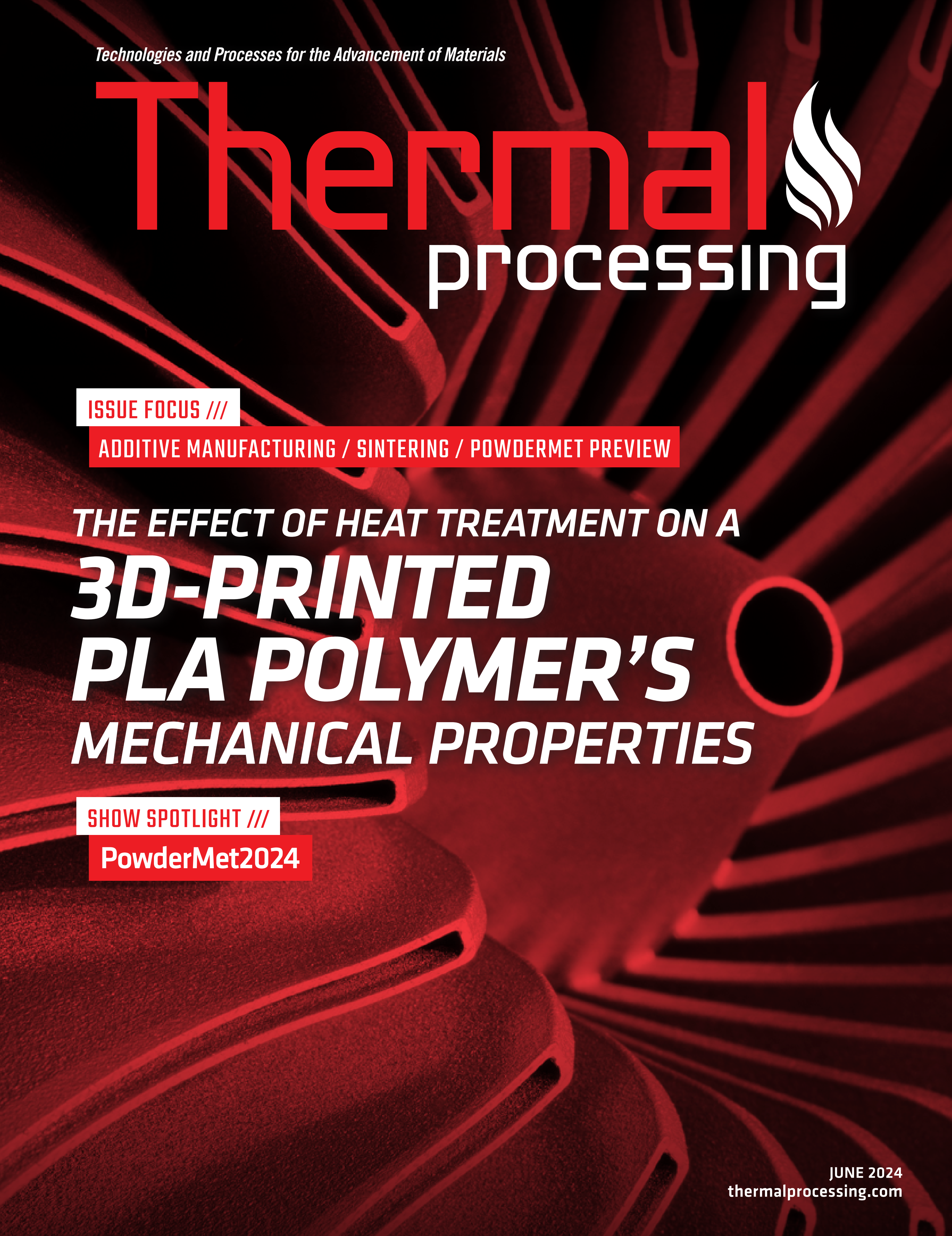

Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

ADDITIVE MANUFACTURING / SINTERING / POWDERMET PREVIEW

THE EFFECT OF HEAT TREATMENT ON A 3D-PRINTED PLA POLYMER'S MECHANICAL PROPERTIES

SHOW SPOTLIGHT ///

PowderMet2024

JUNE 2024
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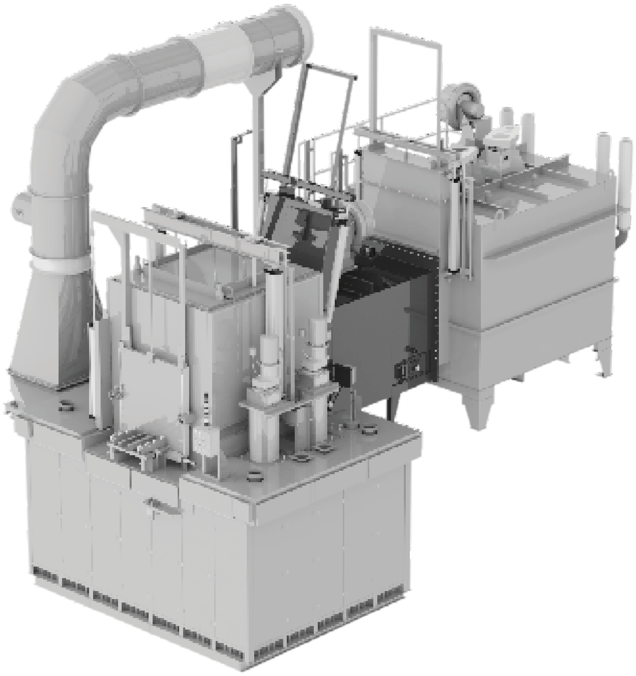

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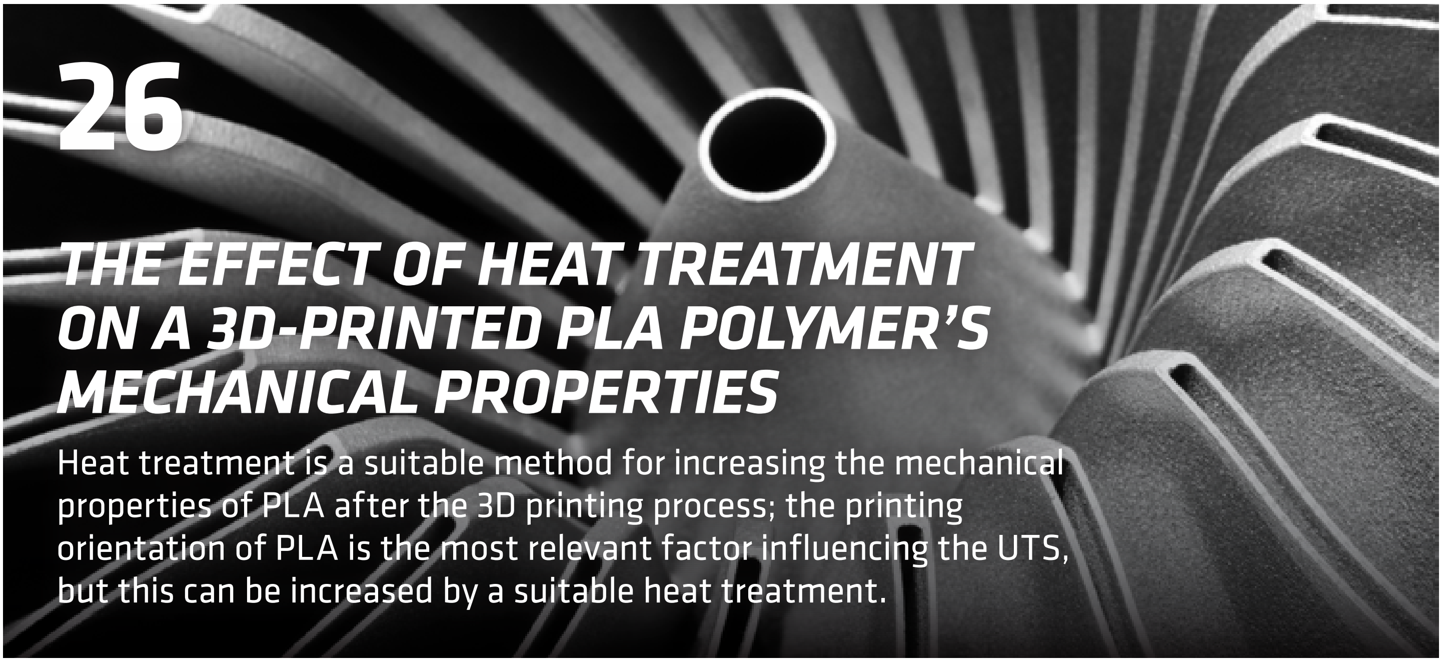

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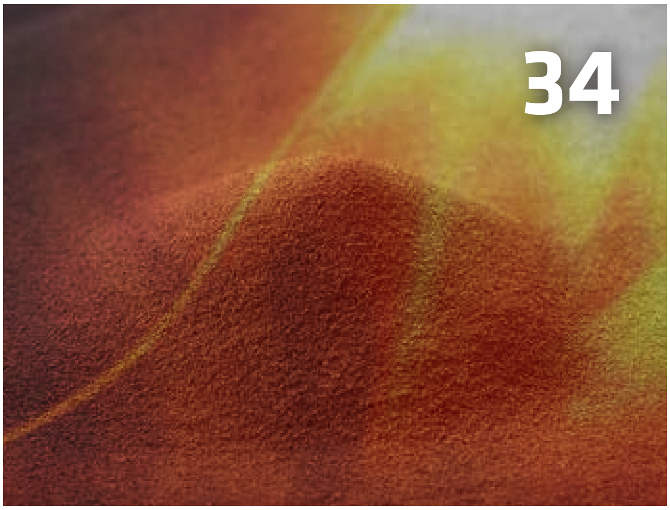
THE EFFECT OF HEAT TREATMENT ON A 3D-PRINTED PLA POLYMER'S MECHANICAL PROPERTIES

Heat treatment is a suitable method for increasing the mechanical properties of PLA after the 3D printing process; the printing orientation of PLA is the most relevant factor influencing the UTS, but this can be increased by a suitable heat treatment.

EFFECTS OF THE SINTERING PROCESS ON AL_2O_3 COMPOSITE CERAMICS

Commercial Al_2O_3 ceramics fabricated using material extrusion and photo-polymerization combined processes with good fracture toughness and flexural strength via TSS will have unique advantages in engineering applications.



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SHOW SPOTLIGHT ///

POWDERMET2024: TAKING IN THE STEEL CITY

PowderMet2024, home to the largest annual exhibit in the Americas featuring the leading suppliers of powder metallurgy, particulate materials, metal injection molding, and metal additive manufacturing processing equipment, powders, and products, will showcase a massive display of PM innovations and technology sessions.

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PowderMet2024.org or AMPM2024.org

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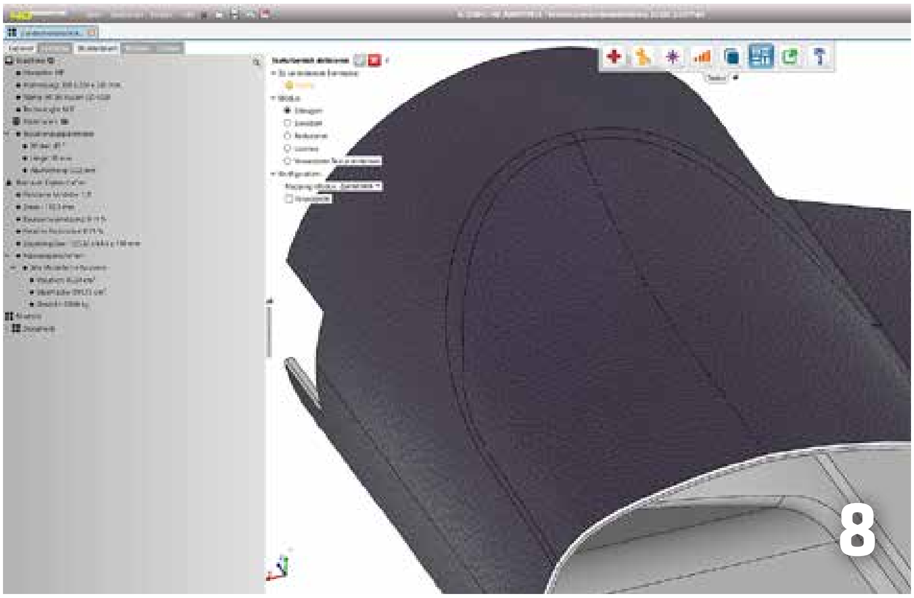
DEPARTMENTS ///

JUNE 2024 VOLUME 13 / NUMBER 6

UPDATE ///

New Products, Trends, Services & Developments



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Thermal Processing is published monthly by Media Solutions, Inc., 266D Yeager Parkway Pelham, AL 35124. Phone (205) 380-1573 Fax (205) 380-1580 International subscription rates: $105.00 per year. Postage Paid at Pelham AL and at additional mailing offices. Printed in the USA. POSTMASTER: Send address changes to *Thermal Processing* magazine, P.O. Box 1210 Pelham AL 35124. Return undeliverable Canadian addresses to P.O. Box 503 RPO West Beaver Creek Richmond Hill, ON L4B4R6.

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FROM THE EDITOR ///

PowderMet 2024 is here!

It's hard to forget about heat-treating if you have to live through a summer in the South. And although the official beginning of summer is in just a few days, in the South, summer feels like it begins around February 12.

By the time you may be reading this, many will be arriving at PowderMet 2024 — the International Conference on Powder Metallurgy & Particulate Materials — in Pittsburgh, Pennsylvania.

PowderMet 2024 is a hub for technology transfer for professionals from every part of the industry, including buyers and specifiers of metal powders, tooling and compacting presses, sintering furnaces, furnace belts, powder handling and blending equipment, quality-control and automation equipment, particle-size and powder-characterization equipment, consulting and research services, and more.

The 2024 show will boast in-person interaction for business deals, information exchange, and panel discussions on the latest innovations in the industry.

With our June issue also being a PowderMet 2024 preview, you'll find a few items inside to help with your show experience.

The sessions at PowderMet may be a bit overwhelming to sort through if you're mainly interested in heat-treatment and other related issues.

To assist with that, be sure and check out our PowderMet section that highlights the sessions that deal with heat treating. Hopefully that will help out with honing your show decisions.

And if you missed it last month, I am happy to make Executive Director/CEO of the MPIF and APMI International James P. Adams' Q&A available again for this issue. His insights about the show and what attendees can expect to see are more tools that may help aid in what you get out of this year's PowderMet.

But, if you're not lucky enough to be walking the floors of PowderMet this month, this issue also has a few entries that take on the topics of additive manufacturing and sintering.

As we take the plunge into summer, I'd like to take this moment to remind you to let Thermal Processing be your eyes, ears, and, most importantly, your voice. No matter the challenges you face, we are here, first and foremost, to shine a spotlight on your valuable products, services, and know-how.

Whether it's a powerful ad or an expert article, let us share your insights with the people who are searching for it.

Stay cool, and, as always, thanks for reading!

Kenneth Carter

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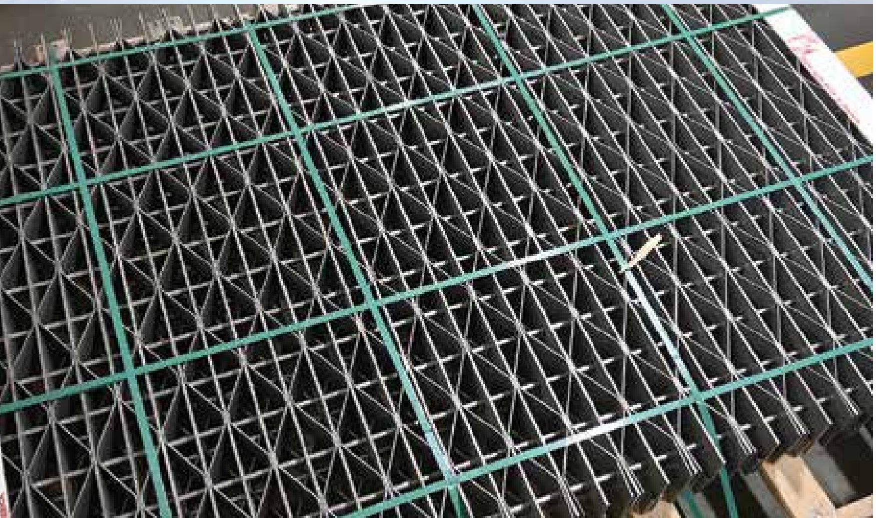

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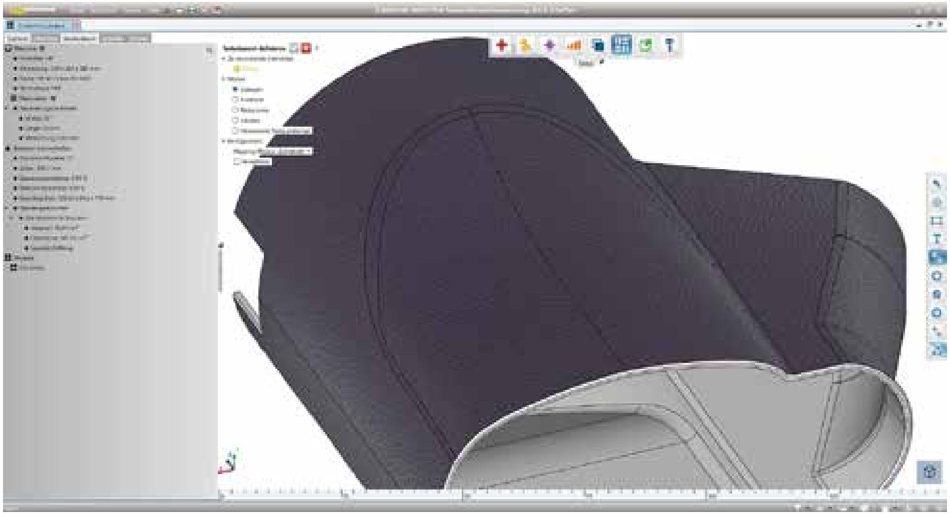


Software pioneer CoreTechnologie has equipped the 3D printing software 4D_Additive with a special texture library that is based on the VDI 3400 guideline. With 4D_Additive, VDI surface textures are generated directly on the CAD models to eliminate the stair-stepping effects in 3D printing. (Courtesy: CoreTechnologie GmbH)

CoreTechnologie optimizes surface refinement for AM

The 3D printing software 4D_Additive from the Franco-German software developer CoreTechnologie now has a texture library in accordance with the VDI 3400 guideline. With the optimized textures module, the surfaces of 3D printed components can be visually and functionally enhanced with just a few clicks.

The textures of the optimized 4D_Additive Software tool improve the appearance, give additively manufactured components an aesthetic look, and conceal irregularities that occur during production and printing, just as in injection molding. For the new type of surface finishing, special textures based on the VDI 3400 standard are now available in the textures module. The surface finishes of the VDI 3400 Surface Finish Guideline of the Association of German Engineers (VDI) are used worldwide for products for which a certain texture or grain is desired for aesthetic and functional reasons.

Designers and engineers simply select the right texture for surface design and surface finishing from the extensive texture library. The 4D_Additive software works directly with the exact CAD models. The desired surfaces and texture areas are selected with just a few clicks and the surface structures predefined in the library are generated. The stair-stepping effect, which is particularly undesirable in 3D printing, is automatically concealed.

In contrast to the time-consuming process of creating textures in toolmaking, additive manufacturing allows surface design to be created on any 3D/CAD geometry in just a few seconds using the software.

The relevance of surface finishing is increasing, particularly in the increasingly important process of additively manufactured small series parts. From a commercial perspective, products with high surface quality and aesthetics that are provided with textures and graining are more attractive to customers and convey a higher quality standard.

MORE INFO www.coretechnologie.com

Kanthal expands in Japan to meet heat solution demands

Today, industries such as lithium-ion battery, semiconductor, and automotive show a strong demand for sustainable heating solutions to help them achieve higher efficiency and reach their decarbonization targets. To meet the increased need, Kanthal will expand its production capacity in Sakura, Japan, an investment of approximately SEK 100 million. The aim is to capture mid- and long-term market growth in Asia.

The strong global growth in lithium-ion batteries and semiconductors is a driver for an increased demand for Kanthal's sustainable heating solutions. In addition, a broad range of industries, such as steel and automotive, are looking to convert their heating processes from fossil fuel to electric solutions, making their production more energy efficient while also lowering their CO_2 emissions.

The total investment is approximately SEK 100 million between 2024 and 2025 and includes the development of a new facility near the current premises in Sakura, as well as new equipment and a new layout. The expansion is expected to be fully operational in the end of 2025, increasing the current production capacity by approximately 60 percent and enabling additional job opportunities.

The investment will continue to ensure a strong local presence, improving manufacturing capacity, lead times, and serviceability.

"We see this investment as necessary to meet our customers' current and future needs," said Simon Lile, VP and president of Business Unit Heating Systems at Kanthal. "We expect a rapidly growing demand for our heating solutions, both for our traditional products but also for our high-temperature process gas heaters, as they enable industries to make the green technology shift. The investment will ensure that we

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.

At the Kanthal production site in Sakura, Japan, the company manufactures products for electrification of industrial heating processes. (Courtesy: Kanthal)

can capture the demand in Asia."

During the past year, expansions in Walldorf, Germany; Perth, Scotland; and Concord, United States; have been announced. This investment is another example of how Kanthal expands its production capacity to meet demand.

