Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

SINTERING / POWDERMET PREVIEW

MICROSTRUCTURE AND TENSILE PROPERTIES OF AL PM PREPARED BY NOVEL LOW-PRESSURE SINTERING

COMPANY PROFILE ///

Ohio Carbon Blank Inc.

JUNE 2022
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Sample Preparation Solutions for Powder Metallurgy

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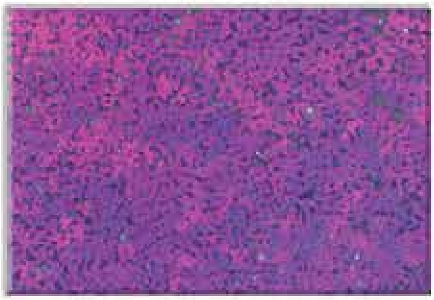
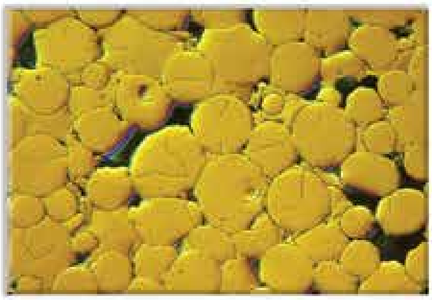

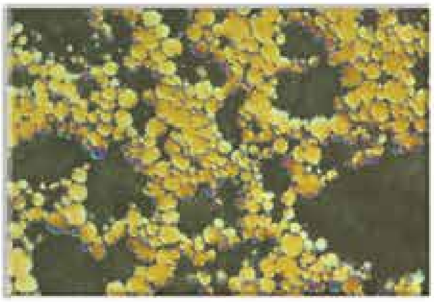



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FROM THE EDITOR ///

This month, sintering gets the spotlight

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 2022 — the International Conference on Powder Metallurgy & Particulate Materials — in Portland, Oregon.

PowderMet 2022 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.

With last year's PowderMet produced as a virtual event, it's great that the 2022 show will boast in-person interaction for business deals, information exchange, and panel discussions on the latest innovations in the industry.

And speaking of the heat-treat industry, if you're experiencing some summer heat right now, we have a few articles in this month's issue that might keep your mind off it — at least for a while.

On the topic of sintering (as well as powder metallurgy), our cover article looks at the microstructure and tensile properties of aluminum powder metallurgy prepared by novel low-pressure sintering.

In addition to our main articles, make sure you check out our columnists. They're always offering up must-know expertise on a variety of important heat-treating subjects.

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!

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Tenova received two contracts from TenarisDalmine for the steelmaker's new investment in special steel production. (Courtesy: Tenova)

Tenova receives two contracts for steel production

Tenova, a leading developer and provider of sustainable solutions for the green transition of the metals industry, was awarded two contracts by Tenaris, global manufacturer and supplier of steel pipes and related services, for its mill in Dalmine (Italy). Both contracts are related to the steelmaker's new investment in special steel production. The two companies belong to the Techint Group.

The Dalmine project is divided into three phases, two of which will be supplied by Tenova. The first phase consists of a state-of-the-art melt shop ladle furnace. The ladle furnace will be used for secondary metallurgical treatment of the liquid steel.

The second project phase will consist of a Tenova-designed and supplied heat treatment furnace for special steel bars. This movable hood-type furnace is specifically designed to charge very large bars with a length of 12 meters and is equipped with 34 hydrogen-ready self-recuperative burners. These environmentally friendly burners will be capable of using up to 100 percent hydrogen as a fuel source.

Tenova self-recuperative burners provide energy savings compared to traditional preheated air burners, playing a significant role in reducing CO2 emission levels in steelmaking plants. In addition to fuel savings, Tenova burner flameless technology produces the lowest NOx emission level.

Optimal thermal uniformity, extended combustion stability, advanced control technology, low maintenance costs, and continuous product evolution are Tenova regenerative burners' main and distinguished features. Flexibility in fuel combustion is also another important advantage, as they are already designed and manufactured to be hydrogen-ready.

"The installation of a new furnace 100 percent H2 ready is part of Tenaris' commitment to reducing the environmental impact of its activity, embracing innovation and technological change," said Giuseppe Pandini, Tenaris senior project manager. "Besides selecting the best energy saving technology for the burners, we took the opportunity of this project to make a step forward. Working with Tenova's engineering and R&D, we designed a plant ready to start the substitution of natural gas with hydrogen as fuel for our industrial furnaces."

"We are particularly proud to be part of this new investment by TenarisDalmine, that confirms Tenova's continuous innovation for higher efficiency and sustainable solutions," said Marcello Tomolillo, customer service manager at Tenova Italimpianti.

With this investment, Dalmine will produce high-grade special steel resistant to corrosion in carbon dioxide and hydrogen sulphide environments. The special steel product will also be used for renewable energy technologies such as geothermal wells.

MORE INFO www.tenova.com

L&L receives orders for two furnaces, closes out good Q1

L&L Special Furnace Company recently received orders for a floor-standing box furnace for heat-treating saw blades along with a large floor-standing, fiber-lined furnace that will be used to stress-relieve and temper large steel castings.

The L&L XLE3648 has an effective work zone of 34" wide by 34" high by 44" deep. It includes an electric vertical door, an alloy hearth, and a complete control system. The furnace's primary function is to heat treat various tool steels that are used for saw blades, including high-speed tool steels.

The L&L FB336 has an effective work zone of 36" wide by 36" high by 72" deep. The fiber-lined furnace will be used to temper and stress-relieve steel castings. It includes

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.

L&L Furnace's Model FB4410 fiber lined box furnace. (L&L Special Furnace Company)

a pneumatic vertical door, 24-inch-high convection alloy fan, a complete control system, castable piers, and a cast-alloy load platform for forklift loading.

Considering current events and the global economy in general, L&L has had a steady stream of business inquiries, with a higher than average quote-to-order ratio, which means that buyers are eager to buy and the key is for equipment manufacturers to be able to meet customer needs.

L&L notes bustling demand in general heat-treating along with an increasing pulse coming back into the aerospace industry. Additive manufacturing and CMC production continues to demonstrate consistent growth and make significant advancements in technology.

The company certainly has seen its share of delays due to suppliers postponing deliveries, in some cases. L&L plans to keep its model GS1714, GS2026, and dual-chamber heat-treating and quench tanks in stock for quick delivery. It is beginning to see a bit of understanding as well, indicating that customers are more aware of unavoidable equipment delays due to existing supply chain issues.

In uncertain times, this type of business is encouraging but not without its hurdles, such as inflation, alloy pricing, and various supply chain issues that are a constant problem, according to the company. Being able to source and substitute on the fly is key, along with paying particular attention to scheduling. L&L sends out biweekly updates to its customers so they can track their equipment progress from production through to completion.