Kanthal is an Alleima company and a world-leading brand for products and services in the areas of industrial heating technology and resistance material. The company develops innovative solutions in creative partnerships with its customers, and with a strong commitment to reduce the environmental impact.

MORE INFO www.kanthal.com

NGC Gears adds two EndoFlex generators from UPC-Marathon

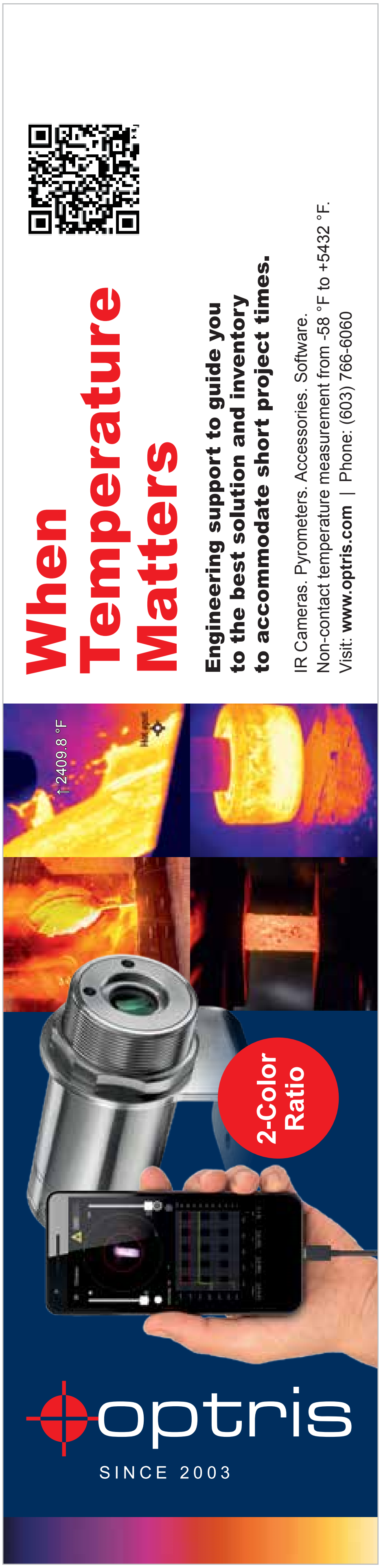
NGC Gears, one of the world's largest wind power gearbox manufacturers, has completed the installation of two additional EndoFlex generators from UPC-Marathon, a Nitrex company, at its new facility in Jinhu, China. This acquisition brings the total of generator sets to five since 2022, collectively generating an impressive 800 m /h (22,252 ft3/h) capacity of endothermic gas supplied to carburizing and hardening furnaces used for processing various gear components. The latest installations in February and March of 2024 support the heat-treating operations of the company's wind energy gearbox production.

NGC's decision to expand capacity is in response to the growing demand for wind power solutions in China and globally. Recent statistics indicate a robust growth trajectory for wind energy, with the country leading the world in both installed capacity and the manufacture of wind-power equipment. The new endothermic gas generating systems will significantly enhance the company's production capabilities, enabling NGC to meet increasing market needs with greater efficiency and reliability.

EndoFlex offers several benefits, including precise control of production media to the carburizing and hardening environments, leading to higher quality gear production with improved longevity and performance. The result is improved carburizing and hardening processes, higher-quality hardened gears, reduced operating costs, and increased efficiency. The EndoFlex mixes ratios more accurately and efficiently, ensuring a constant furnace atmosphere and consistent gas quality. This leads to immediate cost savings through reduced electricity and gas consumption and minimized waste.

"The latest EndoFlex investments align with NGC's development of low-consumption, high-efficiency gearbox products for large-scale onshore and offshore wind turbines," said Johnny Xu, general manager at UPC-Marathon China. "Our collaboration with NGC is focused on advancing excellence in the wind power sector, and we are thrilled to see the tangible benefits our EndoFlex units bring to NGC. This partnership highlights the strength of our products and reinforces our commitment to providing quality, local solutions to meet the demands of modern manufacturing for a greener future. We look forward to continuing our work with NGC and delivering the superior endogas quality needed for their high-standard production processes."

UPC-Marathon, a Nitrex company, pioneers industrial process control, automation, and digitalization for heat treatment and combustion markets. The company mission is to support furnace OEMs and equipment end-users with innovative solutions, enhancing profitability and reliability while optimizing operational efficiency. End-to-end control



EndoFlex from UPC-Marathon offers several benefits, including precise control of production media to the carburizing and hardening environments, leading to higher quality gear production with improved longevity and performance. (Courtesy: Nitrex)

solutions encompass probes, analyzers, controllers, flow control systems, upgrades/retrofits, SCADA, and engineered solutions for various heat-treat processes. Leveraging the digitalization platform QMULUS, customers gain a deeper understanding of their assets and production processes.

MORE INFO www.nitrex.com

Siemens software IDs vulnerable production assets

Production facilities are increasingly the targets of cyberattacks. Industrial companies are therefore required to identify and close potential vulnerabilities in their systems. To address the need to identify cybersecurity vulnerabilities on the shop floor as quickly as possible, Siemens has launched a new cybersecurity software-as-a-service.

The cloud-based SINEC Security Guard offers automated vulnerability mapping and security management optimized for industrial operators in OT environments. The software can automatically assign known cybersecurity vulnerabilities to the production assets of industrial companies. This allows industrial operators and automation experts who don't have dedicated cybersecurity expertise to identify cybersecurity risks among their OT assets on the shop floor and receive a risk-based threat analysis. The software then recommends and prioritizes mitigation measures. Defined mitigation measures can also be planned and tracked by the tool's integrated task management. SINEC Security Guard is offered as cybersecurity software-as-a-service ("SaaS"), is hosted by Siemens, and will be available for purchase in July, 2024 on the Siemens Xcelerator Marketplace and on the Siemens Digital Exchange.

"With SINEC Security Guard, customers can focus their resources on the most urgent and relevant vulnerabilities, while having full risk transparency in their factory," said Dirk Didascalou, CTO of Siemens Digital Industries. "It is unique because it takes the specific situation of the customer's operational environment into consideration while providing a single pane of glass for security-relevant information in the OT area. When developing the SINEC Security Guard, we drew on our extensive experience with cybersecurity in our own factories."

Today, industrial operators are tasked with continuously safeguarding their production assets on the shop floor. They need to analyze vendor security advisories, manually match them to the asset inventory of their factory and prioritize mitigation measures. Because this process is time-consuming and error-prone using the existing tools, factories are running the risk of missing critical vulnerabilities in their assets or producing false-positives. This can lead to incorrectly configured plant components and inadequately allocated resources. With the SINEC Security Guard, industrial operators can tackle these challenges without needing in-depth cybersecurity knowledge.

For a comprehensive view of IT and OT cybersecurity, SINEC Security Guard will also offer a connection to Microsoft Sentinel, Microsoft's Security Information and Event Management (SIEM) solution for proactive threat detection, investigation, and response. Once connected, SINEC Security Guard can send alerts for security events including attacks to Sentinel, enabling a security ana-

SINEC Security Guard is a cloud-based cybersecurity software that provides full risk transparency and cybersecurity management of OT assets. (Courtesy: Siemens) lyst to incorporate SINEC Security Guard insights and conclusions in investigations and responses with Microsoft Sentinel powered Security Operations Centers.

"As information technology and operational technology systems continue to converge, a holistic cybersecurity architecture is key to protecting IT and OT capabilities alike," said Ulrich Homann, corporate vice president, Cloud + AI at Microsoft. "By combining our domain knowledge, Siemens and Microsoft make it easier for industrial operators to efficiently detect and address cybersecurity threats at scale."

SINEC Security Guard also supports the manual upload of existing asset information for asset inventory. Siemens recommends, however, that industrial operators use the Industrial Asset Hub, the Siemens cloud-based Asset Management solution, to enable continuous automated asset inventory management.

Functionalities also include signature-based network intrusion and attack detection via the SINEC Security Guard Sensor, an Industrial Edge app, which gives users live information about their industrial network. The SINEC Security Guard Sensor App is available at the Siemens Industrial Edge Marketplace.

The initial release of SINEC Security Guard only supports Siemens OT assets but third-party device support is planned in the future. SINEC Security Guard will expand the existing Siemens software portfolio for OT network security consisting of SINEC Security Inspector and SINEC Security Monitor.

MORE INFO www.usa.siemens.com/sinec-security-guard

Nitrion do Brasil gets nitriding solutions from Seco/Warwick

Commercial heat treater Nitrion do Brasil — the largest nitriding service provider in the region — has purchased another Seco/Warwick Vector vacuum furnace.

The solution will operate in a new production hall and will handle their increasing order volume. Nitrion do Brasil is another commercial heat treater from South America that has chosen Seco/Warwick's solutions. This latest project is the result of the synergy with the Group's strategic partner in the region — Combustol.

In Brazil, commercial heat treaters are particularly fond of Vector single-chamber vacuum furnaces. This line of furnaces was used by Supertrat, who wanted to improve and increase their hardening process power and boost the process economics. Dynamic sales growth and good forecasts on this market are the result of close cooperation between Seco/Warwick and strategic partner – Combustol.

"Combustol supports Seco/Warwick not only in sales, but also in service activities

Another Seco/Warwick Vector vacuum furnace has been purchased by commercial heat treater Nitrion do Brasil, the largest nitriding service provider in the region. (Courtesy: Seco/Warwick)

and the supply of spare parts," said Maciej Korecki, vice-president of the Vacuum Furnaces Segment in the Seco/Warwick Group. "Such a partner in such a remote location is a huge advantage, helping us to beat the competition. In the case of cooperation with Nitrion de Brasil, another factor determined the success. The customer bought a furnace that we could deliver quickly."

The Vector vacuum furnace on order will solve Nitrion do Brasil's problem of hardening larger elements, because the furnace is equipped with a large working space. This will affect the process economics (energy savings and the graphite chamber's increased efficiency) as well as the process cleanliness and speed. The furnace is equipped with convection heating — a system which improves the heat transfer efficiency when heating at lower temperatures, as well as directional cooling, which allows the system to efficiently cool parts with problematic shapes in various ways.

"We were looking for a solution which would help not only increase our metal processing capabilities, but also efficiency and effectiveness," said Peter Lutz, president of Nitrion do Brasil. "Vector is the first-choice furnace and will operate in a completely new production hall. We know that it works in many commercial heat-treating plants in Brazil, and works perfectly everywhere in the country. The fact that Seco/Warwick cooperates with a Brazilian company operating locally is important."

Commercial heat treaters are one of the Seco/Warwick Group's main partners. Every day, commercial heat treaters deal with many types of materials, a wide range of processes and technologies. What all customers in this industry have in common is the key parameter — operational efficiency, i.e. short production cycles and low production costs.

"We know the South American market; we have supplied vacuum furnaces to the largest commercial heat-treating plants on this continent," said Łukasz Chwiałkowski, sales manager, Seco/Warwick. "Again, we executed the fastest vacuum furnace delivery on the Brazilian market."

MORE INFO www.secowarwick.com

Delta H/Phillips Federal partner on oven at Edwards AFB

Delta H$^{®}$/Phillips Federal recently commissioned a composite oven at Edwards Air Force Base, California, for advanced materials applications R&D. The specially designed walk-in oven has a load volume of 8ft x 8ft x 15ft and is operable to 450°F. Additional features include electric heat, oversize recirculation air blower for assuring Class 1 uniformity of +/- 5°F, oversized exhaust blower for rapid cooling, and a vacuum supply and monitoring system.

Delta H initially designed and engineered the walk-in oven using SolidWorks 3D modeling and developed the project as a "kit oven" for easy field assembly. After preassembly of key subsystems at Delta H's Carroll, Ohio, facility, the system was shipped to Edwards AFB. The entire field assembly project required two weeks including commissioning and extensive training of USAF personnel. After several months of operation, operators report flawless performance.

The primary controller is a Eurotherm Nanodac programmer/recorder which provides part temperature (cascade) control and a data acquisition system for up to 12 part thermocouples. The Nanodac automatically selects a representative part temperature

The Edwards AFB – Delta H® composite oven for materials research and development is the third Delta H system at the base.

and adjusts air temperature to create sufficient thermal head for precisely increasing the part temperatures at the desired rate (typically 1°F to 3°F per minute to a soak temperature). Following the soak time, the oven systematically engages the exhaust blower and fresh air vents for rapid cooling – so that operators can quickly unload and prepare the next batch of parts.

"The USAF and all of our military branches must be ready at a moment's notice," said Phillips Federal product manager, USAF Retired, SMSgt, John (JD) Murray. "Maintaining that level of readiness is only achieved by employing high quality and extremely reliable equipment. Phillips Federal is proud to partner with Delta H, in fielding reliable, extremely accurate furnaces to meet the most stringent industry and military standards. It is our honor to serve the fighting men and women of the US Armed Forces and provide them with best equipment possible to ensure we meet our enemies full force and face to face."

"This is our third system at Edwards AFB and always a thrill to serve the USAF at this historic facility," said Delta H director/CTO Richard Conway. "From our humble beginnings through our evolution of providing cutting edge military aviation thermal processing solutions to our warfighters, it is something our Delta H team is very proud of. We are especially thankful for our tremendous relationship with Phillips Federal for making this and many other projects possible."

MORE INFO www.delta-h.com

Solar Atmospheres acquires Certified Metal Craft

Solar Atmospheres has announced its most recent acquisition, Certified Metal Craft (CMC) located in El Cajon, California, near San Diego.

With nearly 55 years of serving the Southern California region, CMC and the Wiederkehr Family have established themselves as a trusted and dependable source for heat treating and brazing services. With the addition of CMC to the Solar family of Companies, CMC establishes Solar's sixth location and bolsters Solar's West Coast presence.

CMC has extensive capabilities to include vacuum, aluminum, atmospheric, endothermic, salt bath and cryogenic processing and employs 25 dedicated and loyal employees. Servicing the aerospace, medical, and commercial markets, CMC is Nadcap accredited and holds a long list of customer and prime approvals. Tim Wiederkehr will assume the role of V.P. of Operations and report to Derek Dennis, President of Solar Atmospheres of California, Inc.

"Solar is excited to welcome the dedicated CMC team into the growing nation of Solar companies. We look forward to learning, growing, and working together to modernize the facility with Solar built state-of-the-art

equipment, support systems, and a customer support structure that seamlessly works to meet or exceed our valuable customers' requirements," said Dennis.

"Together, we will continue to grow our west coast footprint while solidifying our industry leading approach of being the 'go-to' choice for all heat treating & brazing needs with an unwavering commitment to honesty and integrity in all relationships," Dennis said.

MORE INFO www.solaratm.com

Quenching and distortion conference issues call for papers

The Third International Conference on Quenching and Distortion Engineering (QDE2025) will be in Vancouver, Canada, May 5-8, 2025. The event brings together practitioners, engineers, and researchers from academia, government, and industry to explore the forefront of distortion control and quenching techniques.

QDE 2025 offers a platform to share cutting-edge research, innovative solutions, and real-world case studies in quenching and distortion control across industries such as automotive, aerospace, manufacturing, and electronics.

Conference highlights include:

» **Cutting-edge research:** Engage in dynamic sessions featuring presentations by global experts, unveiling the latest innovations and case studies in quenching and distortion control.

» **Real-world impact:** Discover practical applications and impactful case studies showcasing advancements in quenching and distortion control across industries.

» **Explore the exhibit hall:** Visit the co-located exhibition showcasing state-of-the-art equipment, technologies, and products in the quenching and distortion control domain.

» **Connect and collaborate:** Network with professionals, forge partnerships, and exchange ideas, fostering future advancements in the field during this ideal platform for collaboration.

The call for papers is now open. The submission deadline is September 5, 2024. Paper topics include:

» Fundamental principles of quenching and distortion.

» Control and elimination of distortion (quench media control, in-process measurement tools, quality management, interactions of different production processes).

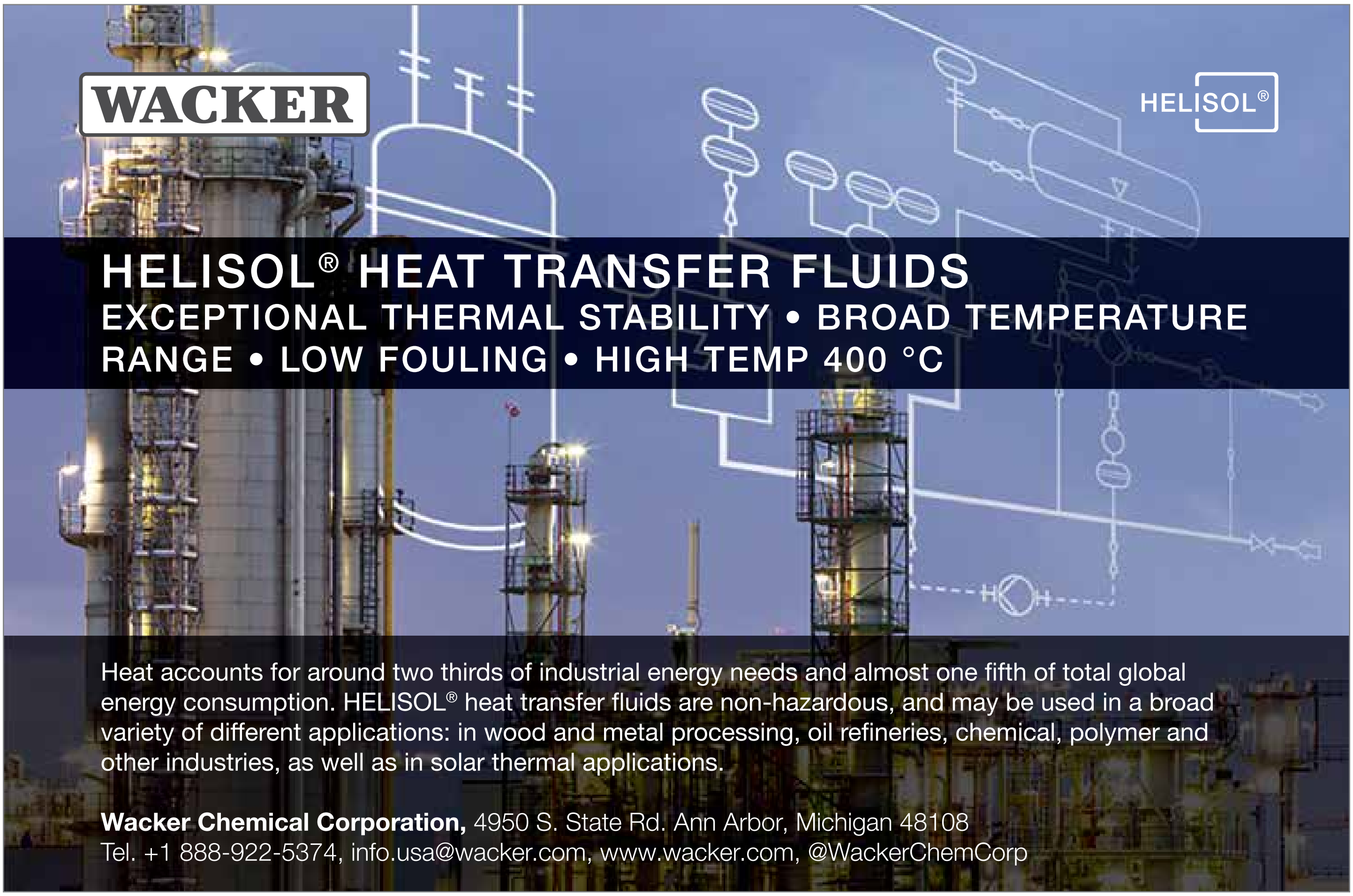
» Agitation measurement and control (including quench media characterization, monitoring, servicing, and facilities).

» Material and shape optimization for distortion control.

» Equipment design and fixturing.

» Case studies on distortion problems.

» Boundary conditions and heat transfer as applied to distortion control (NOTE: these



are combined).

- Modeling of processes and phenomena (including phase field, MD, and other modeling approaches).
- Computational fluid dynamics (including modeling of quench media and heat transfer for both development and in-process applications).
- Finite element analysis and constitutive equations (for distortion during quenching, casting, hot and cold forming, soft and hard machining, and heat treatment).
- Measurement of residual stresses.
- Prediction and control of residual stresses in additive manufactured parts.

MORE INFO www.asminternational.org/qde2025

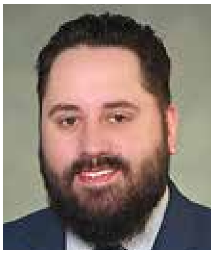
Ipsen expands customer service for aftermarket needs

Ipsen bolstered its aftermarket team with the addition of two new regional sales engineers. Tyler Free will support customers in the Midwest, while Charlie Preston will serve the Southeast region.

They join a seasoned team, including Steve Mondorf (West), Tom Sutherland (South), and Chad Mehmel (Northeast). Ipsen's aftermarket team, along with the regional sales owners, collectively ensure that customers receive the highest level of support for their new equipment, parts, service, and retrofit needs.

Free joins the Ipsen team from Rockford Ball Screw, where he worked as a business development manager. He also has extensive experience in sales, service, and support of industrial machinery from his time at Bourn & Koch, a machine builder in Rockford, Illinois.

Preston holds a Bachelor of Science degree in mechanical engineering from the University of Alabama. Over the course of his career, he has held positions as an Applications Engineer, Mechanical Designer, and Project Engineer.



Tyler Free

Charlie Preston

Moving from his role as the Southeast regional sales engineer, Asher Thoeming steps into a new position as regional service manager for Ipsen's international customers. Thoeming has provided exceptional service to Ipsen's loyal customers in the Southeast and is committed to maintaining the same high level of service to customers across the globe.

The regional sales engineers report to Matt Clinite, who was promoted to director of ICS sales last year. In this capacity, he spearheads strategic initiatives and provides guidance to both inside and outside aftermarket sales teams, aiming to secure the long-term success of Ipsen's customers.

"Ipsen has the largest and most technical aftermarket support team in the industry," said Clinite. "We continue to hire uniquely qualified employees for our customer-facing roles, most of whom have technical degrees. Ipsen is fostering the next generation if industry leaders, and we are extremely excited about the teams we have in place."

Over the last two years, Ipsen has made significant changes to its aftermarket services under the leadership of chief service officer John Dykstra. This included the addition of Christina Connelly, customer service parts manager in 2022, and David Choate, director of field service in 2023. Both have grown their teams, improved operational efficiencies, and led initiatives to enhance customer support.

MORE INFO www.ipsenglobal.com

Seco/Warwick to expand with office in Monterrey, Mexico

The American branch of Seco/Warwick has decided to expand its presence on the conti-

Monterrey, Mexico, is convenient to major road, rail, and air transportation hubs, and major Gulf Coast ports and U.S. points of entry are nearby, making it a perfect base for Seco/Warwick to connect with regional heat treaters. (Courtesy: Seco/Warwick)

nent by opening a sales and service office in Monterrey, Mexico.

Mexico is an important market for Seco/Warwick USA. The new Seco/Warwick, Mexico, division will occupy about 2,000 square feet of office space in a high-rise business park, including garage parking and controlled-access reception.

As Mexico's second-largest city, Monterrey is convenient to major road, rail, and air transportation hubs. Major Gulf Coast ports and U.S. points of entry are not far, either. As one of Mexico's steel production epicenters, the region is also a major manufacturing center. All of this positions the city as a perfect base to connect with regional heat treaters or serve the rest of Mexico, along with Central and South America.

"Once the office has established a foothold as a self-sustaining base of operations for sales and field service, the next step will be to build on existing relationships we have with local contract manufacturers and mechanical contractors to fabricate furnaces and supplement field service staffing through outsourcing, respectively," said Marcus Lord, managing director for Seco/Warwick USA.

Leading the expansion is longtime SWC engineer Luis Barragan, who will continue to manage the establishment of the business until it is on solid footing. At this point, he will pivot to managing sales while Lord will resume operations management. The Mexico office will also have its aftermarket segment, taking on aftermarket support for customers throughout Latin America.

"We've always had furnaces and heat treat partners to support, from Mexico down to Chile," said Sławomir Woźniak, Seco/Warwick Group's CEO. That demand has grown to the point that it is time to open a base of operations dedicated to that market."

MORE INFO www.secowarwick.com

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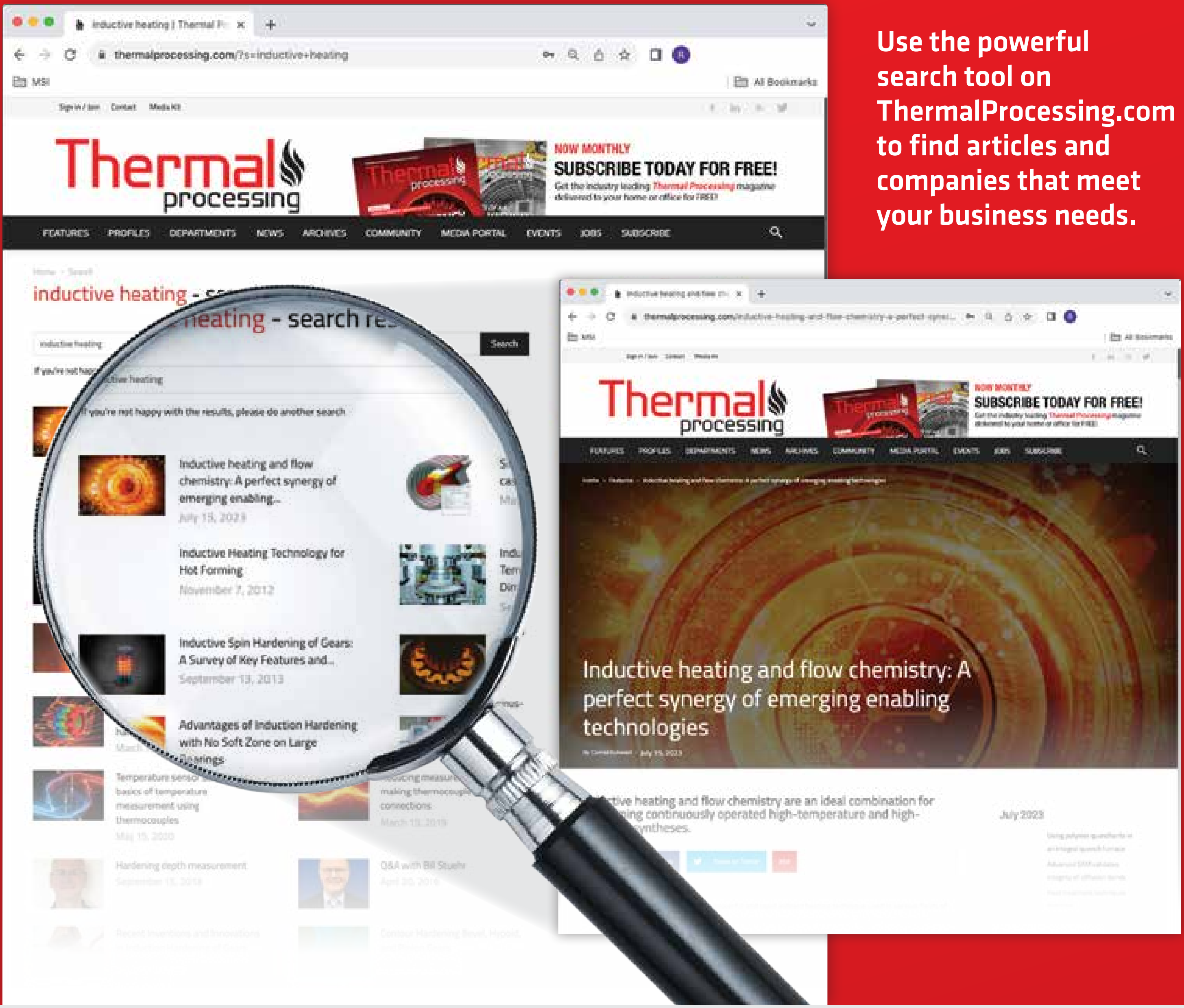

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More World Congress details available

The 29th IFHTSE World Congress, a premier global event dedicated to advancing the fields of heat treatment and surface engineering, will be held Sept. 30 to Oct. 3 in Cleveland, Ohio. (Courtesy: Shutterstock)

The ASM Heat Treating Society (HTS) and the International Federation for Heat Treatment and Surface Engineering (IFHTSE) proudly present the highly anticipated 29th IFHTSE World Congress, a premier global event dedicated to advancing the fields of heat treatment and surface engineering. Co-located with ASM's annual meeting, IMAT 2024, the congress is October 1-3, 2024, in Cleveland, Ohio.

The 2024 IFHTSE World Congress' theme is "Innovations in Heat Treatment and Surface Engineering for a Sustainable Future." Emphasizing the critical role of these technologies in shaping a sustainable world, the event will explore the latest developments, breakthroughs, and practices that can enhance the efficiency, performance, and environmental impact of heat treatment and surface engineering processes. In addition, traditional heat-treating topics will be offered.

FUTURE OF HEAT-TREATING WORKSHOP

As part of the event, a special workshop on the Future of Heat Treating will be Monday, September 30, 2024, 3-5 p.m. This two-hour session will delve into three critical areas of heat treating and surface engineering: Data/IoT, sustainability, and education. Led by subject matter experts and facilitators from IFHTSE, participants will engage in round-table discussions, shaping a strategic plan for the global heat-treat community's needs over the next three to five years. With an interactive format and opportunities for networking, this workshop promises insightful exchanges and actionable outcomes. Reserve your spot now and be part of shaping the future of heat treating. There is no additional fee to participate, however, pre-registration is required.

OTHER CONGRESS HIGHLIGHTS

»**Cutting-edge research presentations:** In addition to the Future of Heat-Treating Workshop, the congress will host a diverse array of presentations and technical sessions led by renowned experts and researchers from around the globe. Attendees will have the opportunity to delve into the latest discoveries, innovations, and case studies in the field.

»**Industry application and case studies:** Practical applications and real-world case studies will be showcased, highlighting the impact of heat treatment and surface engineering in various industries, including automotive, aerospace, manufacturing, electronics, and more.

»**Exhibit Hall (co-located with IMAT 2024):** An expansive exhibition area will feature leading companies, organizations, and manufacturers displaying state-of-the-art equipment, technologies, and products related to heat treatment and surface engineering.

»**Networking opportunities:** The congress provides an ideal platform for networking and collaboration, enabling attendees to interact with professionals, establish partnerships, and exchange ideas, fostering future advancements in the field.

» **Keynote speakers:** Prominent thought leaders from the industry will deliver keynote addresses, sharing their expertise, visions, and predictions for the future of heat treatment and surface engineering.

» **Social events:** The congress will also offer various social and cultural activities, allowing participants to unwind, experience the local culture, and build camaraderie with their peers.

The IFHTSE World Congress 2024 is a must-attend event for anyone passionate about driving progress and sustainability through heat treatment and surface engineering. Join us for this unforgettable experience, where knowledge, innovation, and collaboration converge to shape a better future for our industries and the world.

IMPORTANT DATES

» **Editor Feedback to Authors:** June 14, 2024.

» **Final Manuscripts Due:** June 28, 2024.

» **More info:** www.asminternational.org/ifhtse-congress/

MORE CONFERENCES, MORE INFO

Motion in Heat Treatment – Heat Treatment in Motion
June 4-6, 2025 | Prague, Czech Republic

This conference is the fifth in its series and is sponsored by AZTK (Asociace Pro Tepelné Zpracování Kovů). It will be at the Kaiserstein Palace. This event follows the 3rd conference in Prague in 2016 and the 4th conference in Spartanburg, South Carolina. While the previous focus of the event was primarily on automotive applications, the focus of this conference has been widened to all transport applications including automotive, rail, and aircraft, and marine applications of heat-treated and surface-engineered components. The event is combined with the European Conference on Heat Treatment.

» **More info:** www.ifhtse.org/events/termine/5th-International-Conference-on-Heat-Treatment-and-Surface-Engineering-in-Automotive-and-Transportation-Applications.php

30th IFHTSE World Congress
August 18-21, 2025 | Suzhou, China

This event, sponsored by the Chinese Heat Treatment Society (CHTS), follows the 25th World Congress held in Xi'an in 2018. More details are forthcoming as available.

IFHTSE 2024 EVENTS

JUNE 5-7, 2024
ECHT 2024 Conference and the 50th Annual A3TS Congress
Toulouse, France

SEPTEMBER 30-OCTOBER 3, 2024
29th IFHTSE Congress
Cleveland, Ohio | with IMAT and ASM's annual meeting

MAY 6–8, 2025
3rd QDE - International Conference on Quenching and Distortion Engineering
Vancouver, Canada

JUNE 4–6, 2025
Motion in Heat Treatment – Heat Treatment in Motion
Prague, Czech Republic

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

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Registration open for IHEA's Industrial Heating Decarbonization SUMMIT

IHEA's two-day SUMMIT will tackle the decarbonization challenges in the industrial heating industry. (Courtesy: Shutterstock)

Registration is open for the Industrial Heating Equipment Association's (IHEA) Industrial Heating Decarbonization SUMMIT October 28-30 at the Conrad Indianapolis. Attendance for this distinctive event is limited so early registration is highly recommended.

The two-day SUMMIT will tackle the decarbonization challenges in the industrial heating industry.

"IHEA's Industrial Heating Decarbonization SUMMIT is the most comprehensive collection of information regarding sustainability and decarbonization within the industry," said Chad Spore, John Deere's Enterprise Materials Engineering Supervisor, Metals – Region 4. "You will walk away with confidence on how to take on this challenge within your business."

The SUMMIT is designed to assist everyone using heat technologies to understand and overcome important concerns and provide potential solutions as manufacturers plan for a sustainable future. The program contains topics that will inform and guide attendees in their journey to decarbonization, while a host of tabletop exhibitors will offer products and services that assist the industry in finding pathways to offset carbon emissions and a variety of alternative solutions.

The following SUMMIT program outline includes sessions titles only. For complete details and speaker information on each session, go to: summit.ihea.org/program.html.

The Energy-Carbon Connection

- Energy Consumption and the Resulting Carbon Emissions
- The Scopes of Greenhouse Gas Emissions

Efficiency in Combustion Processes

- Reducing Fuel Consumption
- Selecting the Best Ancillary Equipment
- The Impact of Automation and Controls

Resources & Programs
»DOE Programs and Tools
»ISO 50001 & 50001 Ready Program
Benchmarking - A Global Perspective
»The State of Decarbonization in Europe
»The State of Decarbonization in Japan
Pathways to Decarbonization
»Combustion Processes & Electrical Processes
»Carbon Capture & Sequestration (CCS)
Alternatives to Fossil Fuel Combustion
»Low Carbon Fuels & Hydrogen
»An Overview of Direct Vs. Indirect Electrification
Reaching Net-Zero
»Reducing, Converting, and Trading to Get to ZERO Carbon
Industry Adoption
»Economic & Business Concerns
»Grants and Funding Sources
»Codes and Legislation
»The Risk of Doing Nothing
Collaboration for Decarbonization Panel

The 2024-25 IHEA Board of Directors: Back row, left to right; John Stanley, Bob Fincken, Gary Berwick, Brian Kelly, Scott Bishop, Doug Glenn, and Jeff Rafter. Front row, left to right; Jeff Valuck, Ben Gasbarre, Helen Tuttle, IHEA Executive Vice President Anne Goyer, Jason Safarz, and John Podach. Not pictured: Michael Stowe.

Tabletop exhibition

The event includes a two-day tabletop exhibition where attendees can visit with suppliers to learn more about the products and services that will help them navigate the decarbonization efforts. The unique IHEA approach to sustainable solutions is a comprehensive mix of currently available technologies as well as developing technologies that will allow companies to reduce carbon footprints now while planning for a net-zero future. Tabletops and sponsorships are available on the event website, summit.ihea.org/exhibit.html.

2024-25 BOARD OF DIRECTORS AND OFFICERS ANNOUNCED

IHEA recently announced its 2024-25 board of directors and executive officers. Taking over as president is Jeff Rafter of Selas Heat Technology Co. LLC; vice-president is Gary Berwick of Dry Coolers, Inc., and treasurer is Jason Safarz of Karl Dungs, Inc. Brian Kelly of Honeywell Thermal Solutions assumes the past president position.

Jeff Rafter has been an active member of IHEA since 2020, participating on the Marketing Communication & Membership Committee, as well as speaking on multiple topics at IHEA's Combustion and Safety Standards and Codes seminars. Most recently, Rafter became chair of the Sustainability Committee as IHEA forges a sustainable path for the industrial heating industry.

"I am committed to continuing IHEA's evolution into sustainability education and events to keep the organization at the forefront of energy transition," Rafter said. "Through a leadership position on these challenging topics, we aim to increase value to the industry and grow membership."

Finalizing the lineup of IHEA's board of directors for 2024-2025, the following members continue their tenure: Scott Bishop, Electric Power Research Institute (EPRI); Bob Fincken, Super Systems, Inc.; Ben Gasbarre, Gasbarre Thermal Processing Systems; Doug Glenn, Heat Treat Today; John Podach, Fostoria Infrared; John Stanley, Karl Dungs, Inc.; Michael Stowe, Advanced Energy; Helen Tuttle, WS Thermal Process Technology Inc.; and Jeff Valuck, Surface Combustion, Inc.

In addition, IHEA is equally pleased to note the dedication and service of all members who serve on IHEA committees and divisions. Special appreciation goes to our current committee chairpersons: Sustainability Committee led by Jeff Rafter, Selas Heat Technology Co. LLC; Safety Standards and Codes Committee led by Jason Safarz, Karl Dungs, Inc.; Education Committee led by Brian Kelly, Honeywell Thermal Solutions; Marketing Communication & Membership Committee led by Doug Glen, Heat Treat Today. The Infrared Division is chaired by Marty Sawyer, Trimac Industrial Systems; and the Induction Division is chaired by Michael Stowe, Advanced Energy.

»**Learn from the best. Join IHEA.** Go to www.ihea.org for more information and membership application.

IHEA 2024 CALENDAR OF EVENTS

JUNE 20
Sustainability & Decarbonization Webinar Series – Understanding Carbon Credits & Net Zero

JULY 18
Sustainability & Decarbonization Webinar Series – Industry Adoption: U.S. Codes & Standards

AUGUST 15
Sustainability & Decarbonization Webinar Series – Renewable Fuels

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

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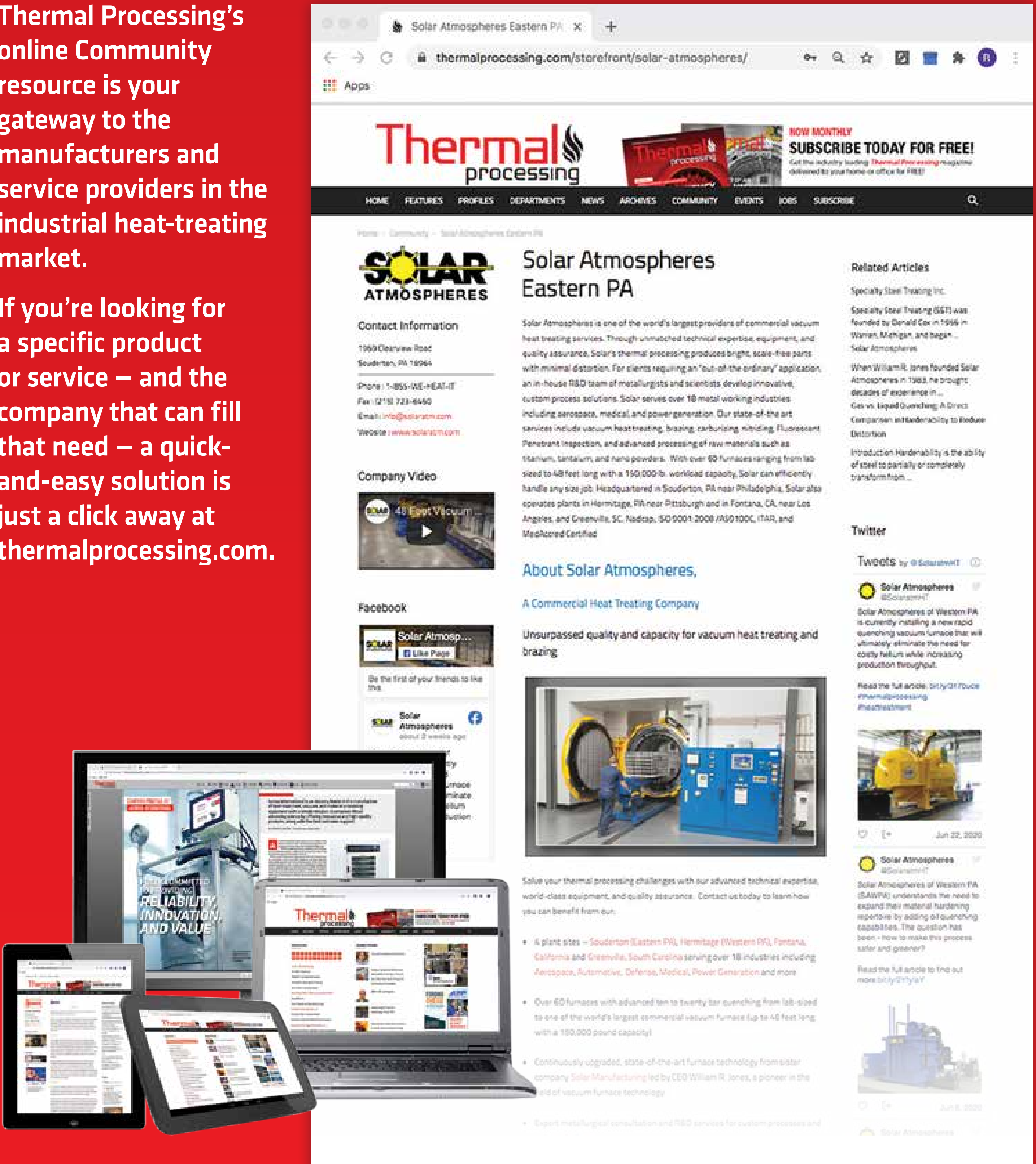

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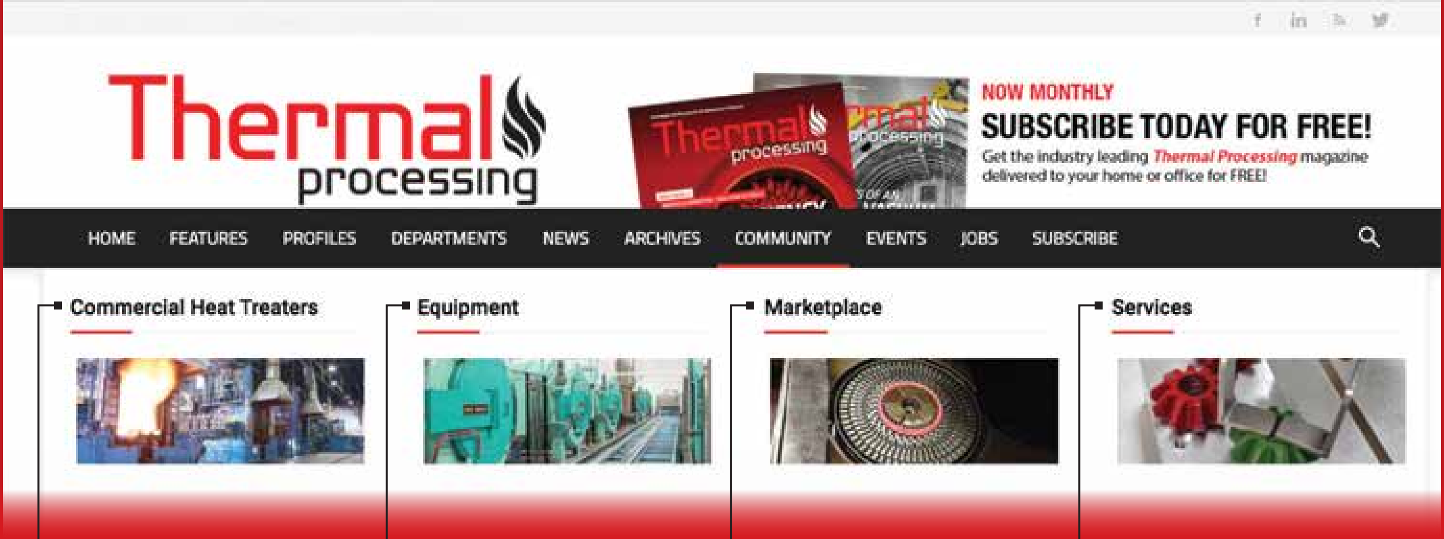
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D. SCOTT MACKENZIE, PH.D., FASM
SENIOR RESEARCH SCIENTIST–METALLURGY /// QUAKER HOUGHTON INC.