The company's strong presence in the heat-treating field, aerospace industry, high tech ceramic space, and medical and automotive sectors allows it to provide products to many businesses in the thermal application market.

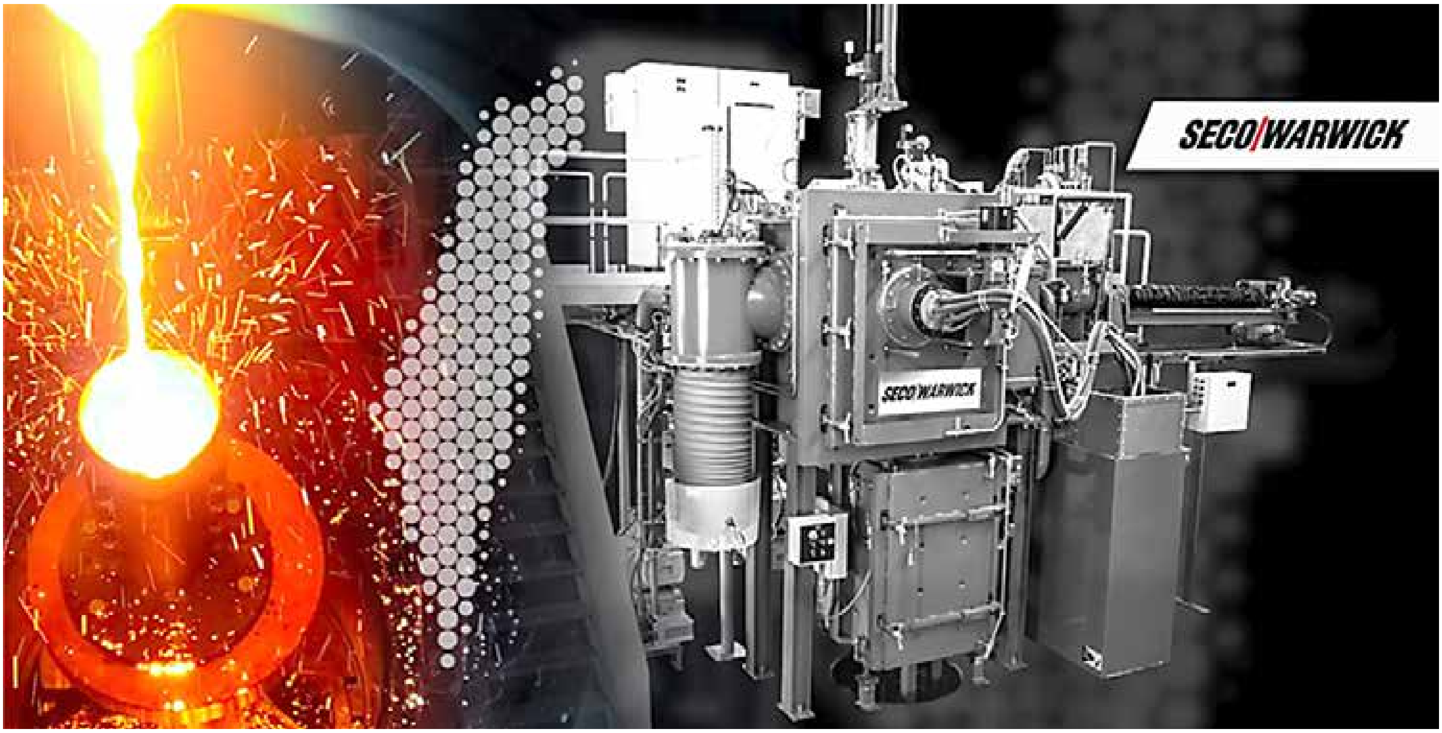
All L&L furnaces can be configured with various options and be specifically tailored to meet customers' thermal needs. The company also offers furnaces equipped with pyrometry packages to meet ASM2750F.

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

MORE INFO www.llfurnace.com

Vacuum furnace for titanium casting first for delivery to Israel

Rafael Advanced Defense Systems, an Israeli pioneer in defense and cybernetic solutions, has purchased a vacuum titanium casting furnace from Seco/Warwick for UPC Precision Castings. This is the first furnace of this type on the Israeli market.



The Seco/Warwick furnace purchased for the UPC Precision Castings foundry makes it possible to obtain both – superalloys and high-quality titanium castings. (Courtesy: Seco/Warwick)

The technology solution (Alloy VIM 40kg-400kW) is a single-chamber furnace, equipped with a hot (ceramic) and cold (copper, for CWI processes) crucible. In the first, ceramic crucible, melting processes of up to 40 kilograms of superalloys, mainly nickel-based, can be carried out. The copper crucible melts 10 kg of titanium at a time. The Alloy VIM furnace has a three-stage vacuum system, is equipped with mechanical, Roots, and diffusion pumps. The system allows the furnace to obtain a high vacuum in the range of 10^{-5} mbar. The device is also equipped with a mold heater. The entire project has been planned so that it can be equipped with additional accessories in the future. The device has stub pipes where additional furnace equipment, such as an alloy additive feeder, can be installed in the future. It is undoubtedly a very versatile and efficient device.

"This is the second vacuum metallurgy solution that we have delivered to Israel. However, this has been the first time a furnace for titanium castings has been supplied to this country. We are proud to be able to introduce innovative, pioneering solutions in this unique and highly growing market. Vacuum melting and casting processes are extremely technologically advanced. They require high precision of individual element execution and process design so that it proceeds in an optimal manner using the unique system advantages. Titanium alloy melting furnaces are mainly used by the aviation, defense, and energy industries," said Sławomir Woźniak, president of Seco/Warwick Group.

The furnace purchased for the UPC Precision Castings foundry makes it possible to obtain both — superalloys and high-quality titanium castings. It is an innovative solution that combines two processes in one device. As a result, it allows foundries to quickly respond to dynamically changing customers' needs. The Alloy VIM furnace allows the customer to adapt the production to current needs.

UPC Precision Castings did not previously use vacuum technology. The device purchased from Seco/Warwick will significantly expand the offer and foundry capabilities. UPC is a foundry that manufactures machine parts and components for the aviation and defense sectors. It is a leading partner with the world-famous Rafael Advanced Defense Systems concern. It manufactures the world's most popular air defense system — the Iron Dome. The company recently publicized the fact that, thanks to this advanced technology, in the period of 10 years of implementation, more than 2,500 rockets have been intercepted, protecting cities, preventing extensive property damage, and saving lives. The system is also used by the U.S. military.

"Seco/Warwick became not only our supplier but also a partner. Because not only did Seco/Warwick provide a vacuum furnace for melting titanium and superalloys, they implemented this new technology in our company. The cooperation is going very well. We feel a real partnership in our business relationship, working with a party with extensive knowledge and experience in the field of vacuum metallurgy.

The first vacuum furnace for titanium melting is already in Israel, and we are very proud that UPC Precision Castings is the forerunner in implementing such advanced technology in the Israeli market. We are significantly expanding our offer and we will certainly be able to attract many customers from various, previously unavailable sectors," said Oded Hammer, general manager of UPC Precision Castings.

MORE INFO www.secowarwick.com

AHT retains Nadcap merit status, adds AMS specifications

Advanced Heat Treat Corp. (AHT), a recognized leader in heat-treat services and metallurgical solutions, has renewed its Nadcap® accreditation in heat treating (ion and gas nitriding) and passed its aerospace quality system (AC7004) audit. The company has also added additional AMS specifications to its scope: AMS 2759/6 and AMS 2759/12.

AMS 2759/6 specifies the procedures and requirements for gas nitriding low-alloy steels such as Nitralloy 135M, Nitralloy EZ, Nitralloy N, 4140, 4340, and H11 steels.

AMS 2759/12 specifies the requirements for producing a continuous white layer by means of a gaseous process using automated controls to maintain the nitriding and carburizing potentials on carbon steels, low alloy steels, tool steels, and cast iron.

With these additions, AHT can now accommodate the following AMS specifications: 2757 (gas nitrocarburizing), 2759/6 (gas nitriding), 2759/8 (ion nitriding), 2759/10 (gas nitriding), and 2759/12 (gas nitrocarburizing).

"We have held Nadcap accreditation for ion nitriding since 2013, and with each audit/renewal we've had something new to celebrate," said Mikel Woods, president. "In 2020, we added gas nitriding; and now, we are excited to add AMS 2759/6 and AMS 2759/12 to our growing list of scopes and accreditations."

The Nadcap® Heat Treating accreditation (Merit Status) is held at AHT's MidPort Boulevard location in Waterloo, Iowa. The heat treater also has locations in Cullman, Alabama; Monroe, Michigan; and another on Burton Avenue in Waterloo, Iowa.

MORE INFO www.ahtcorp.com

Tenova to supply new electric arc furnace for Tosyali Algeria

Tenova was recently awarded a contract for the supply of a new electric arc furnace (EAF) at the Tosyali Bethioua plant in Algeria. This will be the second EAF that Tenova has supplied to this site and is a key component of the current expansion project of Tosyali.

The new EAF will be designed to be almost identical to the current EAF that has been consistently operating on a line steadily producing more than 2 million tons of billets per year. The first EAF supplied to the plant in 2016 achieved the highest productivity levels on record for a DRI- processing furnace.

The new equipment, powered by a 240MVA AC transformer, will process 2.5M per year of DRI pellets to produce hot rolled coil (HRC). Same as the existing EAF, this new furnace will be equipped with an innovative charging system that allows charging

The new Tenova equipment, powered by a 240MVA AC transformer, will process 2.5M per year of DRI pellets to produce hot rolled coil (HRC). (Courtesy: Tenova)

and melting of more than 12 tons of HDRI (hot-DRI) per minute, setting an absolute productivity record for DRI-processing furnaces.

The existing furnace has been fed with a wide range of reduced iron sources including HBI. In addition, the composition of the DRI produced and processed in the Bethioua site is adjusted by blending iron concentrates from different sources to achieve the most profitable balance between cost of raw materials and energy. The advanced EAF process control system compensates for the variations of the raw materials and optimizes the process to reach the optimal yield and consumption figures.

"In 2016, we decided to select Tenova for delivering us an exceptionally productive EAF, the first of his kind, and our choice was rewarded," said Dr. Suhat Korkmaz, Tosyali Holding CEO. "We now trust Tenova to satisfy our expectations again in our new project."

The EAFs designed and built by Tenova are the result of the experience gained on hundreds of reference EAF projects, out of which 28 were specifically engineered to use DRI as main feedstock. Tenova's long history as a supplier of technological equipment is bolstered by the expertise of Tenaris and Ternium, which are producers and direct users of DRI since the inception of the technology. Tenaris, Ternium, and Tenova are all part of the Techint Group.

"Our previous cooperation with Tosyali's team has played a fundamental role in building trust and cooperation with the user, a very demanding and experienced user that is quickly expanding their operation. This is in line with Tenova's commitment to being a reliable partner and always keeping innovation and continuous improvement of our design and technologies as top priorities," said Paolo Stagnoli, sales and marketing director at Tenova for electric arc furnaces.

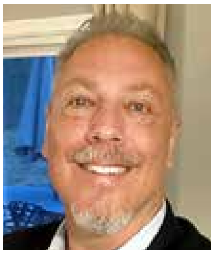
MORE INFO www.tenova.com

Thermcraft announces new general manager

Thermcraft, an international leading manufacturer of thermal processing equipment, has hired Andrew Belling as general manager.

Belling will be responsible for process improvement, positive growth, and continued development within the Thermcraft organization.

Prior to joining Thermcraft, Belling was general manager for Siemens Energy where he was responsible for manufacturing, engineering, quality, and facilities. He has held general manager and plant leadership positions for Morgan Technical Ceramics, Spectrum Control, AVX, and Bourns. Belling has a Bachelor of Science degree in ceramic engineering from Alfred University.



Andrew Belling

Located in Winston-Salem, North Carolina, Thermcraft Inc. is an international leading manufacturer of thermal processing equipment, including industrial and laboratory furnaces, industrial ovens, high temperature ceramic heating elements, high temperature ceramic insulation, temperature control systems, thermocouples, and thermal processing accessories. Founded in 1971, the company offers standard solutions as well as fully engineered customized solutions.

MORE INFO www.thermcraftinc.com

Global bearing manufacturer selects Seco/Warwick

The Seco/Warwick roller-type unit (furnace) is intended for spheroidizing annealing of bearing steel forgings for NSK. (Courtesy: Seco/Warwick)

Seco/Warwick delivered a roller-type unit (furnace) intended for spheroidizing rings for the bearing industry. The solution will be operated in the Kielce plant of the global bearing manufacturer NSK.

This is a second delivery of the same device. The first line featuring a Seco/Warwick roller-type unit has been operating in the factory for seven years. This type of equipment has technological roots in the United States. It was on that market that Seco/Warwick started its technological adventure.

The unit is intended for spheroidizing annealing of bearing steel forgings. The process line built around a roller-type furnace is intended for heat treatment of workpieces which, after the downstream processes, are assembled into bearings that are used e.g. in the automotive sector.

The entire automated process line delivered consists of a loading table with the drive, loading elevators with side handling, heating chambers and controlled cooling chambers, cooling tunnels, unloading elevators and tables, as well as the control cabinet featuring a complete automated visualization system that provides comprehensive control over the course of the production process. Such an equipment line fully guarantees total automation of the process, and perfect repeatability of the workpieces. The repeatability and the high quality are also important factors for the production of items as sensitive as bearings.