A method to calculate the amount and size of agitators needed for a quench tank is discussed, with options to adjust the flows through proper motor controls, such as a frequency drive.

Determining the agitation needed in a quench tank

In this column, I will review the basic requirements of agitation, and illustrate a method of determining the right amount of agitation.

Recently, a customer wanted to create a new quench tank for polymer quenchants. This tank was to quench long carburized shafting that had previously been quenched in oil. The customer's goal was to reduce costs and reduce the smoke and fire hazard.

The quench tank was simple. It was a cylinder 3m (118 inches) in diameter, and 6m (236 inches) deep. There was a slight radius at the bottom of 500 mm (20 inches) to help direct flow. Agitation was provided by a single 3.75 KW (5 HP) 300 mm (12 inches) marine-type agitator in the middle of a 325 mm (13 inches) draft tube that was 3.5 meters (137.75 inches) long (Figure 1). The desired flow rate is upwards through the load, preferably at greater than 0.5 m/s (98.4 ft/min).

A simple model of the quench tank was created to examine the flow. Since the impeller has a twisting flow, it was not appropriate to look at the flow as in symmetry. While this increased computational time, the results would be improved.

The resulting flow through the work zone was poor. While the flow was predominantly directed upward through the work zone, the upward velocity in the quench tank was very low, at 0.015 m/s (2.95 ft/min). This flow rate is entirely inadequate for quenching and is essentially a "dead" tank. Figure 2 shows the resultant flow pattern in the tank.

Additional agitation is needed to meet the desired flow rate of greater than 0.5 m/s.

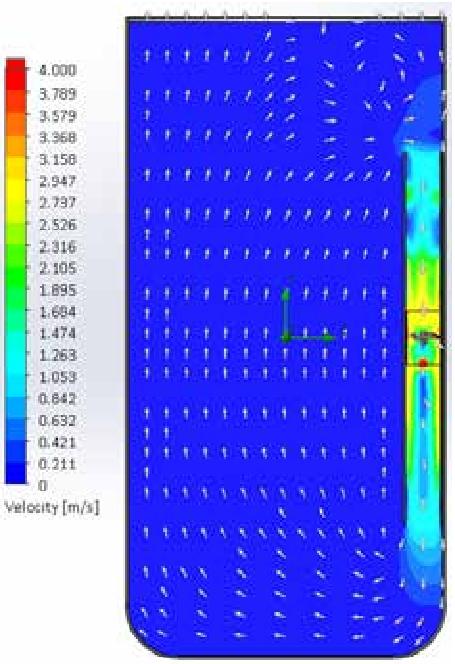


Figure 1: Illustration of proposed customer quench tank (left).

Figure 2: Resultant flow in tank. Flow is very poor, with an upward velocity of 0.015 m/s (above).

Tank Volume (Gallons)	Typical Marine-type Propeller (480 RPM)		Modern Airfoil-type Impeller (280 RPM)	
	Oil (HP/gal)	Water or Brine (HP/gal)	Oil (HP/gal)	Water or Brine (HP/gal)
50-800	**0.005**	**0.004**	**0.003**	**0.002**
800-2,000	**0.006**	**0.004**	**0.003**	**0.002**
2,000-3,000	**0.006**	**0.005**	**0.003**	**0.002**
> 3,000	**0.007**	**0.005**	**0.004**	**0.003**

Table 1: Power requirements for impeller agitation [3] [2].

SIZING AGITATION

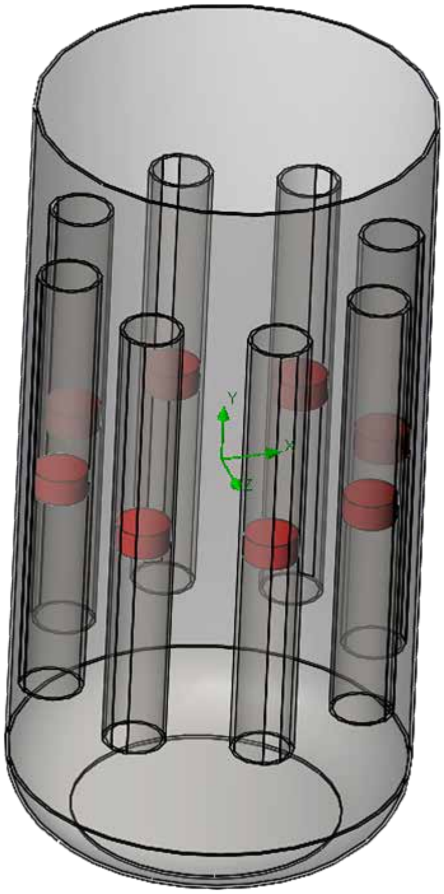
The first requirement is to determine the amount of quenchant that must be moved. The volume of a cylinder is:

$$V = \pi R^2 L$$

Where R is the radius of the tank (R = 1.5m) and L is the length (L = 6m). We will ignore the radius at the bottom of the tank for simplicity. From the above, the volume of the tank is 42.41 m^3 (42,410 liters) or 11,200 gallons.

Much of the early work on impellers for quenching applications is based on the classic work by U.S. Steel [1]. This work was based on marine-type impellers. However, many improvements have been made to improve the flow and energy efficiency of impeller or propeller type agitators.

In this work, the power requirements for marine-type impellers



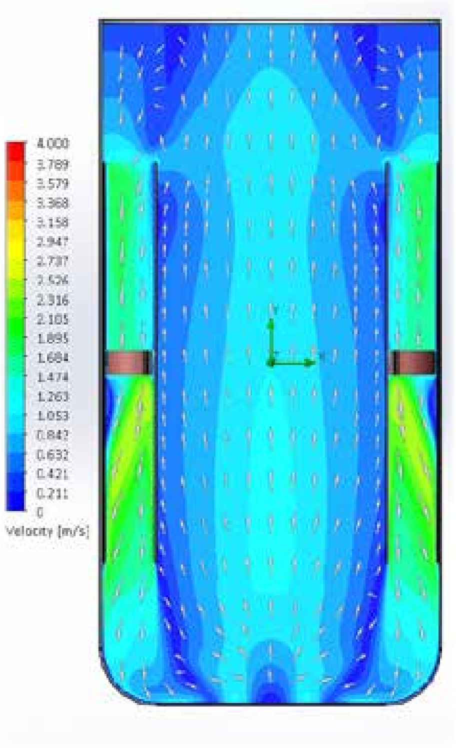


Figure 4: Model of the modified quench tank. Red disks simulate the presence of impellers (left).

Figure 5: Results of CFD of the modified quench tank (above).

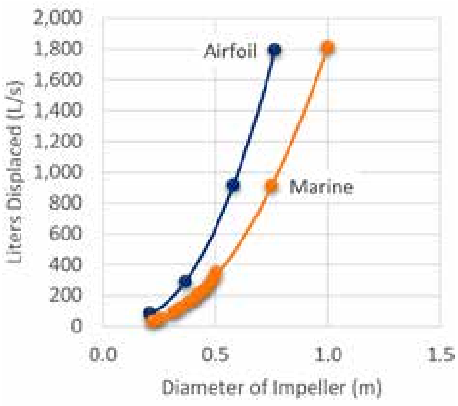


Figure 3: Volumetric flow as a function of impeller size for marine- and airfoil-type impellers [4].

Velocity Needed (m/s)	Volumetric Flow (m^3/s)	Volumetric Flow (L/s)
0.015	0.11	106
0.250	1.77	1767
0.500	3.53	3534
0.750	5.30	5301
1.000	7.07	7069
1.500	10.60	10603
2.000	14.14	14137

Table 2: Volumetric flow required as a function of desired velocity.

were illustrated. However, improvements in impeller and motor design have enabled 40 percent greater flow efficiency with modaern airfoil-type impellers operating at lower speeds. The recommended power requirements for impeller agitation are shown in Table 1. These values should be considered as minimum power requirements [2].

Using the values for modern airfoil-type impellers (0.003 HP/gal), a total power required is 33.6 HP.

The volumetric flow required is velocity (v) * Area or

$$V = \pi R^2 L$$

This is shown in Table 2. Based on the desired minimum flow rate of 0.5 m/s, this would mean that a minimum volumetric flow rate of 3,534 L/s is required. Examining Figure 3, it shows that the existing 300 mm marine impeller only produces a volumetric flow rate of approximately 90 L/s. This explains the very low flow in the quench tank and matches closely with that calculated using CFD.

To achieve the desired flow rate of 0.5 m/s minimum, additional agitators are needed. Six 500 mm diameter airfoil agitators are needed, or eight 400 mm diameter airfoil agitators are required.

Taking the calculated number of agitators, a new model of the tank was created. In this case, eight 400 mm impellers were placed at 45° around the quench tank periphery (Figure 4). To reduce the computational load, disks were placed at the location of the impellers, with inlet/outlet flows of 400 kg/s (400 L/s) for a combined total of 3,200 L/s.

The results of the analysis (Figure 5) show that the flow in the center of the tank is approximately 1.0 m/s, while at the edges of the work zone is 0.5 m/s. The resultant flow is greater than expected and can be the result of the synergy of the flows coming together in the center to produce a higher velocity in the center of the tank. The flow appears to be uniform, and appropriate for quenching shafts. The overall flow meets the minimum flow requirement of 0.5 m/s.

CONCLUSIONS

In this column, a method has been demonstrated to calculate the amount and size of agitators needed for a quench tank. The method shown is conservative and will often produce higher agitation rates than are necessary. However, the flows can be reduced through proper motor controls, such as a frequency drive.

Should you have any questions on this article, or suggestions for new articles, please contact the editor or the writer.

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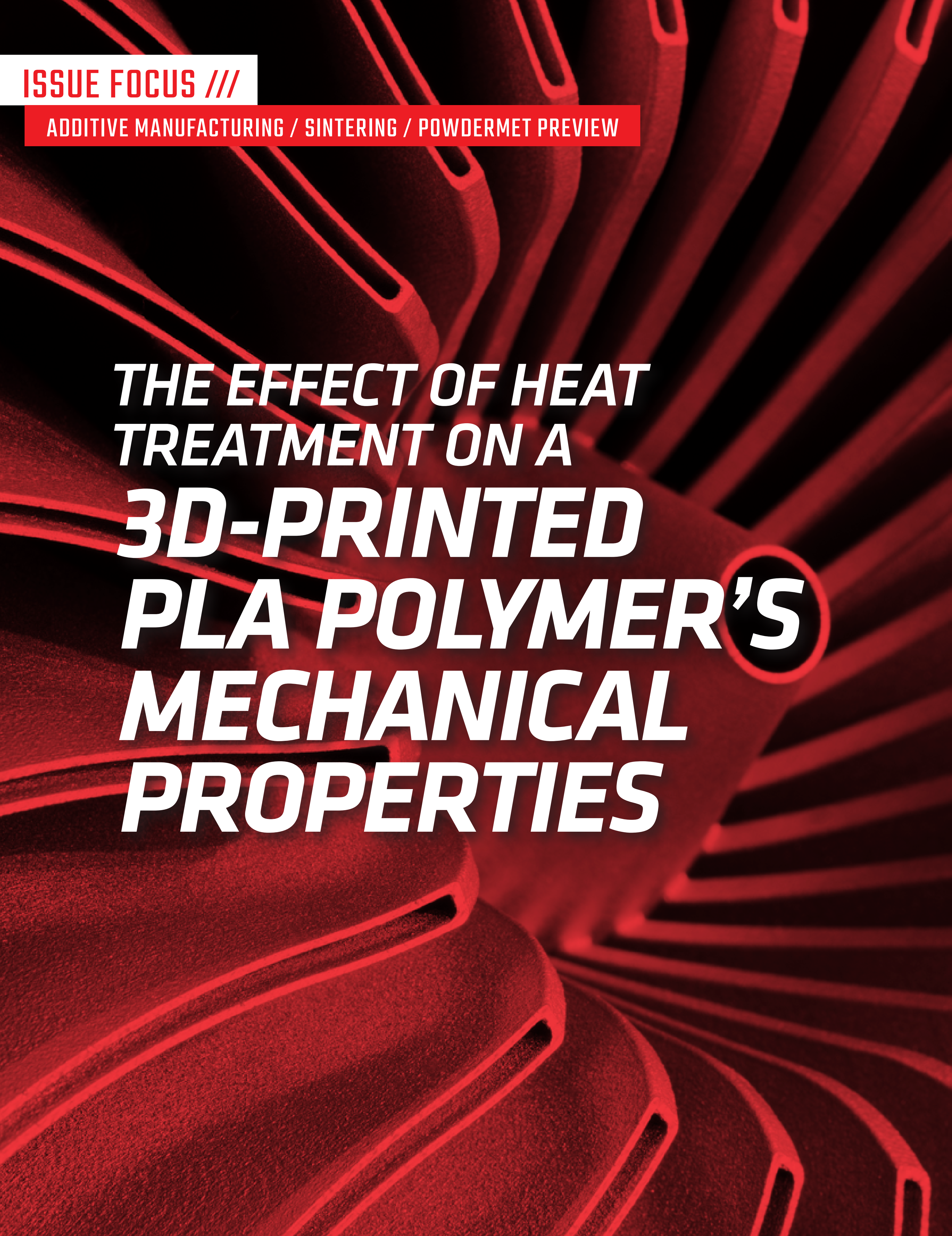

ISSUE FOCUS ///

ADDITIVE MANUFACTURING / SINTERING / POWDERMET PREVIEW

THE EFFECT OF HEAT TREATMENT ON A 3D-PRINTED PLA POLYMER'S MECHANICAL PROPERTIES

Heat treatment is a suitable method for increasing the mechanical properties of PLA after the 3D printing process; the printing orientation of PLA is the most relevant factor influencing the UTS, but this can be increased by a suitable heat treatment.

By MARIAM SHBANAH, MÁRTON JORDANOV, ZOLTÁN NYIKES, LÁSZLÓ TÓTH, and TÜNDE ANNA KOVÁCS

Three-dimensional printing is a useful and common process in additive manufacturing. The advantage of additive polymer technology is its rapidity and design freedom. Polymer materials' mechanical properties depend on the process parameters and the chemical composition of the polymer used. Mechanical properties are very important in product applicability. The mechanical properties of polymers can be enhanced by heat treatment. Additive-manufactured PLA's mechanical properties and structure can be modified via heat treatment after the 3D printing process. The goal of this research was to test the effect of heat treatment on the mechanical and structural parameters of additive-manufactured PLA. This was achieved via the FDM processing of standard PLA tensile test specimens with longitudinal and vertical printing orientations. After printing, the test specimens were heat-treated at 55°C, 65°C and 80°C for 5 hours and after being held at 20°C for 15 hours. The printed and heat-treated specimens were tested using tensile tests and microscopy. Based on the test results, we can conclude the optimal heat treatment process temperature was 65°C for 5 hours. Under the heat treatment, the test specimens did not show any deformation, the tensile strength increased by 35 percent and the porosity of the PLA structure decreased.

1 INTRODUCTION

Additive manufacturing is an advanced manufacturing process used to rapidly prepare prototype components, innovate a new geometry, or replace parts. PLA is a very useful and common polymer material widely used for the additive manufacturing process. PLA is a biodegradable and biocompatible thermoplastic polymer [1,2]. Melt polycondensation in PLA processing can be carried out without organic materials or a solvent. This method is simple, making the technology cheap, but the sensitivity of the reaction conditions is a major problem [3,4]. PLA is considered a bioplastic because it is produced from materials derived from renewable biomass products. The thermal, mechanical, and biodegradation characteristics of lactic acid polymers are known [5,6]; they are made up of lactic acid units, which are small organic acids similar to those found in many of the foods we encounter every day — think sourdough bread, yogurt, soy sauce, and, of course, corn. Anything with glucose in it can theoretically be converted into lactic acid molecules. Among other things, their low glass transition temperature makes PLA parts easy to melt and manipulate, and, therefore. easy to 3D print [7]. However, this low glass transition value is also the reason why PLA parts are relatively less resistant to ambient temperatures.

Additive manufacturing, also known as 3D printing, has been in use in the industry for about 30 years and, in recent years, has been used for rapid prototyping and small-batch production of plastic and metal products. The additive manufacturing technologies (FDM, EBF, DMLS, EBM, SHS, SLS, PP, LOM, SLA, DLP) use different but essentially similar processes to produce a three-dimensional shape. FDM is a complex additive manufacturing process with a large number of technical parameters that influence product quality and material properties, and the combination of these parameters is often difficult to understand [7,8]. The printing parameters, such as printing orientation, layer thickness, raster angle, raster width, air gap, infill density, and pattern and feed rate, have a substantial effect on the quality of FDM-printed parts [9,10,11,12].

The machine builds the spatial object layer by layer. The starting point is always a virtual model, which the target software converts into interpretable instructions before printing [8]. These technologies are mainly used in rapid prototyping, where production times can be reduced from weeks to one to two days. Rapid prototyping can quickly complete the development phase, allowing the tool to be made for mass production or even 3D printed. Increasingly, 3D printing is being used for small batches or one-off items for the final product. FDM printers process plastic fibers wound on a spool by melting them and then printing them layer-by-layer on a printing platform [7,8,9,10,11,12]. Thanks to the compatibility of materials and their user-friendliness, FDM printers are among the most popular 3D printers on the market. Among the process parameters that are most relevant to the mechanical properties is the printing direction [7,13]. The mechanical parameters of additive-manufactured polymers can be enhanced with heat treatment after the printing process [14,15,16,17,18,19,20,21,22,23,24,25]. The material properties of 3D-printed samples can be characterized via material testing [26,27]. Several researchers have conducted tensile tests to determine FDM-printed and heat-treated specimens' mechanical properties, measuring the increase in UTS (32%) by annealing the specimens at 90°C for 1 hour [25].

Polymer additive technology is widely used in many areas today, such as the aerospace, automotive, food, and healthcare industries [28]. PLA is a biodegradable polymer useful for several applications, and this material can be composted.

This study aimed to find a cheap and suitable process and material for the rapid fabrication of laboratory devices. The dimensions of the device were determined considering the geometry of the tested specimen. The choice of material was primarily based on the need to choose a material with low density and adequate strength, due to the manual handling required for this study. The aim was to identify the specifications of a complex technology that give the best result using the chosen material quality and production technology.

2 MATERIALS AND METHODS

2.1 3D Printing of the Test Specimens

The test specimens were prepared via the FDM process, and the printer used was the Ultimaker S5 Pro Bundle (Ultimaker, Utrecht, The Netherlands) with the Ultimaker Cura 5.0 software (Ultimaker, Utrecht, The Netherlands). The equipment used operated with efficient air filtration and humidity control. The filament material used was an Ultimaker PLA (RAL 1003) (Ultimaker, Utrecht, The Netherlands) with a 2.85 ± 0.10 mm diameter and 1.24 g/cm3 density on the base of the technical datasheet of the filament. The used printer's maximal power was 600 W, and the position precision in X-Y-Z axes was 6.9 µm, 6.9 µm, and 2.5 µm. The layer resolution supported by Makerbot (Ultimaker, Utrecht, The Netherlands) was 20-600 µm. The used PLA filament's ultimate tensile strength (UTS) was 49.5 MPa. The geometry of the printed specimens was suited to the ASTM D638 IV standard tensile test specimen (length 115 mm, width 6 mm and thickness 3.6 mm). The test samples were printed in vertical and longitudinal orientations. The test samples' orientations on the printer table are shown in Figure 1.