"We know that bearing production requires a huge amount of precision. The required metallographic structure can be achieved in the production process only with a strict and repeatable regime during the thermal process cycle," said Piotr Skarbiński, vice president in charge of this product segment, Seco/Warwick Group. "That is why our production line intended for this purpose is based on the full automation of processes. This enables the elimination of all errors resulting from the human factor.

"This is the second example of our cooperation with NSK. We are delivering exactly the same product as in 2015, showing us that we are a reliable partner for them. After seven years of operation of the first system, NSK again selected Seco/Warwick. We couldn't expect a greater compliment. We strive to be a partner that listens, solves problems, customizes the technology, and above all, meets the requirements of even the most demanding production processes," said Skarbiński.

NSK Ltd. was established in 1916, taking over the interests of Nippon Seiko Limited Partnership Company. For more than 100 years they have been manufacturing high-quality bearings used in virtually all industries. The Polish plants of NSK manufacture rolling bearings that require a lot of precision, thus the purchase of the unit for spheroidizing annealing of bearing steel forgings that will significantly increase the capacity of the Kielce plant.

"Seco/Warwick is a pioneer of modern technologies for metal heat treatment," said Grzegorz Banachowski, NSK. "The design of the line that we purchased enables achieving the highest strength and structural parameters of the workpieces and, most importantly, ensures production repeatability. We have selected Seco/Warwick again based on our previous positive experience and their quality that we learned ourselves. We have been operating the first device for seven years now and it still offers reliability and precision. This is why when it comes to metal heat treatment, Seco/Warwick is a good choice for us."

MORE INFO www.secowarwick.com

Ipsen USA's Q1 2022 vacuum furnace orders spanned several industries including automotive, additive manufacturing, aerospace, commercial heat treating, and tool and die. (Courtesy: Ipsen USA)

Ipsen USA finishes record-breaking first quarter

Following a record year for new equipment orders in 2021, Ipsen's Vacuum Technology Excellence Center continued that trend by booking 22 new vacuum furnace orders during the first quarter of 2022.

"We continue to see improved business levels in all target markets, driven by the need for additional production capacity along with customer requests for more unique thermal process capabilities," said Ipsen USA president and CEO Patrick McKenna.

Vacuum furnace orders spanned several industries including automotive, additive manufacturing, aerospace, commercial heat treating, and tool and die. Ipsen also saw a wide variety in furnace models, from large vertical bottom loading units for aerospace to small vacuum debind and sinter furnaces for additive manufacturing.

Other orders included those for Ipsen's technologically advanced AvaC® low-pressure carburizing capability, as well as high-pressure gas quenching used in conjunction with vacuum compression brazing.

Ipsen also rounded out the first quarter with record parts bookings and is on track for a record year in aftermarket services as well. In Q1 2022, Ipsen performed more than 250 field service visits related to installation and start-up, furnace relocation, hot zone replacement, preventive maintenance, calibrations, and leak checks.

"Our aftermarket business is strong and only getting stronger," said Ipsen chief service officer John Dykstra. "We continue to add resources to the team and complete strategic initiatives designed to improve response times and reduce downtime for our customers."

In addition to the growing demand for new equipment and aftermarket support, Ipsen continues to focus on expanding customer service offerings and increasing hiring efforts. In the first quarter, Ipsen USA hired 12 new employees.

MORE INFO www.ipsenusa.com

The recently ordered furnace has a temperature uniformity of ±10°F and is AMS2750 compliant with vacuum levels in the low micron range. (Courtesy: Solar Manufacturing Inc.)

Solar gets furnace order from firearms manufacturer

Solar Manufacturing Inc. announces the receipt of a vacuum heat-treating furnace order for a firearms manufacturer based in the United States.

The furnace, Model HFL-5748-2IQ, has a hot zone of 36” x 36” x 48” deep with a weight capacity of 5,000 pounds, and maximum operating temperature of 2,400°F, and heats to 2,500°F for hot zone bake out. The furnace design also has a temperature uniformity of ±10°F and is AMS2750 compliant with vacuum levels in the low micron range.

For rapid turnaround for work cooling, a 100 HP gas blower is provided for operating at 15 PSIG (2-bar) in nitrogen gas. The furnace is complete with a SolarVac® Polaris fully automated and programmable industrial controls package, and a Eurotherm digital chart recorder.

The system also includes a Magnetic Specialties, Inc. (magspecinc.com) SCR-based dry power supply rated at 225 kVa.

Solar Manufacturing designs and manufactures a wide variety of vacuum heat treating, sintering, and brazing furnaces and offers replacement hot zones, spare parts, and professional service.

MORE INFO www.solarmfg.com

Gasbarre ships mesh belt brazing and annealing line

Gasbarre Thermal Processing Systems announced the commissioning of a 28-inch wide, four zone mesh belt annealing and brazing furnace for Bluewater Thermal Solutions, one of the largest U.S.-based commercial heat treaters. The furnace is installed in Bluewater’s annealing and brazing facility in Coldwater, Michigan. The mesh belt furnace is designed with a maximum operating temperature of 2,100°F

A repeat Seco/Vacuum customer has ordered a 2-bar Vector® vacuum heat-treating furnace to increase production of fuel injector components. (Courtesy: Seco/Warwick Group)

with a capacity of 1,600 pounds/hour, and uses a blend of nitrogen and hydrogen atmospheres. The system incorporates an Allen-Bradley PLC and integrated dewpoint meter to ensure precise process control for consistent and reliable part quality. This is the fifth such Gasbarre furnace at this location. Gasbarre was selected as the equipment manufacturer based on their expertise in the equipment design, proven performance, and post commissioning support.

With locations in Livonia, Michigan; Cranston, Rhode Island; and St. Marys, Pennsylvania; Gasbarre Thermal Processing Systems has been designing, manufacturing, and servicing a full line of industrial thermal processing equipment for nearly 50 years. Gasbarre's equipment is designed for each process by experienced engineers and metallurgists.

Bluewater Thermal Solutions operates 12 different heat treatment and brazing facilities in the United States and Canada and is one of the largest heat-treating and brazing companies in North America. Each location has different capabilities and equipment to offer specialized different types of processing required by local markets.

MORE INFO www.gasbarre.com
www.bluewaterthermal.com

Global automotive parts maker orders vacuum furnace

Seco/Vacuum, a Seco/Warwick Group company, has received an order for a 2-bar Vector® vacuum heat-treating furnace from an OEM who had recently ordered six new tempering furnaces for its machine tool manufacturing facility.

The international buyer's automotive division placed an order for a single-chamber high-pressure quench horizontal vacuum furnace to increase its annealing production of fuel injector components. The new heat-treating furnace will complement an existing Seco/Vacuum furnace in operation at that location since 2002. Because the new furnace is a nearly identical model, they share standard components and will reduce the necessary inventory of spare parts.