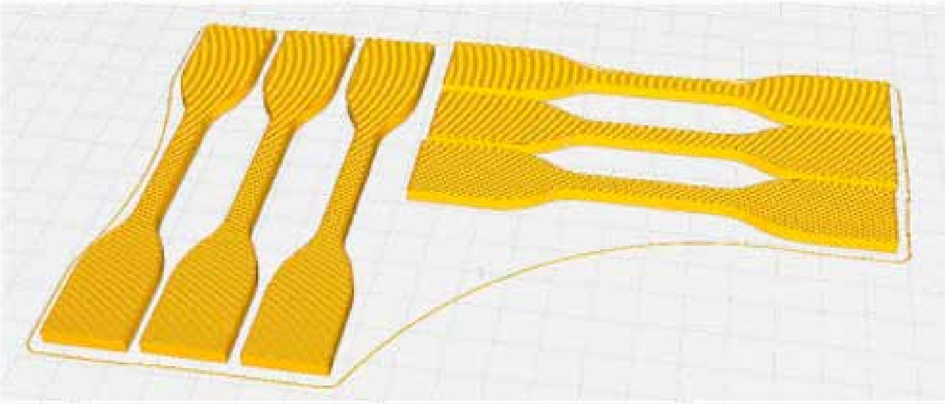

Figure 1: Test specimens on the work table.

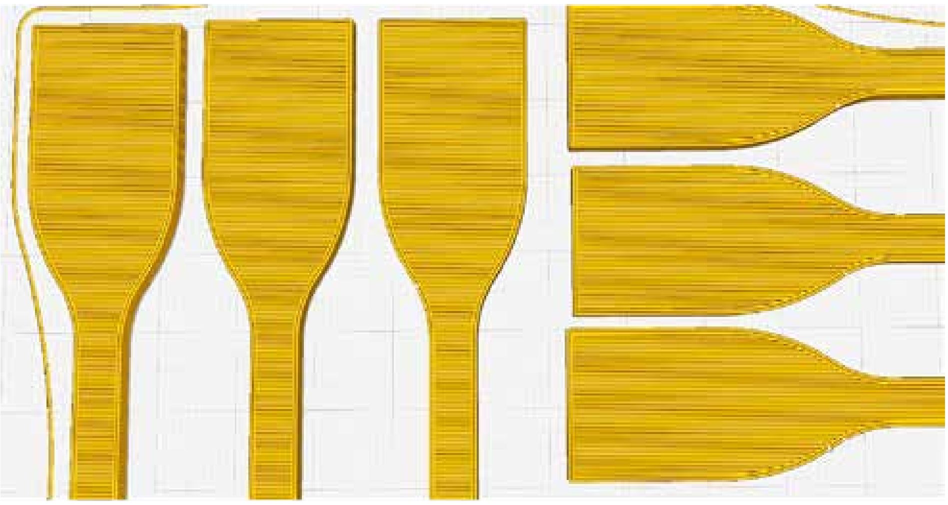

Figure 2: The orientation of the test specimens (vertical and horizontal).

The test samples were printed without support. The work table was preheated to 60°C, and the extruder melted the PLA filament at 200°C. The printing speed was 35 mm/min, and the prepared layer thickness was 0.2 mm. Printing parameters were chosen according to the filament and printer manufacturer's recommendations. All specimens were made with 22 layers with constant orientation. The printing time for three vertically and three horizontally orientated specimens was 4.5 hours. Vertical orientation refers to a position perpendicular to the test specimen's length, and the horizontal orientation corresponds to the test specimen's length (Figure 2).

The cooling time of the test specimens after printing was 15 hours. The cooling process was carried out in open air at room temperature (20°C) in standard humidity conditions.

2.2 Heat Treatment Process

The heat treatment was carried out for 15 hours and took place in a precision furnace preheated to a standard temperature. The heat treatment temperatures were 55°C, 65°C, 80°C, and 95°C. Cooling was carried out in the open air at room temperature for all specimens for 15 hours. After the cooling period, all test specimens were tested via visual inspection and size control using a caliper. After the heat-treatment process, the specimens heat-treated at 95°C were significantly deformed. The heat-treated test specimens' deformation can see in Figure 3. The other heat-treated specimens did not show any deformation and kept their original geometry and sizes. The deformed specimens were not examined further.

Figure 3: Deformed specimens after heat treatment.

2.3 Tensile Test

The tensile test was conducted using a mechanical testing machine. We measured the maximal force (F_{max}) and determined the tensile strength using Equation 1.

$$R_m = \frac{F_{max}}{S_0} \ [\text{MPa}]$$

Equation 1

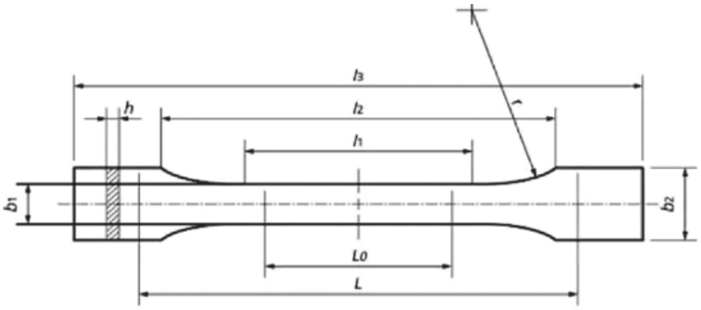

Figure 4: ASTM D638 IV standard test specimen design.

Id. n.	b_1 (mm)	h (mm)	S_0 (mm^2)	F_{max} (N)	ΔL (mm)	Rm (MPa)
V	6.0	3.5	21.0	745.4	1.28	35.6
H	6.0	3.5	21.0	1075	2.65	51.25

Table 1: The tensile test results of the vertically orientated, V, and the horizontally orientated, H, specimens.

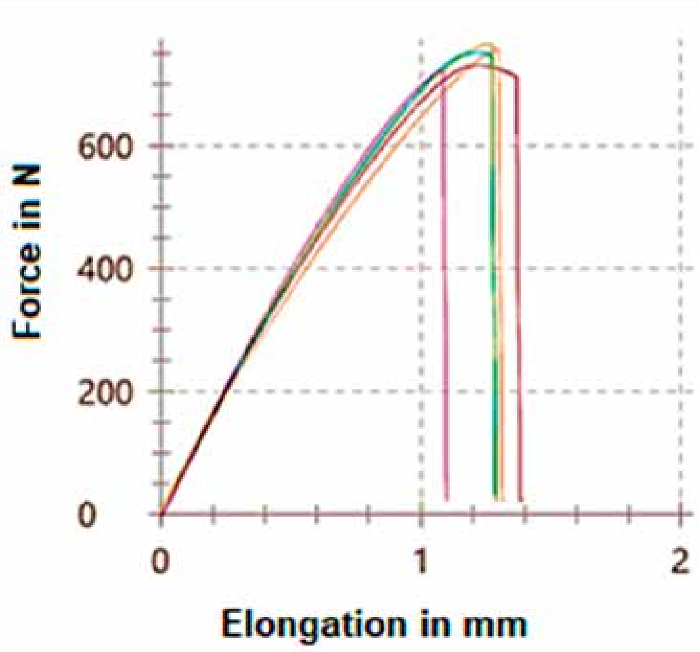

Figure 5: Tensile curves of the vertically orientated test specimens.

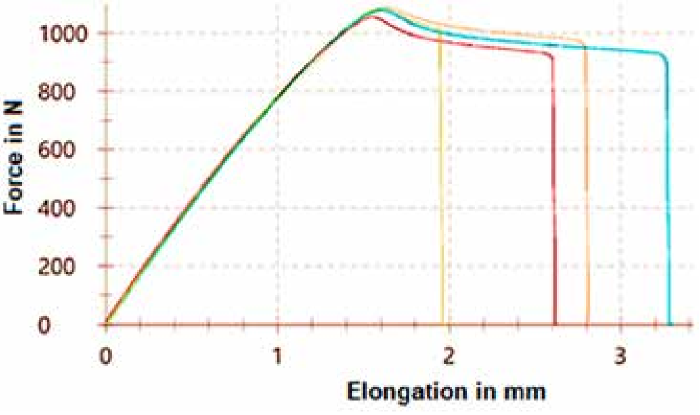

Figure 6: Tensile curves of the horizontally orientated test specimens.

where S_0 is determined using Equation 2:

$$S_0 = b_1 \cdot h \left[\mathrm{mm}^2\right] \qquad \text{Equation 2}$$

where b_1 is the width and h is the thickness of the test specimen. The design of the standard test specimen is shown in Figure 4.

A tensile test was carried out on the printed test specimens to determine their tensile strength as a function of the orientation. Five specimens in both orientations were tested. The results (vertical orientation, V, horizontal orientation, H) of the tests are shown in Table 1. The tensile test was carried out at room temperature in climatized environments.

The tensile curves determined in the case of the vertically orientated test specimens are shown in Figure 5 and the horizontally orientated test specimens in Figure 6.

It can be concluded the tensile test results depended on the test specimens' printing orientation. In the case of the horizontal orientation, the average tensile strength was 51.25 MPa, and in the case of the vertical printing orientation, it was 35.6 MPa. These tests were conducted to determine the printed specimens' tensile strength as a function of the printing orientation.

2.4 Microscopy

The printing efficiency was tested using an Olympus DSX 1000 (Olympus Corporation, Tokyo, Japan) microscope. The cross-sections of the vertically and horizontally orientated and heat-treated test specimens were tested. The samples were prepared for microscope observation via metallographic preparation, grounding, and polishing. The cross-sections of the horizontally and vertically orientated test specimens are shown in Figure 7. The crossing direction was perpendicular to the printing direction of the test specimens.

2.5 Shore D Test

The hardness of the specimens was determined using a Shore D tester. The test was conducted at room temperature according to ISO 868. The technical datasheet of the filament gives 83 (D Shore) as a characteristic value of the 3D-printed state, as determined using a durometer (Innovatest SHD0002, Innovatest Europe BV, Maastricht, The Netherlands). There was no reference value for the direction of printing.

3 RESULTS AND DISCUSSIONS

The goal of the experiments was to determine the heat-treated specimens' tensile strength and structure as a function of the heat treatment in the case of both printing orientations. The heat treatment was carried out as described above at 55°C, 65°C, 80°C, and 95°C. The latter temperature, 95°C, led to deformation (see Figure 3) of the specimens; these were not examined further.

3.1 Heat-Treated Specimens' Tensile Test Results

The other specimens' tensile test results are summarized in Table 2. The labels in the table below are explained as follows: The first digit shows the printing orientation, where V is vertical and H is horizontal; the second digit, h, indicates these specimens were heat-treated; and the third digit is the temperature of the heat treatment in °C.

Table 2 summarizes the tensile test results of the printed and heat-treated specimens. Based on the UTS results in the case of the PLA and printing process parameters used, the heat treatment at 65°C led to the best performance for the vertically printed specimens and the heat treatment at 80°C led to the best results for the horizontally printed specimens. Between the 65°C and 80°C heat treatments, in the case of the horizontally printed specimens, there was a 0.5 MPa difference in UTS.

Numerous research reports suggest the reason PLA's mechanical properties are enhanced as a function of heat treatment is the improvement in the crystallinity of PLA. This refers to heat treatments conducted between 90°C and 100°C [29,30].

3.2 Tensile Test Resulted in Ruptured Surfaces

After the tensile test, the specimens' surfaces were examined via visual inspection and microscopy. The microscopy test showed differences as a function of the printing direction and the heat treatment in the extent of damage to specimens' surface. Only the printed specimens and those heat-treated at 65°C were tested because, according to the tensile test results, the vertically printed specimens showed the highest UTS. Figure 8 shows the vertically printed specimens' ruptured surface.

The ruptured surfaces of the horizontally printed specimens are shown in Figure 9, where Figure 9a shows the non-heat-treated specimen and Figure 9b shows the heat-treated specimen.

The ruptured surfaces show the heat treatment effects. The surfaces had some brittle fractures (Figure 9c).

The 3D pictures of the ruptured surfaces better show the difference between the heat-treated and non-heat-treated specimens (Figure 10). The heat treatment temperature was 65°C.

3.3 Microscopy of the Specimen Cross-Section

The microscopy results of the printed and the heat-treated test specimens' cross-section are shown in Figure 11. Samples from both horizontally printed and vertically printed specimens were cut in two directions for microscopic examination. The printed and heat-treated specimens' cross-sections were tested.

Figure 11 shows the structure of the printed and heat-treated specimens as a function of the printing orientation and the cross-section cut direction. It can be seen that the heat treatment decreased the porosity of the samples. In the case of the printed samples' cross-sections, we can see the porosity was different between the top side and the back side of the specimens. During the printing process, the temperature was different in each layer. To achieve suitable mechanical properties and the lowest porosity possible in a printed structure, polymerization needs to be maintained, which requires suitable temperature and environmental properties.

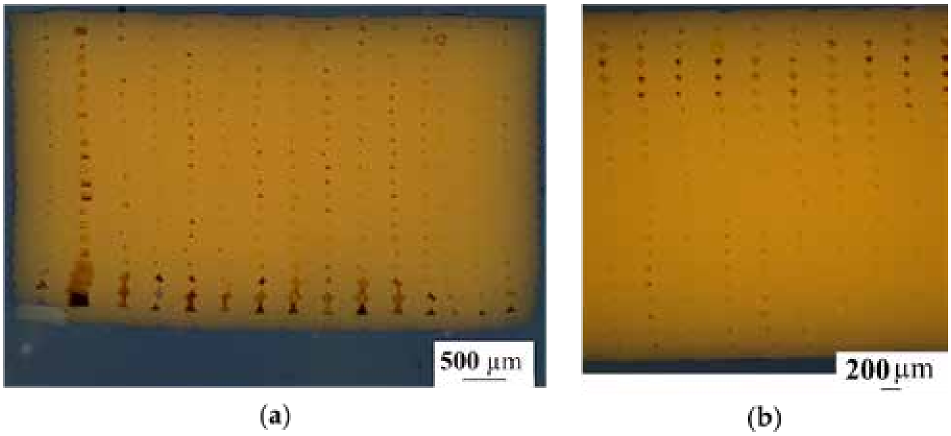

Figure 7: The test specimens' cross-sections. (a) Perpendicular cross-section of a horizontally printed specimen; (b) perpendicular cross-section of a vertically printed specimen.

Sample	b_1 (mm)	h (mm)	S_0 (mm^2)	F_{max} (N)	ΔL (mm)	Rm (MPa)
V	6.0	3.50	21.00	745.40	1.28	35.60
H	6.0	3.50	21.00	1075.00	2.65	51.25
Vh55	5.99	3.50	20.97	873.00	1.23	41.33
Hh55	6.02	3.50	21.05	1273.33	1.90	60.33
Vh65	6.00	3.51	21.18	969.33	1.47	46.00
Hh65	6.00	3.50	20.98	1403.33	2.00	67.00
Vh80	6.01	3.51	21.10	662.00	0.85	31.00
Hh80	6.01	3.50	21.03	1415.00	2.00	67.50

Table 2: The tensile test results of the heat-treated vertically orientated (V) and horizontally orientated (H) specimens as a function of the heat treatment temperature.

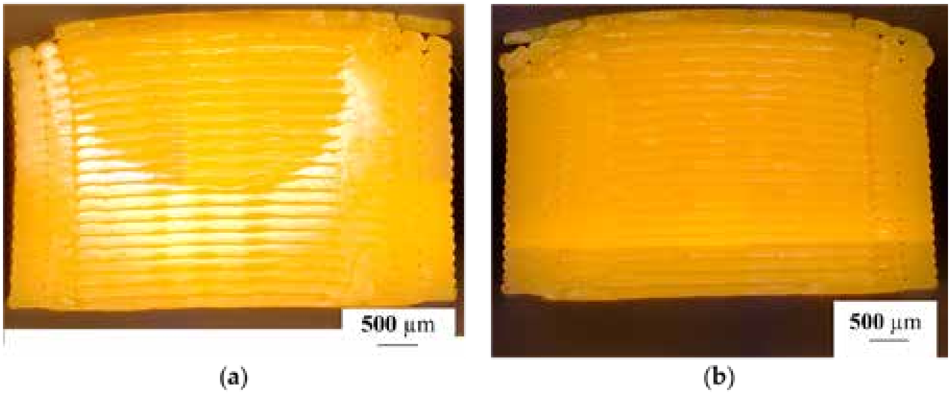

Figure 8: The ruptured surface of the vertically printed test specimens after the tensile test. (a) A specimen that did not undergo heat treatment; (b) specimen heat-treated at 65°C.

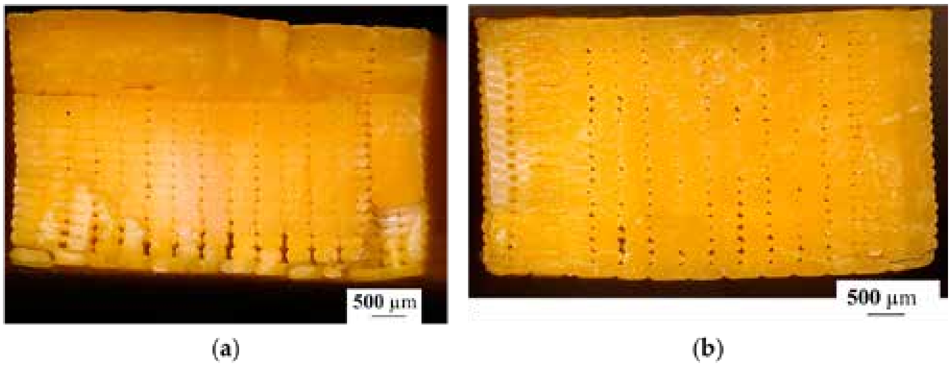

Figure 9: The ruptured surface of the horizontally printed test specimen after the tensile test. (a) A specimen that did not undergo heat treatment; (b) a specimen heat-treated at 65°C.

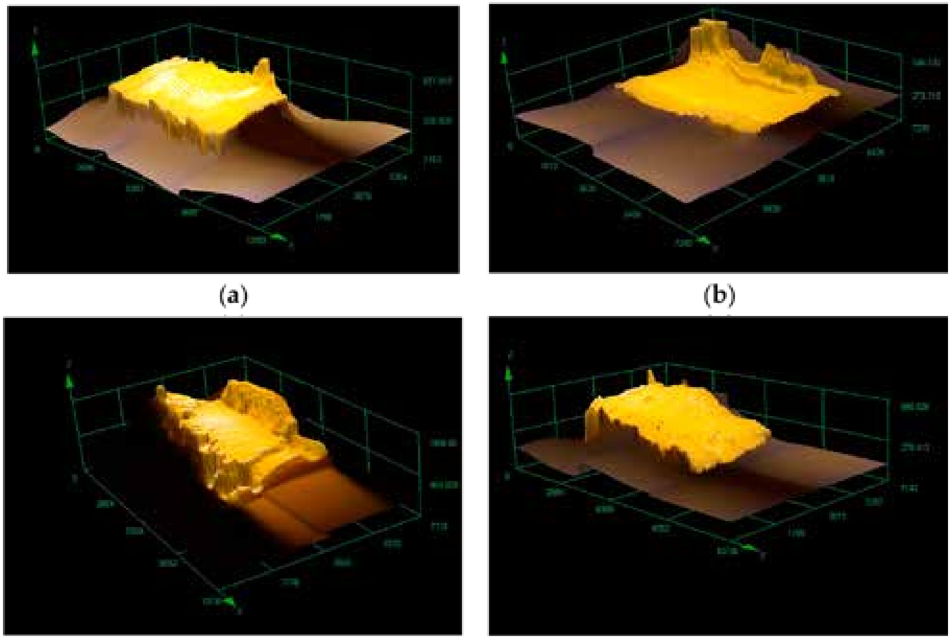

Figure 10: The ruptured surface of the horizontally and vertically printed test specimens after the tensile test. (a) The ruptured surface of a vertically printed specimen; (b) the ruptured surface of a vertically printed and heat-treated specimen; (c) the ruptured surface of a horizontally printed specimen; (d) the ruptured surface of a horizontally printed and heat-treated specimen.

3.4 Shore D Hardness Tests

The Shore D test results are collected in Table 3. The test was carried out on the parallel and perpendicular cross-sections of the seven horizontally and vertically printed specimens heat-treated at 65°C.

The average hardness in the case of all specimens was in harmony with the datasheet data and with the literature [31]. The heat treatment at 65°C led to a decrease in hardness compared to the hardness value after printing. The applied heat treatment resulted in softening of the PLA.

4 CONCLUSIONS

Mechanical properties' dependence on the printing direction is well understood. In the introduced experimental study, the results confirm this fact. The tensile test results are in harmony with the literature data; the printed tensile specimens showed a variable UTS as a function of the printing orientation [31]. This work is devoted to developing a heat-treatment process able to enhance the mechanical properties of 3D-printed PLA products. The heat-treatment process modified the UTS in the case of both vertical and horizontal printing directions. The heat treatment at 65°C led to the greatest increase in the UTS of the vertically printed specimens. In the case of the horizontally printed specimens, all heat treatments increased the UTS (Table 2).

Based on the visual and microscopy tests of surface rupture after the tensile test, we can see fractures in the surface (Figure 9 and Figure 10).