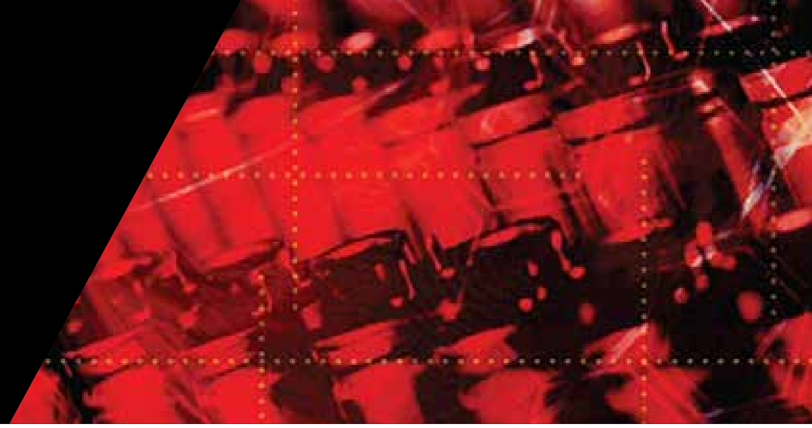
"Once again, we have been rewarded for a good track record of performance and service support by this international automotive and machine tool components manufacturer," said Peter Zawistowski, Seco/Vacuum's managing director. "This furnace brings to seven the number of vacuum heat-treating systems we will have delivered to them in the past three years. It proves the familiar adage, 'If we take care of you, you will take care of us.' It is also very gratifying to know that their 20-year-old furnace is still performing well with our support."

The new furnace will have a chamber size of 36" x 36" x 48" deep with a load capacity of 3,300 pounds. It is designed for a temperature uniformity of ±10°F to meet the qualifications of CQI-9 and AMS2750F. The furnace will be equipped with Seco/Warwick's state-of-the-art control system, which includes a PLC and Seco/Vacuum SCADA systems. A battery-operated electric loader will also be provided to allow safe and convenient loading/unloading operations.

Vector, Seco/Warwick's single-chamber horizontal vacuum furnace, is loaded with capabilities. With hundreds of systems installed worldwide, Seco/Warwick's vacuum furnaces have a proven record of meeting and exceeding performance expectations.

Seco/Vacuum's Vector single-chamber vacuum heat treating furnace is the workhorse of the automotive supply chain, performing a wide range of processes including hardening, tempering, annealing, solution heat treating, brazing and sintering, as well as low-pressure carburizing. Vector produces clean, uniform, high-quality parts with repeatable accuracy.

MORE INFO www.secowarwick.com



Mark your calendars for these important 2022 conferences

The International Conference on Steels in Cars and Trucks will focus on the sustainability and future of steel in automotive applications. (Courtesy: Shutterstock)

EUROPEAN CONFERENCE ON HEAT TREATMENT/ IFHTSE 27TH CONGRESS

September 5-8, 2022 | Salzburg, Austria

At the present time, more than 90 authors from 22 countries have provided abstracts to the 27th IFHTSE Congress and ECHT2022. The conference, sponsored by the Austrian Society for Metallurgy and Materials and taking place at the Wyndham Grand Salzburg Conference Center, will also feature a symposium in memoriam to Sören Segerberg. This special symposium is dedicated to the late Swedish researcher who passed away last year.

›› **For more information:** www.ifhtse-echt2022.org

6TH INTERNATIONAL CONFERENCE ON STEELS IN CARS AND TRUCKS

June 19-23, 2022 | Milan, Italy

This event will be at the NH Milano Congress Center and will allow more than 500 participants from all over the world to visit Milan, Italy, and join more than 160 presentations from industry and research. The keynote speaker will be Gregory Ludkovsky, VP R&D, ArcelorMittal. The title of his presentation is "Reinventing steel in a world of disruption." Other keynote speakers will be speaking about sustainability and the future of steel in future automotive applications.

›› **For more information:** www.sct-2022.com

ADVANCES IN MATERIALS AND PROCESSING TECHNOLOGIES

October 10-14, 2022 | Portorož, Slovenia

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

» **For more information:** www.AMPT2022.org

14TH HTS INTERNATIONAL EXHIBITION AND CONFERENCE

November 2-4, 2022 | Mumbai, India

The recently rescheduled event will be at the Bombay Exhibition Center in Mumbai. The three-day international concurrent conference on “Advances in Heat Treatment” will have sessions on equipment, process improvement, emerging technologies, and innovations and case studies. The HTS conference will focus on advances in the area of heat treatment with specific topics such as NADCAP certification, Industry 4.0, process modeling, optimization and control, and case studies with specific reference to different industry sectors — transportation, power, defense, etc.

» **For more information:** htsindiaexpo.com

SPOTLIGHT ON MEMBERS

Institute of Metals and Technology

The Institute of Metals and Technology (IMT) was established in 1948 to provide support for the steel industry and became a public research institute in 1997. Its mission is to create new knowledge in the fields of metallurgy, metallic materials, nanoscience and nanotechnology, vacuum optoelectronics, metrology, engineering materials, environmental protection, transfer of knowledge to industry, and training of young researchers. The general aim is to improve the quality of life and enable sustainable development.

The institute primarily works in the field of research of metallic materials with an emphasis on research related to steel and aluminum alloys. The main activity of the institute is conducting high-quality research activities in the fields that are of national importance for Slovenia, have a high impact, are in the public interest, and are expected to prosper in the following decades. The main missions of the institute are basic and applied research, developmental and infrastructural activities according to the Research and Innovation Strategy of Slovenia. The present director is Associate Professor Matja Godec (matjaz.godec@imt.si). For more information: www.imt.si.

IFHTSE UPCOMING EVENTS

JUNE 19–23, 2022
6th International Conference on Steels in Cars and Trucks
Salzburg, Austria I www.sct-2020.com

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

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

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

APRIL 21–24, 2023
5th International Conference on Heat Treatment and Surface Engineering of Tools and Dies
Liangzhu Dream Town, Hangzhou, China

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

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

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

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INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

MEMBER PROFILE

MP Combustion: Supply and support of the best combustion equipment

Despite being a new company, MP Combustion is not new to the world of combustion. Ryan McClain and Justin Powell started MP Combustion in 2019 after leaving their respective jobs at Honeywell Thermal Solutions and Heat Equipment and Technology.

MP Combustion, based in Cincinnati, Ohio, is IHEA's newest member company. MP is a regional leader in the supply and support of industrial combustion equipment for process heating applications. The company takes pride in its field expertise, and that it not only distributes parts but also provides application solutions and technical support.

"MP Combustion has worked hard to provide Star Combustion with timely answers, fast pricing, and overall excellent customer service," said Andrew JH Kemppainen, managing director of Star Combustion Systems LLC. "When we need help getting the vendors, they represent to ship an order out; they fight on our behalf to make sure we get our shipments on time. When they can't get a shipment out, they provide us with honest answers and practical alternatives. When we have questions, their technical expertise is second to none. They are hands down the best distributor we work with."

Despite being a new company, MP Combustion is not new to the world of combustion. Ryan McClain and Justin Powell started MP Combustion in 2019 after leaving their respective jobs at Honeywell Thermal Solutions and Heat Equipment and Technology. Their combined 35 years of combustion industry experiences prepared them for the technical and commercial requirements of the new business. From the start, MP established key partnerships with world-class

The MP Combustion team works hard to be a trusted resource to its customers and a valuable partner to its principles.

vendors, and the company leverages those relationships to do whatever is in the best interest of its customers. MP Combustion acts as a conduit between the customer and the manufacturers to provide great solutions and application expertise.

"We have relied on Ryan and now the folks at MP Combustion for years," said Ben Mueller, senior project manager with The Dupps Company. "I am always impressed with their adept customer service and ability to provide parts and specialist hands-on service in critical times of need. They are a real asset to our product and service portfolio."

The MP Combustion team works hard to be a trusted resource to its customers and a valuable partner to its principles. The customer service team is the backbone of the company's efforts. The two CSRs, Sharon Mirande and Karen Krabacher, understand the need for timely responses with accurate information. They fill many other important roles, too, keeping the customers happy and the MP engine running smoothly. Sales Engineers Adam Cook and Eddy Pappalardo round out the current team, and join McClain and Powell in providing estimates, project management, and technical support. Cook and Pappalardo's impressive stature is easily matched by their ambition and desire to grow the business. Understanding the countless combustion applications, component functions, and specs is a daunting task, but these two are not afraid of any challenge.

MP Combustion will be in a new office space in the coming weeks. The company will be moving to 5825 Creek Road in Blue Ash, Ohio. The larger space will facilitate continued growth in two primary ways: First, the new space has greater warehousing capacity, which will be stocked with more strategic inventory. The strategy to increase inventory will help to reduce the supply chain struggles that most customers are experiencing lately. MP is even stocking configured burners and valves that can be modified as needed. And second, the new space will include a large shop floor that will allow for the construction and assembly of custom equipment.

"MP Combustion has provided me and SSI a great resource of knowledge and support," said Chris Davidson, senior project engineer with Super Systems, Inc. "With real hands-on experience, they can direct me in great detail on troubleshooting and support. Additionally, they have the knowledge and resources to understand how to maintain existing systems, and update to modern NFPA codes."

"In a world of supply chain delays and issues, it is so nice to have the team at MP Combustion working for us," said Patti Reeder, project administrator with Super Systems, Inc. "They are responsive and eager to help me find the right part for my jobs. Justin and Ryan are a pleasure to work with."

MP Combustion is honored to join the ranks of the esteemed companies and individuals that make up IHEA and will gladly join them in promoting the interests of the industry.

»**For more information:** www.mpcombustion.com

IHEA 2022 CALENDAR OF EVENTS

JUNE 15–16

Process Heating & Cooling Show

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

Donald E. Stephens Convention Center | Rosemont, Illinois

JUNE 28–30

Electrification 2022 International Conference & Exposition

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

Charlotte Convention Center | Charlotte, North Carolina

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

TRIRATNA SHRESTHA
MANAGER OF METALLOGRAPHIC LABORATORY AND CENTRAL COATINGS LABORATORY /// METCUT RESEARCH INC.

This high-performance alloy crucial to the aerospace, power generation, and oil and gas industries must undergo strenuous testing to assess its behavior and predicted life.

Fatigue failures in nickel-based austenitic Superalloy 718

Superalloy 718 is widely used for aerospace, nuclear, power generation, metal processing, medical, material processing, and chemical and petrochemical industries due to its excellent resistance to corrosion and high temperature deformation. Especially in aerospace application where materials see thermo and mechanical fatigue, the alloy is used for disk, seal, stator assemblies, diffuser/exhaust case, fastener, shaft, tube, impeller, etc. Enhanced elevated temperature property makes the alloy suitable for all types of welding/joining applications. The weldability property is paramount to parts manufactured via additive manufacturing processes, such as electron-beam, direct metal laser sintering, selective laser melting, and directed energy deposition, as an as-build part goes through a series of melting and resolidification during the build process. Fatigue testing is vital in understanding a material's behavior as a factor of test conditions, manufacturing processes, and the ability to predict fatigue life.

Fractography of a fatigue-fractured surface is important in identifying failure modes of a test specimen. It helps identify rate-controlling cause of crack initiation and its propagation mode. In most ductile failures, fatigued samples can have a primary crack initiation site and multiple secondary sites. In some cases, crack initiation is limited to a primary crack site. Fractography can be used to identify stable crack growth and crack overload regions as well. The primary crack site (1), stable crack growth region (2) and overload region (3) are shown in Figure 1. Fatigue striations or 'beach mark' can be measured to correlate crack length growth and potential drop. An optical microscope is used for low magnification characterization of a fracture surface. A scanning electron microscope (SEM) is typically used for higher magnification and detailed characterization of a fractured surface. Figure 2 shows Zeiss EVO 15, LaB6 SEM equipped with Bruker energy dispersive spectroscopy (EDS) and eucentric stage for better mobility of samples in the chamber. Semi-quantitative chemical analysis of inclusions is performed with EDS. The SEM has capability to image samples in the range of 10X – 100KX magnification. Regardless of technique used to image fracture surface, the ability to tilt the sample is key in better imaging and characterization of crack sites. Elemental mapping technique in EDS is used to locate the concentration and distribution of elements present in inclusion and surrounding area.

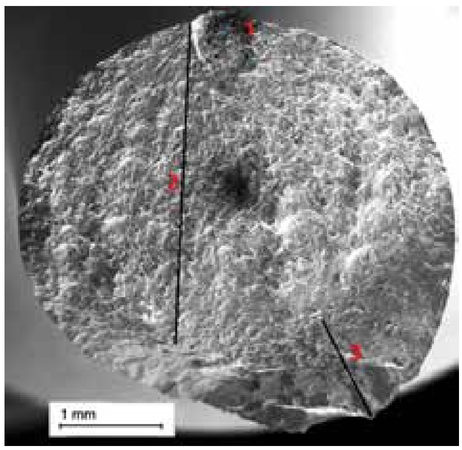

Figure 1: Fatigued fracture sample showing crack initiation site (1), stable crack growth region (2), and overload region (3).

Figure 2: SEM equipped with Bruker EDS.