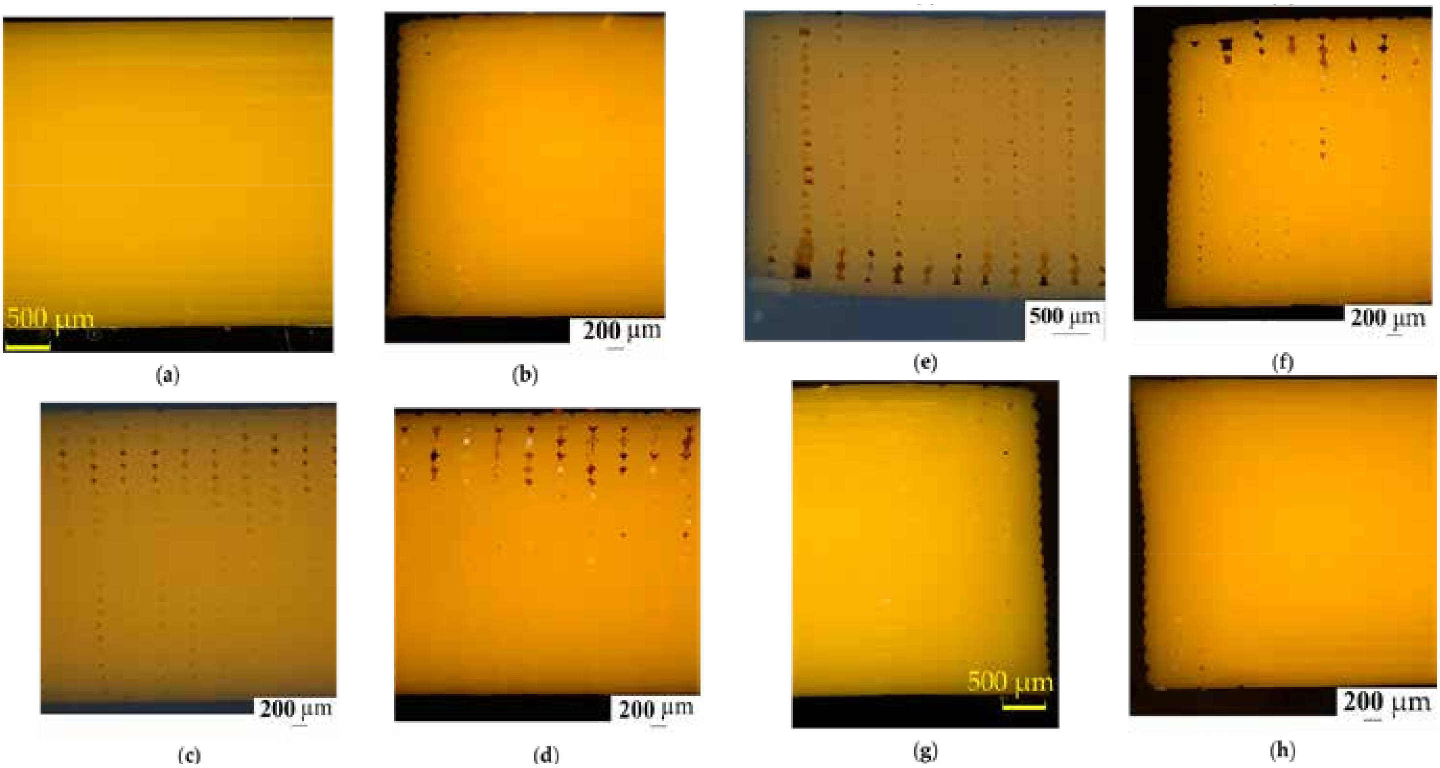

Figure 11: The microscopy tests of the printed and heat-treated specimens. (a) The vertically printed specimen cut parallel to the printing orientation; (b) the vertically printed specimen cut parallel to the printing orientation, after heat treatment at 65 °C; (c) the vertically printed specimen cut perpendicular to the printing orientation. (d) The vertically printed specimen cut perpendicular to the printing orientation, after heat treatment at 65°C; (e) the horizontally printed specimen cut perpendicular to the printing orientation; (f) the horizontally printed specimen cut perpendicular to the printing orientation, after heat treatment at 65°C; (g) the horizontally printed specimen cut parallel to the printing orientation; (h) the horizontally printed specimen cut parallel to the printing orientation, after heat treatment at 65°C.

Sample	Hpa	Hpp	Vpa	Vpp	Hh65pa	Hh65pp	Vhpa	Vhpp
Shore D	83	82	82	83	80	81	81	80

Table 3: The Shore D test results of the printed and the heat-treated (h65) vertically printed (V) and horizontally printed (H) specimens' parallel (pa) and perpendicular (pp) cross-sections.

The microscopy tests of the printed specimens heat-treated at 65°C showed relevant differences in the structure of the specimens. Figure 11 shows the printed and heat-treated specimens, where it can be seen that, after the heat treatment, the porosity decreased in all test specimen structures. The size of the test specimens was controlled by using a caliper, so there was not a measurable difference before and after the heat treatment in the case of the treatments at 55°C, 65°C, and 80°C. We can conclude that the heat treatment at 95°C caused deformation (Figure 3). The increase in the UTS could be explained by the improvement in the crystallinity as the literature suggests, but on the basis of the experimental results, this cannot be fully concluded because the crystalline fraction was not determined in this study. The effectiveness of the heat treatment, which is in harmony with the literature, is likely to be due to the reduction in stress as a result of the heat treatment [25,32]. All test specimens contained 22 layers, each of which stayed at a different temperature during the printing process for different durations of time.

It can be declared that heat treatment is a suitable method for increasing the mechanical properties of PLA after the 3D printing process. The printing orientation of PLA is the most relevant factor influencing the UTS, but this can be increased by a suitable heat treatment.

AUTHOR CONTRIBUTIONS

Conceptualization, M.S. and M.J.; methodology, T.A.K.; validation, Z.N.; formal analysis, M.S. and M.J.; investigation, M.J.; data curation, M.S.; writing — original draft preparation, T.A.K.; editing and visualization, Z.N.; supervision, L.T.; project administration, L.T. All authors have read and agreed to the published version of the manuscript.

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INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data used for the research are available upon request.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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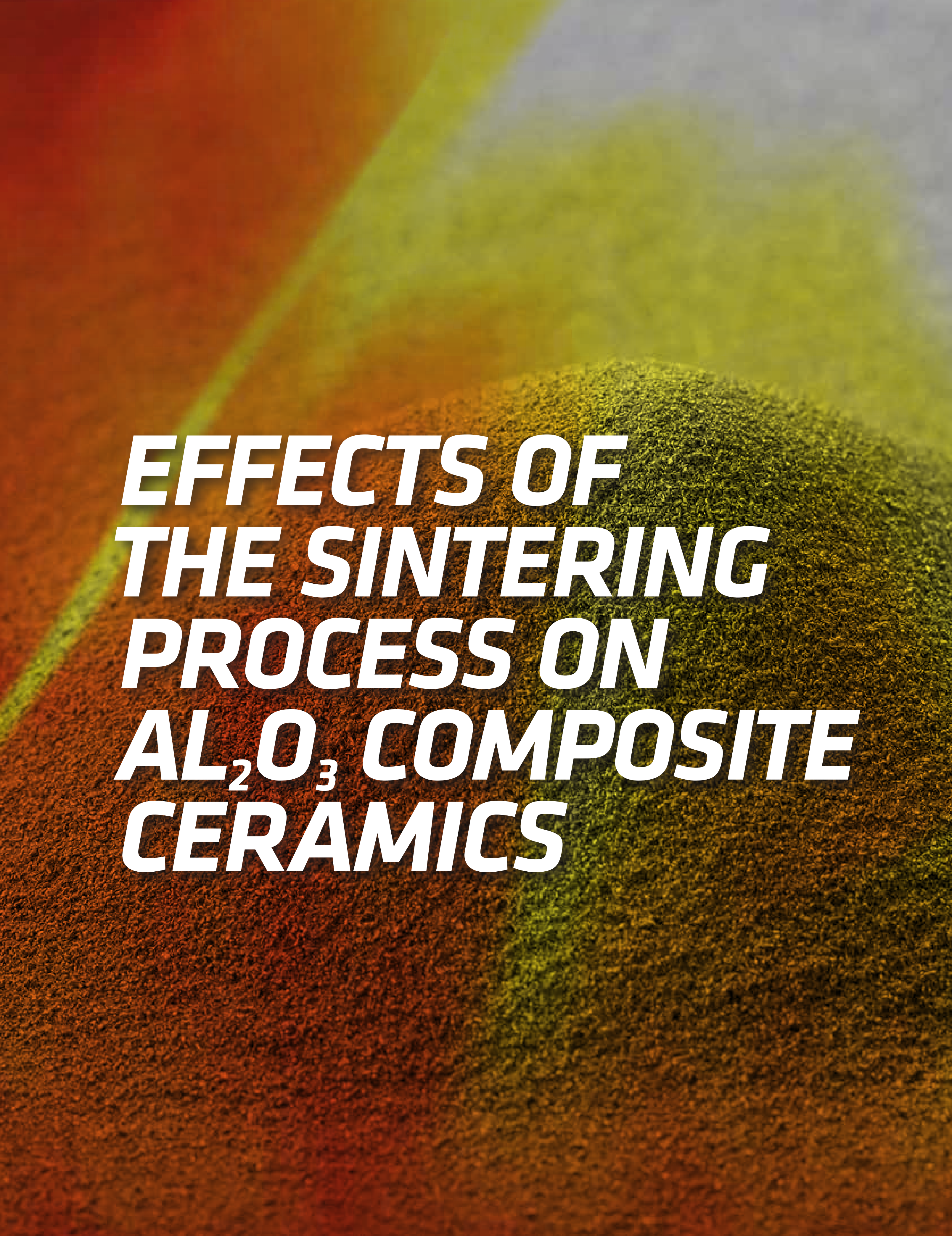

EFFECTS OF THE SINTERING PROCESS ON AL$_2$O$_3$ COMPOSITE CERAMICS

Commercial Al_2O_3 ceramics fabricated using material extrusion and photo-polymerization combined processes with good fracture toughness and flexural strength via TSS will have unique advantages in engineering applications.

By XIN HE, JIE XU, LIJIE HE, and WEIXI JI

The sintering process can improve the microstructure of Al_2O_3 composite ceramics and enhance their comprehensive properties, but the effects of the sintering process on Al_2O_3 composite ceramics are still unclear. Herein, a novel Al_2O_3 composite ceramic was printed using the material extrusion and photo-polymerization combined process, and the final ceramic was obtained using one-step sintering (TS) and two-step sintering technology (TSS). Based on the testing results, such as the relative density (D_{rel}), average grain size (AGS), hardness, bending strength, and fracture toughness, TSS was suitable for the refinement of commercial Al_2O_3 ceramics. Moreover, the highest sintering temperature of the second step (T_2) was at 1,550°C, while that of the shortest holding time (t) was at 4 hours (TSS_8), which was to ensure densification before rapid grain growth. The D_{rel} and AGS of the best ceramics obtained via TSS_8 were 97.65% and 1.52 µm, respectively. Their hardness, bending strength, and fracture toughness were also enhanced, and they were affected by T_2, t, and the interaction. In sum, the TSS obtained better fracture toughness and bending strength, which had great potential in the application of the additive manufacturing field.

1 INTRODUCTION

Al_2O_3 ceramics is one of the most common engineering materials, and its performance depends on the density and control of fine particles [1]. In the technology of obtaining dense and fine particle ceramics, fine particles in raw material will reduce the fluidity of the slurry, which has limited the form of the green body [2,3], and it will hinder the further application of the commercial Al_2O_3. Dense and fine-grained ceramics can be obtained via pulse plasma sintering, liquid-phase sintering, laser sintering, adding additives, etc., but the sintering process is complex, and the cost is high [4,5,6,7,8]. One-step sintering (TS) is common, economical, and easy to operate, which cannot only improve compactness through higher sintering temperatures but also promote grain growth [9,10,11]. The slightly lower sintering temperature can uniformly refine the particles and reduce their compactness [12], which limits the application of ceramic structure densification and refinement.

As ceramic fabrication technology develops, two-step sintering (TSS) is adopted to control the sintering rate and achieve the density and refinement of ceramics [13,14,15] to improve their mechanical properties [16,17]. Generally, the first step of sintering to the maximum temperature is recorded as T1. After a brief stay, it quickly cools to T_2 as the second step to sintering temperature and cools down to room temperature after holding temperature for t_2 [18]. The dense Al_2O_3 ceramics [19,20,21], $BaTiO_3$ ceramics [22], and other ceramics [23,24] are obtained using TSS to inhibit the growth of ceramic grains.

Z. Razavi et al. [25] prepared and characterized sub-micrometer Al_2O_3 ceramics (grain size, 150 nm) using different TSS and discussed the effects of T_1 and t_2 on the densification and grain of ceramics.

Components	Grain Size (µm)	Theoretical Density (g/cm^3)	Content (wt%)
Al_2O_3	1 µm	3.98	54
Al_2O_3	200 nm	3.98	10
TiCN	1µm	5.08	30
Ni	1µm	9.90	2
Mo	1µm	10.20	2
MgO	1µm	3.58	2

Table 1: Properties and content of raw materials [30].

Compared with TS, when t_2 = 60 h, T_1 goes from 1,300°C to 1,150°C, the grain size in the bulk was reduced from 1.2 µm to 0.85 µm. The grain size decreased to 0.5 µm when T1 dropped to 1,250°C, and the relative density (D_{rel}) was less than 88% at T_2 = 1,100°C, indicating that temperature played a vital role for TSS, but the period of t_2 was longer, and the effects on average grain size (AGS) and D_{rel} has not been analyzed. N.J. Lóh et al. [26] used this technique to obtain the three commercial Al_2O_3 of different purity (92, 96, and 99 wt% of Al_2O_3), evaluate the effects of T_2 and t_2 on density, and conclude the maximum T_2 (1,550°C) and minimum t_2 (4 hours). Moreover, the interaction of T_2 and t_2 significantly affected the density of 99.7 wt% Al_2O_3 (particle size = 0.73 µm) [27]. However, the systematic evaluation of sintering parameters on compactness, AGS, and mechanical properties are still unclear, and the AGS is within the range of sub-micrometer (150-200 nm) and micrometer (0.73-2.16 µm), the application of TSS in multi-components of micro-nanometer particles composite ceramics has not been analyzed.

In this study, Al_2O_3, TiCN, and the other micro-nanometer particles were used as raw powder. The ceramic green body was fabricated via material extrusion and the photo-polymerization combined process (MEX-PPM) [28], and using two-step degreasing [29] and TSS, the final ceramic parts. The effect of the sintering process on Al_2O_3 composite ceramics fabricated using the MEX-PPM process was studied through D_{rel}, AGS, mechanical properties, and microstructure measurements.

2 MATERIALS AND METHODS

2.1 Materials

Al_2O_3 (Tuopu Metal Materials Co., Ltd., Suzhou, China) was used as the matrix material, TiCN as the additive, MgO as the sintering additive, Ni and Mo as the metal binder (Tuopu Metal Materials Co., Ltd., Suzhou, China), 0.15 wt% oleic acid (OA) as the surfactant [28], and 1,6-hexanediol diacrylate (HDDA) (Changxing Chemical Co., Ltd., Shanghai, China) as the prepolymer solution. Diphenyl (2,4,6-trimethylbenzoyl)-phosphate oxide (TPO) (BASF GmbH, Shanghai, China) was used as a photoinitiator. The properties and content of raw materials are listed in Table 1.

2.2 Preparation Process

The preparation of ceramic slurry for the MEX-PPM process can be divided into three steps: modifying ceramic powder, preparing prepolymer solution, and mixing slurry. Firstly, the ceramic powder was added to deionized water containing OA, mixed evenly, and dried to obtain the modified powder. Then, the modified ceramic powder was added into the HDDA prepolymer solution with TPO and milled for 4 hours. Finally, the milled slurry was subjected to ultrasonic vibration to eliminate bubbles in the slurry, and the available ceramic slurry was obtained.

In the process of printing ceramic bulk using the MEX-PPM process, the ceramic slurry is extruded through the round nozzle and deposited on the workbench, which receives UV light radiation to maintain the shape and prevents the collapse and deformation of the deposited slurry caused by gravity [31]. The round nozzle and UV light source are fixed on the equipment. The 3D printing software slices the parts to generate a G-code, drives the workbench to move, and obtains the final ceramic bulk through the layer-by-layer deposition of slurry and UV light curing. The schematic diagram of the MEX-PPM process is shown in Figure 1.

The above MEX-PPM process was used to print the dense ceramic bulk at a printing speed of 5 mm/s and a radiation energy of 20 J/cm^3 at room temperature and obtain the final ceramic parts through degreasing and sintering technology.

2.3 DEGREASING AND SINTERING PROCESS

2.3.1 Degreasing Process

This work adopted a two-step degreasing (TSD) with a controllable pyrolysis rate [29] to remove the organic binder HDDA in the ceramic bulk; the TSD process is shown in Figure 2.

Combined with the experimental conditions, the first step of degreasing in this study was carried out in a tubular furnace (GSL-1700X, Hefei Kejing Material Technology Co., Ltd., Hefei, China) at the rate of 1°C/min. The temperature was held for 30 minutes every 100°C increased, hold for 180 minutes when it reached 600°C, and then the furnace was then cooled to room temperature. The second step of degreasing was carried out in an air furnace, which was heated to 200°C, 600°C (holding for 200 minutes), and 1,000°C (holding for 30 minutes) at 2°C/min, 1°C/min, and 4°C/min, respectively, and then the furnace was cooled to room temperature to complete the whole degreasing process.

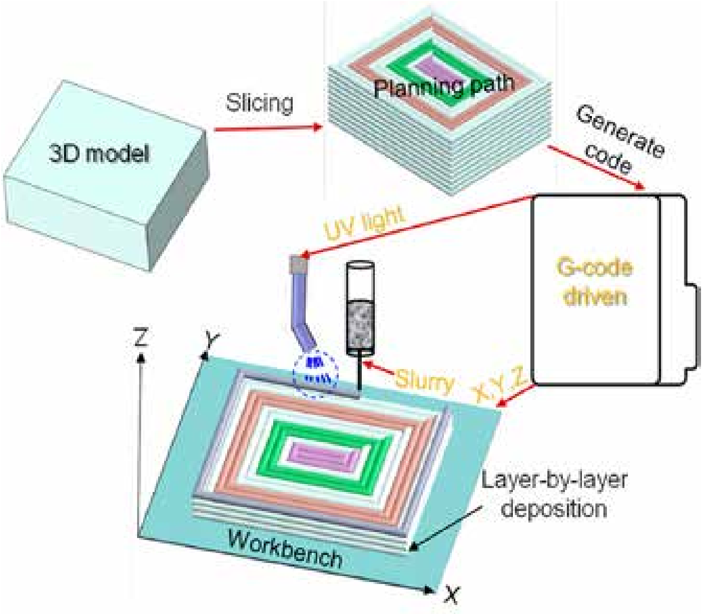

Figure 1: Schematic diagram of the MEX-PPM process.

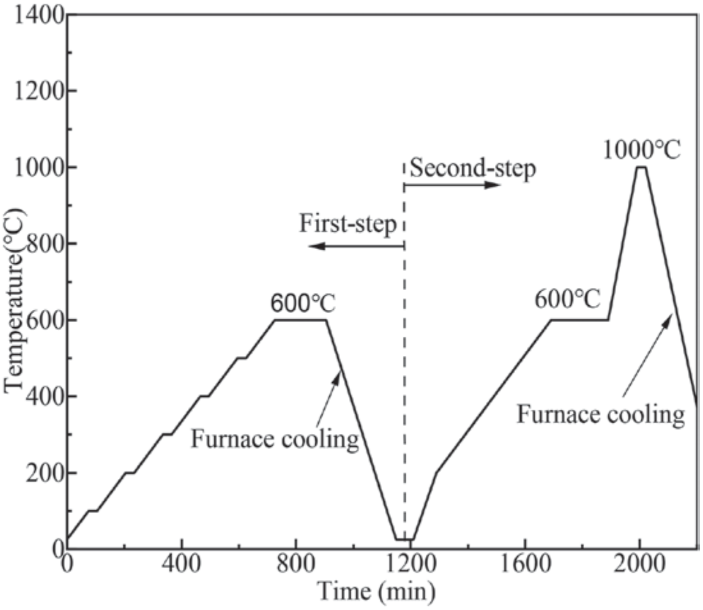

Figure 2: TSD process.

2.3.2 Sintering Process

After degreased Al_2O_3 composite ceramic adopts the traditional TS and the designed TSS to obtain the final ceramic parts, the process of TS and TSS is shown in Figure 3.

Figure 3a shows the changing curve of sample TS. Firstly, the temperature was raised to 1,200°C at a rate of 10°C/min, then it was increased to T_1 at a rate of 3.75°C/min. After that, the temperature was cooled to 1,200°C with a rate of 3.75°C/min. Finally, the temperature was cooled to room temperature. As shown in Figure 3b, the changing curve of TSS is similar to that of TS in the initial stage and then stays briefly after heating to the maximum temperature of T_1, and then it is cooled down to T_2 at a rate of 50°C/min, and held at t for a certain time. While the other temperature-controlling procedures were the same as that of TS, TSS sintering technology was carried out with two factors and three levels. The specific sintering parameters are shown in Table 2.