Understanding and characterizing the crack initiation sites aids in better design and processing of additive manufactured parts as they have anisotropic materials behavior. Balachandramurthi et al. reported electron beam powder bed fusion manufactured and post-treated alloy had better low cycle fatigue life in build direction compared to transverse direction [1]. The anisotropic behavior was primarily due to difference in the material's yield strength. Reduced fatigue life in additive-manufactured samples can be attributed to lack of fusion, presence of precipitates, voids, grain distribution, and surface defects. Study conducted by Homberg et al. has shown four-point bend fatigue-tested samples to have higher fatigue life with smoother surface finish [2]. A rougher surface acts as a sea of stress concentration sites and at times coupled with grit embedment, fatigue life can be significantly reduced. A heat-treated and machined sample tends to have better fatigue life compared to as-built samples. Partial least square model has been used to establish correlation between fatigue life and surface finish [2] as such:

$$Fatigue = K_1S_1 + K_2S_2 + K_3FWHM_{XRD} + K_4$$

$K_{1\text{-}4}$ are various constants; S1 and S2 are surface roughness parameter; is the X-ray diffraction peak.

Given fatigue properties of different batches of selective laser melted as-built samples were similar, Balachandramurthi et al. predict that the surface roughness may have a greater effect than microstructural effects [1]. This finding points to the need for better surface preparation and points to possible defect sites. Apart from microstructural effect, test parameter like fatigue frequency

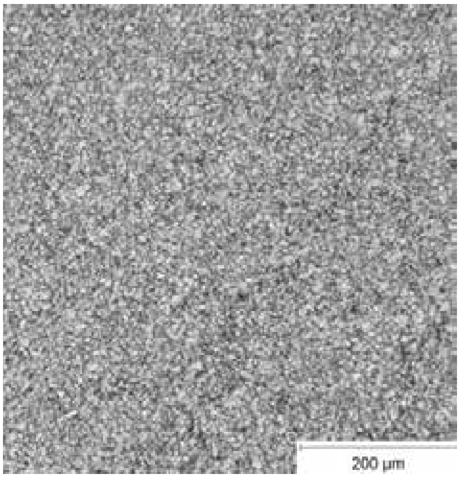

Figure 3: As-received microstructure of superalloy 718 having ASTM grain size of 10.

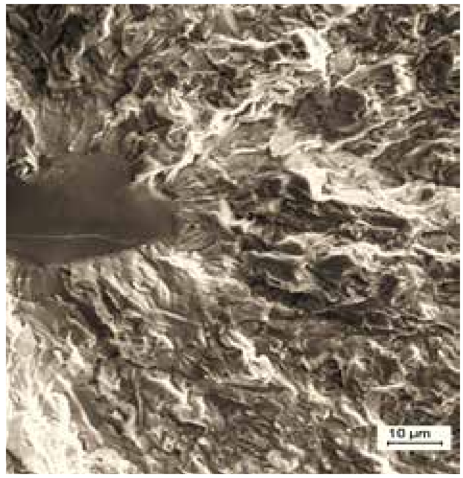

Figure 4: Surface inclusion as primary crack initiation site.

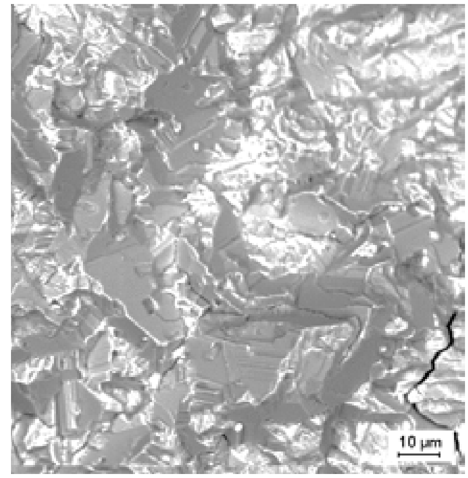

Figure 5: Fractography showing coarse grain failure as the primary crack initiation site.

also plays a role in the state of fracture mode. Generally, it is established that transgranular failure and oxidation/intergranular mode is dominant in high-frequency and low-frequency tests, respectively.

Nishijima et al. used a crack initiation area to estimate the fatigue limit of material [3].

$$\sigma_L = 1.56(VHN + 120)/(\sqrt{A_d})^{1/6}$$

σ_L = estimated fatigue limit, VHN = Vickers microhardness, A_d = Area of defect

Fatigue life can be attributed to multiple factors, such as materials property, grain size, surface conditions, test environment, stress conditions — a ratio $(R = \frac{\sigma_{min}}{\sigma_{max}})$, mean $\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$, etc. A material's grain size inverse correlation to its tensile property, which in turn has direct correlation with the fatigue strength. The Hall-Petch relationship

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

shows the inverse relation between yield strength (σ_y) and grain size (d), where σ_0 and k_y are constants for a specific material. For a high reversal stress cycle fatigue of R = -1, Nishijima et al. showed the relationship between fatigue and tensile strength as $\sigma_{L\,(R=-1)} = 0.5\,\sigma_y$ [3]. With higher density of grain boundaries, fine-grained materials are highly effective in disrupting dislocation flow compared to coarse grain structure. A fine-grained Alloy 718 with ASTM grain size 10 with twinning is shown in Figure 3. In addition to fine grain structure promoting higher strength, FCC structure of austenitic superalloy promotes twinning, which impeded dislocation flow and is highly effective in blocking slip.

In fatigue tests, a crack can initiate at the surface due to a surface defect because of machining or prevalence of inherent material defect, see Figure 1. Spot 1 in the figure shows an inherent material defect on the surface that extends inward. For these defect types, crack initiates at the defective site as a result of high stress concentration and propagates from there. Sample machining and manufacturing processes — both traditional and additive must be optimized to minimize/eliminate surface defects.

Cracks can also initiate from an inclusion, which can be located at the surface or subsurface or internally. Figure 4 shows an inclusion on the surface of a specimen that was the primary crack initiation site. Typical inclusions in Superalloy 718 are Nb- and Ti-based, such as NbTiC, NbTiN, TiNbN, TiNbCN, TiNbS, TiNbSC, NbTiMoWCrC, etc. Grain size and their distribution also impact crack initiation. Materials with multimodal grain distribution and as-large-as grain structure are prone to grain failure, which act as crack initiation sites. Materials with multimodal grain distribution have high degree of microstructural misfit that act as microstress concentration sites.

A fractured surface with coarse grain as primary crack initiation site is shown in Figure 5. The micrograph shows a mixed trans and intergranular failure mode. Fatigue fracture in Superalloy 718 are trans or intergranular in nature, see Figure 4 for a transgranular fracture. Belan et al. reported transgranular ductile failure with striations in 718 alloy with ASTM 12 grain size which was three-point fatigue tested at room temperature with static pre-load of -15 kN and dynamic force in the range of 6.31 – 12.8 kN [4]. Gopikrishna et al. [5] observed that high cycle fatigue life increased in finer grain sizes for both smooth and notch specimens tested at room temperature and 650oC. Thus, the morphology of fractured surface appeared transgranular in nature. These findings shed some light on the state of materials' microstructure at the time of failure.