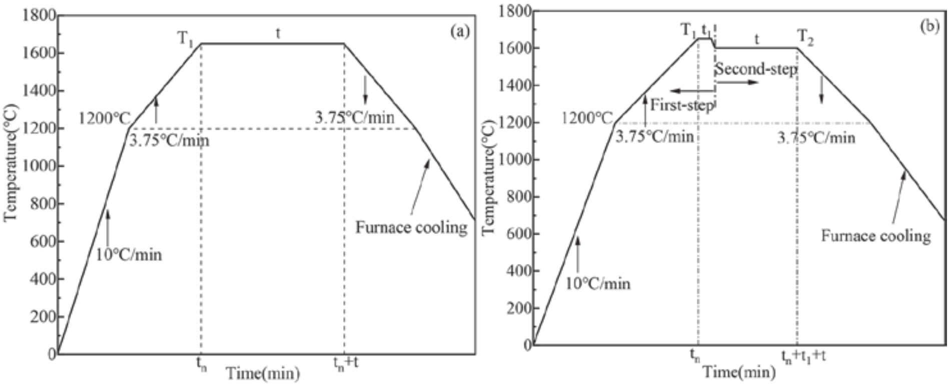

Figure 3: (a) TS sintering process and (b) TSS sintering process.

Sintering Process	T_1/°C	T_2/°C	t/h
TSS_1	1500	1450	2
TSS_2	1500	1450	4
TSS_3	1500	1450	6
TSS_4	1550	1500	2
TSS_5	1550	1500	4
TSS_6	1550	1500	6
TSS_7	1600	1550	2
TSS_8	1600	1550	4

Table 2: The specific parameters of TSS and TS sintering.

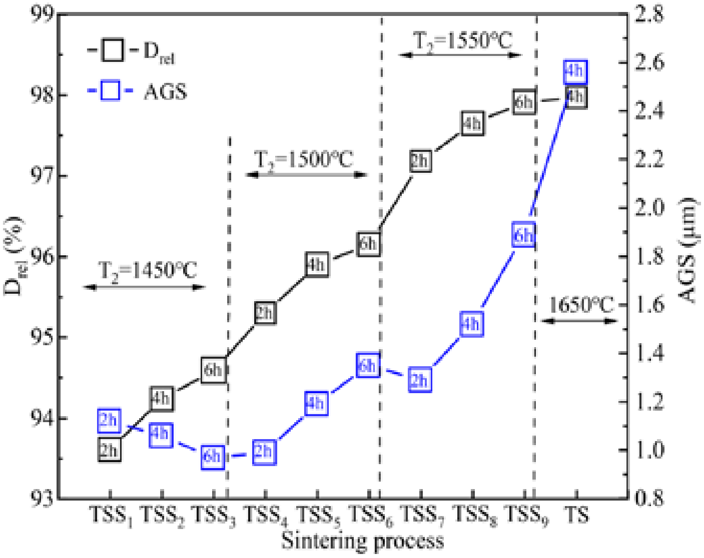

Figure 4: The D_{rel} and AGS of Al_2O_3 composite ceramics treated with TSS and TS.

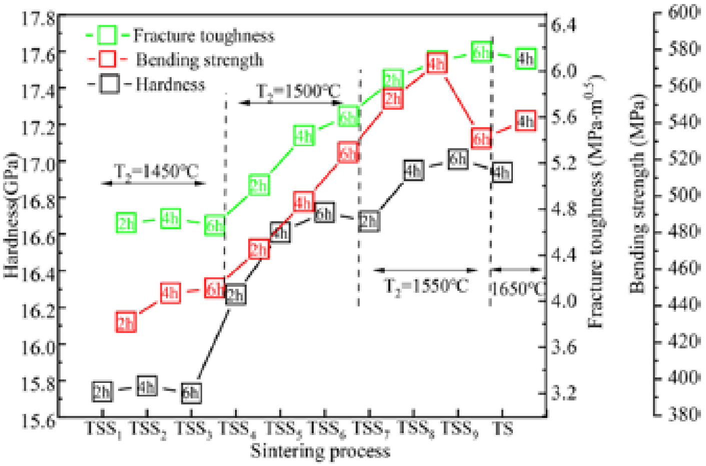

Figure 5: The mechanical properties of Al_2O_3 composite ceramics treated via TSS and TS.

2.4 Characterizations of the Prepared Samples

To evaluate the properties of Al_2O_3 composite ceramic obtained by various sintering technologies, the ceramic sample was obtained by cutting, polishing with diamond particles, cleaning, drying, and gold spraying. The density was measured using the Archimedes drainage method; the microstructure was characterized using a scanning electron microscope (SEM, Evo18, Zeiss, Oberkochen, BW, Germany), and the grain size was measured using the line intercept method. The hardness, fracture, and toughness were measured using a Vickers hardness tester (HV-1000ZCM-XY, Anyi Instrument Co., Ltd., Shanghai, China), and the three-point bending test was carried out using an electronic universal testing machine (WDW-100KN, Instron Co., Boston, MA, USA). The fracture toughness and bending strength of ceramic specimens were obtained from Equations 1 and 2, respectively.

$$KIC = 0.203 \times 1.8544\ P/(4C^{3/2}) \qquad \textbf{Equation 1}$$

where P is the pressure load, and C is the average crack length.

$$\sigma = (3F \times L)/(2b \times h^2) \qquad \textbf{Equation 2}$$

where F is the failure load, L is the span, and b and h are the width and thickness of the specimen, respectively.

In addition, the density, particle size, and mechanical properties of the ceramics were characterized using an average of seven tests per sample out of 20 samples from the same batch.

3 RESULTS AND DISCUSSION

3.1 Comparison of Results from TSS and TS

The TS and TSS were applied to Al_2O_3 composite ceramics, and the D_{rel} and AGS of ceramic sintered bodies were obtained, as shown in Figure 4.

Figure 4 shows the D_{rel} (black mark) and AGS (blue mark) of Al_2O_3 composite ceramics under the action of each TSS and TS. The same holding time t = 4 h, the D_{rel} (TSS_8) (97.65%) obtained via TSS is slightly lower than that of TS (97.97%), but the AGS (TSS_8) (1.52 μm) is significantly lower than TS (2.56 μm). With the increase in t to 6 hours, the D_{rel} (TSS_9) (97.91%) treated via TSS is close to TS, and the increased AGS (1.89 μm) is still lower than that of TS. Although the D_{rel} of other ceramics (93.61–97.18%) treated with TSS is lower than that of TS, their AGS (1.12–1.29 μm) is significantly lower than that of TS. TSS is more beneficial to Al_2O_3 composite ceramics from the compactness and grain refinement point of view.

In addition, the D_{rel} and AGS increase the amount of ceramic obtained via TSS with the T_2. When t = 2 hours, T_2 from 1,450°C increases to 1,550°C, causing the D_{rel} from 93.61% to increase to 97.18% and the AGS from 1.12 μm to increase to 1.52 μm. When the t increases, the change in compactness is not always obvious, and the AGS still grows. At T_2 = 1,550°C, t from 2 hours increased to 4 hours, the D_{rel} from 97.18% (TSS_7) to 97.65% (TSS_8), and the AGS rapidly from 1.29 μm to 1.52 μm. The t increased to 6 hours, the D_{rel} increased to 97.91%, and the AGS increased to 1.89 μm. Slightly lower T_2 ensures fine-grained ceramics; the changing compactness leads to different mechanical properties, as shown in Figure 5.

Figure 5 shows the mechanical properties of Al_2O_3 composite ceramics; the black, red, and green marks correspond to hardness, bending strength, and fracture toughness, respectively. Good ceramic hardness and fracture toughness can be obtained under the sintering conditions of T_2 = 1,550°C and t = 6 hours (TSS_9), which are 17.01 GPa and 6.17 MPa·m$^{0.5}$, respectively. The t was shortened to 4 hours, and the ceramics obtained via TS (16.94 GPa, 6.11 MPa·m$^{0.5}$) at 1,650°C were equivalent to TSS_8 (16.95 GPa, 6.09 MPa·m$^{0.5}$) at 1,550°C. The bending strength obtained via TSS_7 (553.34 MPa) at 1550 °C for 2 hours is higher than TS (541.23 MPa).

The mechanical properties of ceramic are improved with the T_2. When T_2 from 1,450°C to 1,550°C at t = 2 hours, the hardness, bending strength, and fracture toughness increased from 15.74 GPa, 431.14 MPa, and 4.68 MPa·m0.5 to 16.67 GPa, 553.34 MPa, and 5.93 MPa·m0.5, respectively. But, the mechanical properties do not improve significantly with the increase in t. For example, the hardness at T_2 = 1,550°C, t = 4 hours (TSS_8), and t = 6 hours (TSS_9) are close, the fracture toughness increases slowly, and the bending strength decreases.

The fine particles of dense ceramics can be obtained under the

T_2 = 1,550°C, t = 4 hours or 6 hours (Figure 4), and the mechanical properties under the T_2 = 1,550°C, t = 4 hours (Figure 5) are close to TS. So, the sintering parameter for obtaining the best Al_2O_3 composite ceramics is TSS_8 with T_2 = 1,550°C, t = 4 hours. Using the TSS_8 process, the D_{rel}, AGS, hardness, bending strength, and fracture toughness were 97.65%, 1.52 μm, 16.95 GPa, 572.59 Mpa, and 6.09 MPa·m0.5. The above results preliminarily show that the T_2 and t in TSS have varying degrees of effect on the properties of Al_2O_3 composite ceramics. The impact and reliability of the T_2 and t on the properties of ceramics need to be further analyzed through data statistics.

3.2 Effects of T_2 and t on Al_2O_3 Composite Ceramics

The reliability of the impact of factors (T_2 and t) on variables (D_{rel}, AGS, and mechanical properties) was evaluated using SPSS software. In the statistical analysis, the adjusted R^2 is used to assess the fitting degree of the model, and the standard effect quantity (η^2) and *p*-value are used to evaluate the degree and significance of the effects of T_2 and t on ceramic properties, respectively. It is assumed that when p-value < 0.05, the factors have significant effects on variables. On the contrary, the effect of factors on variables is not significant.

3.2.1 Effects of T_2 and t on D_{rel} and AGS

The statistical analysis results of T_2 and t for D_{rel} and AGS are shown in Table 3, which shows the effects of T_2, t, and their interaction (T_2 by t) on the D_{rel} of Al_2O_3 composite ceramics. The adjusted R^2 is 0.994, which indicates that the linear regression model has a high degree of fit. The p-value of T_2 (0.0016288) and t (0.0029354) is less than 0.05, and the p-value of interaction between both T_2 and t (0.6149418) is more than 0.05, which indicates that D_{rel} is only affected by individual T_2 and t. Moreover, T_2 (η^2 = 0.9861565) has a stronger impact on D_{rel} than t (η^2 = 0.9639632). Figure 6a shows the interaction between T_2 and t for D_{rel}. Figure 6a indicates that there is no interaction between T_2 and t because the three kinds of sintering temperatures at holding for 2, 4, and 6 hours are approximately parallel in the t vs. D_{rel} curve.

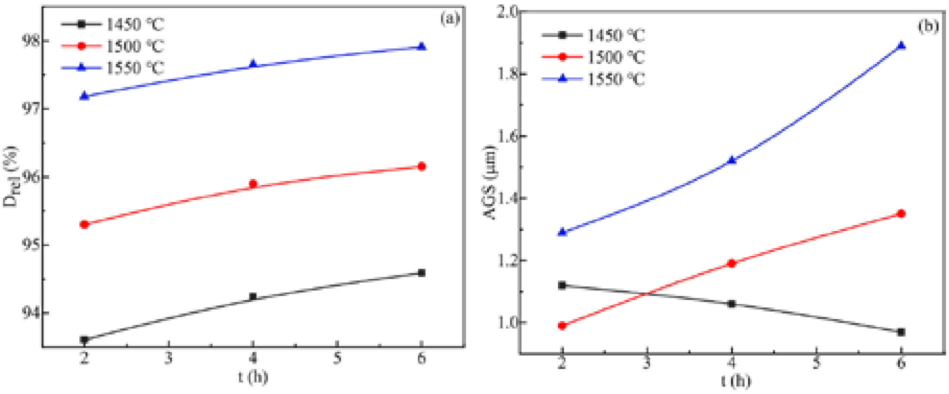

Figure 6: The interaction of T_2 by t. (a) Effect of T_2 by t on D_{rel}. (b) Effect of T_2 by t on AGS.

Variable	Factor	η^2	*p*-Value	The Adjusted R^2
D_{rel}	T_2	0.9861565	0.0016288	0.994
	t	0.9639632	0.0029354	
	T_2 by t_2	0.2768595	0.6149418	

Table 3: The effects of T_2 and t on D_{rel}.

Variable	Factor	η^2	*p*-Value	The Adjusted R^2
AGS	T_2	0.8967313	0.0331859	0.986
	t	0.9674137	0.0025214	
	T_2 by t	0.9755070	0.0038332	

Table 4: The effects of T_2 and t on AGS.

Variable	Factor	η^2	*p*-Value	The Adjusted R^2
Hardness	T_2	0.8813812	0.0408536	0.978
	t	0.8513854	0.0254951	
	T_2 by t	0.7652519	0.1137373	

Table 5: The effects of T_2 and t on hardness.

Variable	Factor	η^2	*p*-Value	The Corrected R^2
Fracture toughness	T_2	0.9608961	0.0077327	0.995
	t	0.9060330	0.0125882	
	T_2 by t	0.8801710	0.0414804	

Table 6: The effects of T_2 and t on fracture toughness.

Table 4 shows the effects of T_2, t, and their interaction on the AGS of Al_2O_3 composite ceramics. The adjusted R2 = 0.986 indicates that the static models are valid. The η^2 of T_2, t, and their interaction gradually rose 0.8967313, 0.9674137, and 0.9755070, and their *p*-values were less than 0.5. The results show that the above factors had a significant impact on the AGS. However, the interaction of both T_2 and t is stronger, followed by T_2 and t. Figure 6b shows the interaction between the T_2 and t for AGS. Figure 6b indicates there is an interaction between the T_2 and t because an intersection of the lines is observed.

3.2.2 Effects of T_2 and t on Mechanical Properties

The T_2 and t can be applied to the densification and refinement of Al_2O_3 composite ceramics to promote the mechanical properties. The statistical analysis of its effect on mechanical properties is shown in Table 5, Table 6, Table 7, and Table 8. The adjusted R^2 are 0.978, 0.995, and 0.995 (0.918), respectively, which indicates that the statistic models are suitable.

Table 5 presents the impact of T_2, t, and their interaction. Both T_2 (*p*-value = 0.0408536) and t (*p*-value = 0.0254951) significantly affect hardness. However, their interaction is not significant (p-value > 0.05). Moreover, T_2 has a stronger impact on hardness than t (0.8813812 against 0.8513854). Figure 7a shows the interaction between the T_2 and t for hardness. Figure 7a confirms there is no impact on interaction between T_2 and t on hardness because the lines are approximately parallel, as shown in Table 5. In addition, the curve slope is approximately zero at T_2 = 1,450°C, which is caused by lower temperature.

Table 6 presents the impact of T_2 and t on fracture toughness. It is

Variable	Factor	η^2	*p*-Value	The Corrected R^2
Bending strength	T_2	0.8996170	0.0318046	0.918
	t	0.2580958	0.02580958	
	T_2 by t	0.1742553	0.01742553	

Table 7: The effects of T_2 and t on bending strength.

Variable	Factor	η^2	*p*-Value	The Corrected R^2
Bending strength	T_2	0.9829973	0.0170027	0.995
	t	0.9715431	0.0143312	
	T_2 by t	0.9105670	0.0894330	

Table 8: The effects of T_2 and t on bending strength (Excluding T_2 = 1550 °C, t = 6 h).

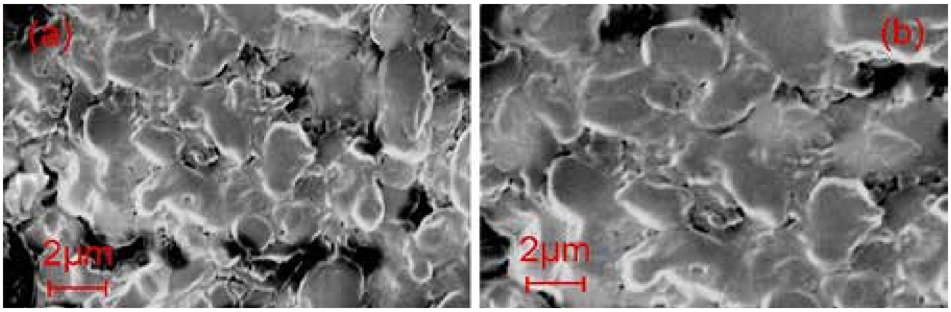

Figure 8: The microstructure of Al_2O_3 composite ceramic acted by (a) TSS_8 and (b) TS.

observed that T_2, t, and their interaction individually affect the fracture toughness and p-values of 0.0077327, 0.0125882, and 0.0414804, respectively. However, the T_2 has a more significant effect (2 = 0.9608961), followed by t and their interaction. Figure 7b shows the interaction between T_2 and t for fracture toughness.

Table 7 presents the p-value of T_2, which is less than 0.05. It is observed that T_2 individually affects bending strength, which obviously contradicts the previous research results (Figure 5). Table 8 shows the impact of T_2 and t on bending strength (excluding the data of 1,550°C for 6 hours). It is observed that T_2 and t individually affect the bending strength and p-values of 0.0170027 and 0.0143312, respectively. Moreover, Figure 7c shows the curves at T_2 = 1,550°C and t ≤ 4 h are almost parallel to each other, and then there is a cross trend at T_2 = 1,550°C, t = 6 hours. Therefore, T_2 = 1,550°C and t = 6 hours are unsuitable for sintering composite ceramics, which is consistent with the results shown in Figure 4 and Figure 5.

3.2.3 Microstructure of Sintered Ceramics

The performance of Al_2O_3 composite ceramics depends on the microstructure. This work verifies the advantages of TSS from the micro-level by comparing the microstructure of Al_2O_3 composite ceramics acted by TS and the TSS_8, as shown in Figure 8.

Figure 8a and 8b show the microstructure of Al_2O_3 composite ceramics obtained via TSS_8 at T_2 = 1,550°C, t = 4 hours, and TS at 1,650°C, t = 4 hours, respectively. It is found that the ceramic grains obtained via TSS_8 are obviously smaller than those obtained via TS. However, there are small gaps between the grains, which results in lower compactness of ceramics obtained by TSS_8. The microstructure shown in Figure 8 is consistent with the results of D_{rel} and AGS shown in Figure 4. The above results show the Al_2O_3 composite ceramics obtained via TSS_8 are significantly better than TS; although its compactness is slightly low, the fine-grained ceramics obtained at low cost can bring good comprehensive properties, especially the bending strength and fracture toughness that determine the engineering properties of ceramics.

4 CONCLUSIONS

In this work, an Al_2O_3 composite ceramic was prepared using the MEX-PPM combined process, and the final ceramic samples were obtained via TS and TSS. The effects of sintering processes on Al_2O_3 composite ceramics were studied using experiments, and the following was concluded:

1. Compared to TS, TSS effectively refined grain size and improved its comprehensive properties. TSS_8 can ensure the densification of ceramic before the rapid grain growth; its highest sintering temperature and shortest holding time were T_2 = 1,550°C and t = 4 hours, respectively. Under this condition, the D_{rel} and AGS of the ceramics were 97.65% and 1.52 μm. Their hardness, bending strength, and fracture toughness were 16.95 GPa, 572.59 Mpa, and 6.09 MPa·m0.5;

2. Both T_2 and t and their interactions individually affect the AGS, fracture toughness, and bending strength significantly, although T_2 has more impact. However, both T_2 and t affect the D_{rel} and hardness more significantly.

In addition, the microstructure of ceramics obtained via the TSS_8 and TS was compared, and the advantages of TSS_8 from the microscopic point of view were verified. Commercial Al_2O_3 ceramics with good fracture toughness and flexural strength via TSS will have unique advantages in engineering applications.

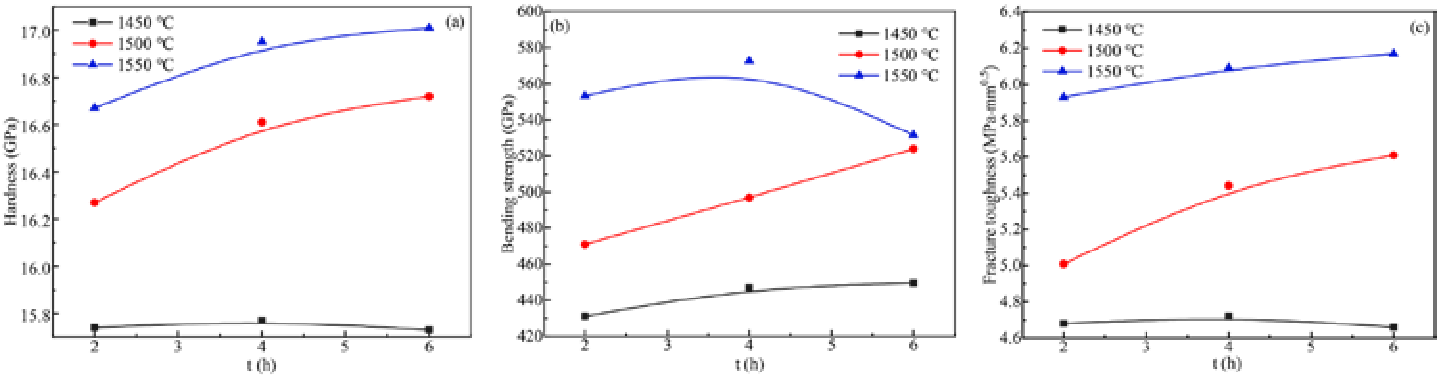

Figure 7: Interaction between T_2 and t (T_2 by t). (a) Effect of T_2 by t on hardness. (b) Effect of T_2 by t on fracture toughness. (c) Effect of T_2 by t on bending strength.

AUTHOR CONTRIBUTIONS

Conceptualization, X.H. and J.X.; methodology, X.H. and L.H.; formal analysis, X.H., J.X., W.J. and L.H.; writing — original draft preparation, X.H.; writing — review and editing, X.H., W.J. and J.X.; supervision, J.X., L.H. and X.H. All authors have read and agreed to the published version of the manuscript.

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DATA AVAILABILITY STATEMENT

Data are available upon request from the corresponding author.

CONFLICTS OF INTEREST

The authors declare that they have no competing interest.

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POWDERMET2024

TAKING IN THE STEEL CITY

PowderMet2024 will offer a variety of networking opportunities along with carefully planned technical programs that will allow attendees to explore the exhibit hall, catch up on the latest R&D, and celebrate industry achievements. (Courtesy: MPIF)

Q&A with James P. Adams of Metal Powder Industries Federation and APMI International I Page 48

PowderMet2024, home to the largest annual exhibit in the Americas featuring the leading suppliers of powder metallurgy, particulate materials, metal injection molding, and metal additive manufacturing processing equipment, powders, and products, will showcase a massive display of PM innovations and technology sessions.

By THERMAL PROCESSING STAFF

Powder metallurgy can be an important part of the thermal-processing world, so it's important that companies who offer this process, as well as companies who need it, can come together in one place to share and discover the latest innovations the powder metallurgy world has to offer.

For years now, the Metal Powders Industries Federation (MPIF) has sponsored PowderMet, the leading technical conference on powder metallurgy and particulate materials in the America.

PowderMet2024 is a hub for technology transfer for professionals from every part of the industry, including buyers and specifiers of metal powders, tooling and compacting presses, sintering furnaces, furnace belts, powder handling and blending equipment, quality-control and automation equipment, particle-size and powder-characterization equipment, consulting and research services, and much more.

This year's trade show is in Pittsburgh, Pennsylvania — the Steel City — at the David L. Lawrence Convention Center, June 16-19.

PowderMet2024 is home to the largest annual exhibit in the Americas showcasing the leading suppliers of powder metallurgy, particulate materials, metal injection molding, and metal additive manufacturing processing equipment, powders, and products. This massive display of PM innovations is a must-see opportunity to review the latest technology.

In addition to PowderMet, the event will be co-located with AMPM2024, additive manufacturing with powder metallurgy.

Along with multiple exhibits, attendees will also have access to more than 200 technical presentations from experts from all over the world on the latest research and development.

The conference will open with welcome remarks from MPIF Executive Director/CEO James P. Adams. MPIF President Mike Stucky will share the State of the Industry report as well.

PowderMet2024 will offer a variety of networking opportunities along with carefully planned technical programs that will allow attendees to explore the exhibit hall, catch up on the latest R&D, and celebrate industry achievements.

Some of the technical programs that may be of interest to industrial heat treaters include (check the PowderMet2024 app for times):

EFFECT OF CHEMISTRY AND PROCESSING ON SINTER-HARDENING PERFORMANCE OF NON-STANDARDIZED ALLOY COMPOSITIONS

MPIF Standard 35 Grade FL-4800 base iron is an adaptable sinter-hardenable base iron, which can provide a fully martensitic structure on large cross section parts. This base material is used in a number of pre-alloyed and sinter-hardenable grades, but does not report a higher graphite composition without the addition of copper. This work will explore using this base iron in a number of compositions outside of the typical standard. Mechanical properties on test bars and parts are explored.

MECHANICAL AND DYNAMIC PROPERTIES OF SUSTAINABLE POWDER METALLURGY ALLOY FL-5008

Sustainability is a growing trend within society and the automotive industry. Powder metallurgy (PM) is already recognized as a green technology that can address the sustainability requirements of current and future applications. A recently introduced lean chromium alloy was shown to provide similar mechanical performance to copper steel materials. This alloy also has a sustainability advantage over copper steels. For many applications, fatigue strength is a limiting factor and reliable fatigue data and models are important in selecting the best material system. In this paper, the mechanical properties of the recently standardized material FL-5008 will be presented. Additionally, fatigue data for the FL-5008 will be compared to copper steels and a fracture mechanics model will be presented to reliably predict the effect of density and stress concentrations on fatigue life.

A MELT-LESS METHOD FOR MAKING SPHERICAL TI ALLOY POWDER

Additive manufacturing (AM) is considered an energy-efficient alternative to conventional subtractive manufacturing of metals. However, the high embodied energy of the feed materials undermines the merits of energy saving in AM. Spherical Ti-6Al-4V alloy powder, widely used in AM, is commercially produced by atomizing Ti alloys made from the Kroll process. This production route incurs high energy consumption due to the low yield, the energy-intensive processes of melting and atomizing the metal into fine particles, and the production of the primary titanium metal. This paper presents a melt-less pathway, called the GSD method, for fabricating spherical Ti-6Al-4V alloy powder from low-cost feedstocks including alloy scrap or oxides. The chemical and physical properties of the fabricated powders are evaluated for AM applications. Energy consumption analysis suggests the process has the potential to significantly reduce the energy consumption of producing titanium alloy feedstock and improve the environmental impact of AM.

C18000 FOR SINTER-BASED ADDITIVE MANUFACTURING

Pure copper has been receiving increased attention and development efforts within the AM community due to its high electrical and thermal conductivity. As the industry evolves, we will need to expand beyond pure copper to meet other application needs. C18000 is a precipitation hardened copper alloy that maintains a reasonable amount of electrical conductivity, but achieves much higher strengths and hardness than pure copper. Here we review results of C18000 printed on a sinter-based AM technology that achieves high density, strength, and conductivity.

VACUUM SINTERING OF HIGH-PERFORMANCE PRE-ALLOYED STEEL

Vacuum sintering is a proven sintering method to improve mechanical properties while eliminating oxidation potential and atmosphere contamination in PM components. Recent progress in vacuum sintering technologies have made this sintering method an attractive manufacturing process for PM materials aiming for property improvement and for the versatility and flexibility to control process parameters. Vacuum sintering furnaces are available in both batch and continuous configurations, with most furnaces using the batch configuration. However, interest in continuous vacuum furnaces continues to grow due to increased production requirements and the advantages over batch vacuum furnaces for processing of larger production quantities. Currently, systematic studies are lacking to compare the vacuum sintering processes with conventional sinter methods for PM steels. In this paper, the sintering responses of a chromium-based, sinter hardenable, pre-alloyed steel were examined in a vacuum.

SMART SOLUTIONS TO IMPROVE SINTERING ATMOSPHERE AND PROCESS

The powder metallurgy industry is increasingly adopting Industry 4.0 technologies and solutions to improve production processes and product quality. Proper specification, measurement, and control of furnace atmospheres are always critical to achieving the desired metallurgical and mechanical properties. The combination of atmosphere measurements and other furnace operating parameters (e.g., furnace temperature and pressure) can provide a better view of the whole production. Thermodynamic calculations and field experiences can be integrated into the smart solution to provide process engineers more capabilities to manage and optimize production. In this article, our recent research and development work on smart solutions for the powder metallurgy industry will be presented and discussed.

PROCESSING OF HIGH ENTROPY AL1.8-CR-CU-FE-NI2 VIA POWDER METALLURGY

High-entropy alloys (HEAs) are presently of great research interest in materials science and engineering. HEAs typically contain at least five elements with equimolar or near equimolar, normally 5 to 35 percent concentrations. HEAs differ from traditional alloys because of high-entropy effects, lattice distortion effects, kinetic delayed diffusion effects, and “cocktail” effects. HEAs have the potential to be used in many applications such as high temperature materials, cryogenic materials, etc. The method traditionally used on industrial scales for preparing HEAs is the vacuum melting method. However, the development of HEAs has been hindered by microstructure defects caused by vacuum melting such as shrinkage cavity, shrinkage porosity, and segregation. This is the motivation for this study to investigate the prospect of using powder metallurgy for preparing HEAs. The results on the influence of the process parameters, e.g., sintering time, temperature, and atmosphere on the microstructure and mechanical properties of the final product will be presented.

ADDITIVE MANUFACTURING ENABLED TRANSITION JOINTS BETWEEN AUSTENITIC AND FERRITIC STEELS

The difference in coefficient of thermal expansion (CTE) prevents joining of austenitic and ferritic alloys used in power plants. Further, the difference in carbon chemical potential results in premature service failure of these joints. We use blown powder additive manufacturing combined with thermo-kinetic calculations to design a transition joint between stainless steel 347H and grade 91 steel to reduce the CTE mismatch and obtain a shallower carbon chemical potential gradient. Our characterization showed that, while the composition change was gradual, the phase change was abrupt, possibly because of the dilution during additive manufacturing. Despite the abrupt phase change, we did not observe cracking at the interphase boundaries, but the dual phase austenitic-ferritic region served as a the failure point during tensile testing. We also subjected the samples to long-term aging to determine the phase stability upon elevated temperature exposure.

INFLUENCE OF PARTICLE SIZE VARIATIONS AND NANOPARTICLE COATING ON FLOW BEHAVIOR OF 316L STAINLESS STEEL POWDER AND MECHANICAL PROPERTIES IN POWDER-BASED ADDITIVE MANUFACTURING

In powder-bed-based additive manufacturing (AM) processes, the flowability of the powder is decisive for the quality of the manufactured part. Since fine particle fractions worsen the flowability, in the laser powder bed fusion (LPBF) process, the lower limit of the powder fraction is usually 15 µm. Nanoparticle coatings can reduce the cohesive forces between particles. It has been investigated how the fumed silica (SiO2) nanoparticle coating affects the initial flow behavior of standard gas-atomized (15-45 µm) 316L powder and powders with modified particle size distribution (0-45 µm, 15-63 µm, 0-63 µm). It was demonstrated that flowability and bulk density increased as a result of the coating. Relative density and mechanical properties of the LPBF specimen showed similar results compared to the uncoated powder with increased tensile strength. The economic potential of coated powder for AM was demonstrated by the successful LPBF processing of fractions 15-45 µm and 0-63 µm.

MATERIALS EXTRUSION ADDITIVE MANUFACTURING (MEX-AM) OF COPPER INFILL STRUCTURES FOR ACCELERATED PART PRODUCTION

Material extrusion (MX) additive manufacturing (AM) combines fused filament fabrication (FFF) and sintering processes to create intricate metallic or ceramic structures using powder-filled polymer filaments. While MX-AM offers design freedom, it faces challenges such as differential debinding in complex parts, leading to cracking and failure. This study explores design and process strategies to mitigate these issues. Copper-filled filaments with 61 vol.% solids were used to 3D print lattice-based infill structures. Samples underwent direct sintering or debinding followed by sintering and were characterized for physical and mechanical properties. Results shed light on density, shrinkage, and mechanical properties for different infill densities (25 percent, 50 percent, 75 percent) using both sintering methods. Findings provide valuable insights for future research and industry, offering innovative strategies for 3D printing complex parts while addressing associated defects and challenges.

UNDERSTANDING CARBON FOOTPRINT AND COSTS OF ATMOSPHERE AND VACUUM THERMAL PROCESSING

With a growing awareness of the environmental impact of thermal processing, environmental considerations are becoming more critical in operations and facilities planning. While financial planning information is often readily available, it can be difficult for heat treaters to compare equipment from a standpoint of environmental impact. This is due in part to the complex and nuanced differences in equipment design and operation with emissions occurring both on and off-site. In this presentation, a case study comparing a gas-fired atmosphere IQ and an electric batch vacuum furnace will be shared. We will review the technical specifications for each piece of equipment and compare utility and energy consumption, operating cost, and CO_2 emissions. We will also highlight the impact of several design variables to consider when specifying and operating equipment. Although the case study is specific, many of the takeaways are generally applicable and can provide insights into how different approaches to heat treat processing can impact operations and the environment.

REDUCE FRICTION WITH A SECONDARY MECHANICAL/CHEMICAL SURFACE TREATMENT PROCESS

In this presentation, we will review a new mechano/chemical surface treatment process that greatly improves the frictional characteristics of intermeshing metallic surfaces. This novel process combines controlled contact between the surface-to-be-treated and carrier materials with the addition of bespoke formulations of chemistry to achieve an improved operational interface, both mechanically and tribologically. The chemistries are specially formulated to chemically react and diffuse into the part surface creating an anti-friction/anti-wear nano layer while simultaneously improving surface topography. This results in surfaces with improved frictional coefficients and greater operational efficiencies that result from a reduction in heat and improved wear life.

HOT ISOSTATIC PRESSING OPTIMIZATION OF ADDITIVE AND MICRO-ADDITIVE MANUFACTURED 316L STAINLESS STEEL VIA METAL BINDER JETTING AND METAL MATERIAL JETTING

Hot isostatic pressing (HIP) is a post-process heat treatment used primarily to improve density, often required for metal additive manufacturing (AM) components in engineering industries, such as aerospace, automotive, and medical. Since its invention in the 1950s, newer HIP equipment has incorporated rapid cooling or quenching, allowing for better microstructural control. To date, a large deal of literature exists for HIP of laser-based AM, but few for sinter-based AM (SBAM). SBAM continues to grow in popularity due to its capability for large scale production and more accessible range of printable material systems. With this in mind, there exists a need to better understand the effects of HIP on their microstructures and mechanical properties. A matrix consisting of altering temperatures (1,000, 1,150, and 1,250°C) and pressures (100, 140, and 207 MPa) was designed for HIP of 316L stainless steel components with the incorporation of rapid cooling. Components were printed via metal binder jetting and metal material jetting for a comparative study between existing AM and micro-AM (metal material jetting — i.e., nanoparticle jetting) processes in their as-sintered and HIP'd conditions. Scanning electron and scanning transmission electron microscopy were implemented to characterize and quantify the resulting microstructures following each processing condition, including existing phases, defects or inclusions, and their morphologies. Bulk density was measured to determine the effectiveness of HIP parameters, while tensile properties and microhardness were measured to determine their mechanical performance.

ADVANCED HIP SOLUTIONS — EXPANDING POSSIBILITIES FOR AM APPLICATIONS

The AM community has accepted hot isostatic pressing (HIP) as a key quality assurance tool, much in the way the casting industry did decades ago. HIP's ability to eliminate internal porosity is essential for critical applications given the phenomenon of shrinkage as alloys solidify and the fact resultant pores degrade mechanical, corrosion, and sealing properties. There is a practical balance to be found in both the foundry and AM industries where adding HIP as a secondary operation allows for more cost and time savings vs. trying to design and test for net-zero shrinkage. Advances in the science of HIP are uncovering new options to lower costs and optimize processing parameters for AM. However, the use of HIP has expanded well beyond porosity elimination into the areas of powder metallurgy (PM) near-net shape (NNS) design and production of massive components, diffusion bonding for high-temperature applications, and HIP cladding of premium materials (typically corrosion and/or wear resistant) onto selective areas of need only. All highlight HIP's ability to bond powder-to-powder, powder-to-solid, and solid-to-solid dissimilar materials. As the design of engineered materials continually advances and the demand for higher sustained operating temperatures increases in aero and orbital space flight and nuclear energy, HIP offers another vital tool to achieve these goals.

DEVELOP LOW BINDER TUNGSTEN CARBIDE GRADES USING BINDER JETTING

Cemented tungsten carbides are the most widely used materials in the metal-cutting industry and wear-resistant applications because of the high hardness and wear resistance. Carbides made by beam-based additive manufacturing have low quality due to large pores, inhomogeneous microstructures, and cracks. Binder jetting can produce carbides with microstructure and properties similar to those made by traditional powder metallurgy processes. Previous work has demonstrated the success of printing cemented carbides with high metallic binders. However, it is more challenging to print carbides that are comparable to conventional materials when the metallic binders are below 15 wt.%. This work focuses on the development of cemented tungsten carbides with 10-17 wt.% of metallic binders using binder jetting. The relationship between powder, printing, and sintering to produce commercial quality carbides will be discussed. In addition, applications enabled by using DFAM principles will be presented.

MECHANICAL BEHAVIOR OF REACTIVE LASER POWDER BED FUSED OF BORATED ALUMINUM ALLOY 6061

This study focuses on determining the impact of finely-dispersed boron on the structural mechanical behavior of additively manufactured aluminum alloy 6061 (AA-6061). Reactive additive manufacturing (RAM) through laser powder bed fusion (L-PBF) is employed to overcome the hot cracking challenges associated with AM of AA-6061 by introducing ceramic elements for enhanced manufacturability and grain refinement. Small cubes were made via RAM/L-PBF followed by their electrical discharge machining (EDM) to harvest both vertically- and diagonally-oriented miniature (approx. 20 mm total length) tensile specimens from them. These specimens, together with wrought AA-6061, were tested for tensile strength using a micro-tensile testing system. Results from testing miniature tensile specimens and ASTM standardized tensile specimens of the wrought AA-6061 are presented to help support ongoing certification efforts of this material in the nuclear industry. The tensile behavior between the RAM/L-PBF and wrought AA-6061 are presented and their implications discussed. The RAM powder technology will also be a focus of the presentation.

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Q&A /// INTERVIEW WITH AN INDUSTRY INSIDER

JAMES P. ADAMS /// EXECUTIVE DIRECTOR/CEO
/// METAL POWDER INDUSTRIES FEDERATION AND APMI INTERNATIONAL

> ***"PowderMet and AMPM will bridge together the industries as we come together under one roof to advance the industry."***

PowderMet2024, in Pittsburgh, Pennsylvania, June 16–19, will be a hub of technology transfer for professionals from every part of the powder metallurgy and metal additive manufacturing industry. James P. Adams, executive director and CEO of Metal Powder Industries Federation and APMI International, recently discussed with Thermal Processing what attendees can expect from this popular conference.

What about the Pittsburgh venue made it ideal for the 2024 show?

It has been 30 years since we last held our conference in the "Steel City." Pittsburgh is within driving distance to the majority of powder metallurgy (PM) and metal additive manufacturing (AM) component manufacturers, material suppliers, equipment manufacturers, and service providers, allowing even more professionals access to this premier event. The region is also a hub for carbide manufacturing. As the hundreds of bridges connect the city, PowderMet and AMPM will bridge together the industries as we come together under one roof to advance the industry.

How will this year's show differ from what attendees experienced in Las Vegas last year?

For this year's conference, we took the PowderMet and AMPM conferences, put everything into a big box, shook it up, and made some great changes to this year's program.

The Design Experience general session has been opened to all conference delegates, providing more visibility to these award-winning parts. The objectives of the conferences are to explore materials advances, assist in the transfer of technology, and investigate new developments to continue growth. For the first time, daily tutorials focused on press and sinter, metal injection molding (MIM), and metal additive manufacturing will be offered to encourage cross training and introduction of these exciting technologies. A Carbide Forum is offered for delegates to explore and learn more about these niche materials.

We have implemented more ways to allow for networking and collaboration among delegates through all areas of the conference, including our usual opening night reception, the PM Evening Alehouse, and the Consolidation Celebration: "Take me out to the ballgame." For more details on the program, schedule, and sessions, visit our website below.

If I were a first-time attendee, what should I expect from this year's show?

As a first-time attendee, you should expect to be surrounded by like-minded individuals who share the common goal of continuing to advance the PM and AM industries through education, networking, and collaboration.

What subjects should I expect presenters to address?

The technical program was developed and organized by industry experts. Professionals in both PM and AM joined forces to collaborate and compile the individual sessions. With 200 presentations by industry experts from around the world, topics will cover all aspects of the technology. Additionally, conference proceedings will capture the technology transfer for future reference.

Programming is aligned to provide an excellent experience for first timers and seasoned attendees alike. Numerous networking opportunities are intentionally designed for interaction with other attendees, speakers, and exhibitors. For 2024, we have over 40 future engineers with us courtesy of student conference grants from the National Science Foundation (NSF), and Center for Powder Metallurgy Technology (CPMT).

What kind of networking opportunities will be available for attendees?

PowderMet provides networking at every corner. From the time you arrive, you will meet with old friends and make new acquaintances at the opening reception. Once the conference kicks off, there are a plethora of opportunities to network and make those meaningful connections. From the exhibit hall to the luncheons, to the Consolidation Celebration and everything in between, the contacts you make will become lifelong friends.

What about the conference will make it feel unique to the Pittsburgh location?

Pittsburgh is such an amazing city, and we are excited to bring our delegates back. We will be submerged in the culture of Pittsburgh throughout the conference. You will get a taste of Pittsburgh through our food and beverage events. We will get a true Pittsburgh experience during our Consolidation Celebration as we head to PNC Park for a major league baseball game, where the group will cheer on the Pittsburgh Pirates as they take on the Cincinnati Reds.

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

As always, I look forward to meeting face-to-face with the industry and having the group together under one roof. The energy that you can get from meeting with your colleagues and peers in the same room is unmatched. I'm also very excited about some new elements that we will be introducing into the conference this year that will continue to build and harvest those networking opportunities and engagement among delegates.

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