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

Identifying inclusion size and distribution grows in importance as the demand for lighter weight and stronger materials grows.

Classifying non-metallic inclusions in steels

In this short column, we will discuss the different types of inclusions present in steels and discuss their physical metallurgy. As property requirements increase, and the demands for lighter and stronger structures increase, steel makers are increasingly concerned with steel cleanliness. The fatigue, ductility, and impact behavior of steel is controlled by the volume fraction, size, type, and morphology of non-metallic inclusions [1] [2]. If the oxygen content of the steel is lowered (and with it the number of non-metallic inclusions), the life of a bearing can be extended nearly 30 times (Figure 1) [3].

For steel castings, the morphology is determined by the solidification of the steel. In wrought products, the shape of the inclusions is determined by how hard the inclusions are to the wrought matrix. This is shown in Figure 2.

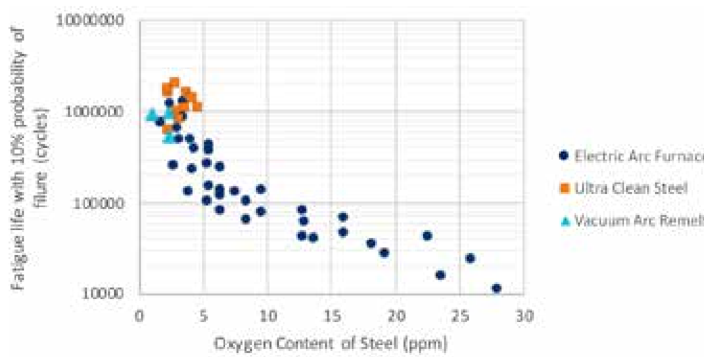

Figure 1: Relationship between fatigue life and oxygen content of steel [3].

CLASSIFICATION OF INCLUSIONS IN STEEL

Steel inclusions are classified according to the source. They are either indigenous or exogenous.

Indigenous Inclusions

Indigenous inclusions are formed during the deoxidation process or precipitated during solidification of the steel.

Deoxidation products

As the steel is deoxidized, titanium, aluminum, and silicon may be introduced to the molten steel. As the steel is transferred from the furnace to a ladle or tundish to a mold, or to a continuous caster, pickup of air during the transfer is virtually unavoidable. Typical inclusions of this type are Al_2O_3 or Silica (SiO_2)

Precipitated Inclusions

During solidification, the dissolved oxygen and nitrogen concentration increases, while the solubility of these elements decreases. Inclusions of alumina (Al_2O_3), silica (SiO_2), aluminum, and titanium nitride (AlN and TiN), and sulfide inclusions precipitate during solidification. The sulfide inclusions often precipitate on metal oxides present in the molten steel. If rare-earth additions are made in the ladle, then rare-earth oxides will also be formed.

Exogenous inclusions

These inclusions form from reoxidation and from mechanical erosion of the refractory. These can be large, and cause problems during machining. They are typically compound inclusions from interaction of the molten steel, slag, and refractory lining. They are often irregular in shape. They are often fewer in number than the smaller indigenous inclusions. Because these inclusions are larger, these inclusions act as large stress risers. They have a large effect on mechanical properties, such as fatigue and ductility.

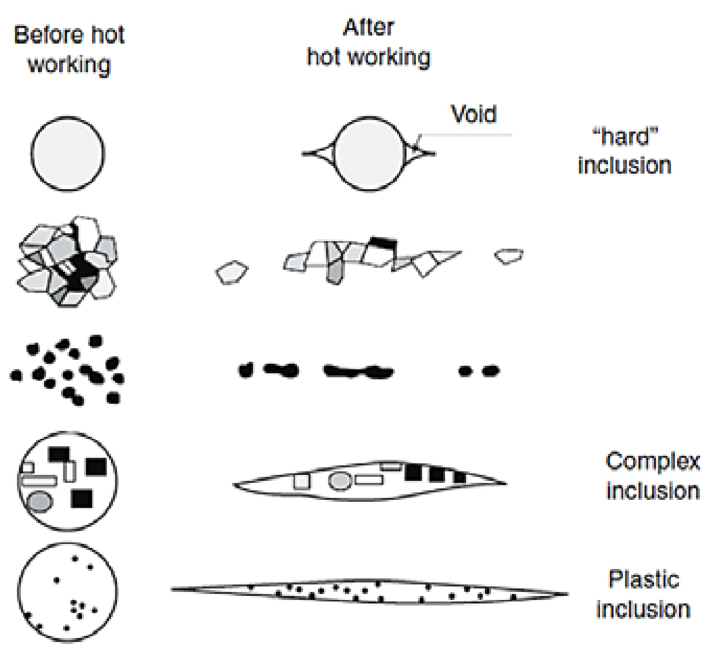

Figure 2: Schematic representation of inclusion shape before and after deformation [4].

Exogenous Inclusions from reoxidation

These inclusions from reoxidation form from air during transfer of the molten metal during pouring — either from the bath to the ladle, or from the tundish to the mold or continuous caster. The air reacts preferentially with Al, Ca, and Si, forming larger inclusions than normal deoxidation inclusions [5].

Another source is the SiO_2, FeO, and MnO in the refractory and slag. They react with the aluminum within the melt and form larger Al_2O_3 inclusions. To minimize this, use of high alumina or zirconia refractory linings with low SiO_2 content in the refractory

lining is recommended [3].

Exogenous Inclusions from slag entrainment

These large inclusions, generally containing CaO or MgO, are produced by turbulent mixing of the slag and molten steel. Often these inclusions are formed from the vortex that occurs as the molten metal is poured from the tundish to the mold (or continuous caster).

Exogenous Inclusions from erosion/corrosion of lining refractory

These inclusions are typically larger than other inclusions, and irregularly shaped. This type of inclusion is very common. They are composed of sand, dirt, refractory brickwork, or ceramic from nozzles. This can be minimized by using high purity Al_2O_3 and ZrO_2 refractory linings [6].

Exogenous Inclusions from chemical reactions

If the Ca treatment for inclusion control is performed incorrectly, then oxides can be produced. These are difficult to identify, because CaO inclusions may also be caused by slag mixed in the molten metal.

DETECTION OF INCLUSIONS

There are many ways of measuring and quantifying inclusions. Magnetic particle inspection [7] can be used to quantify the size and frequency of inclusions. Other methods are described by ASTM E45 [8], including macro-etching, magnetic particle inspection, and metallographic examination. Chemical determination of the inclusion type would use an SEM with EDS (Energy Dispersive Spectroscopy).

CONCLUSIONS

In this short article, inclusions that are commonly found in steel are classified as to source. As demands grow for lighter weight and stronger materials, the importance of inclusion size and distribution will only increase.

Should you have any comments for this article, or suggestions for further articles, please contact the editor or myself.

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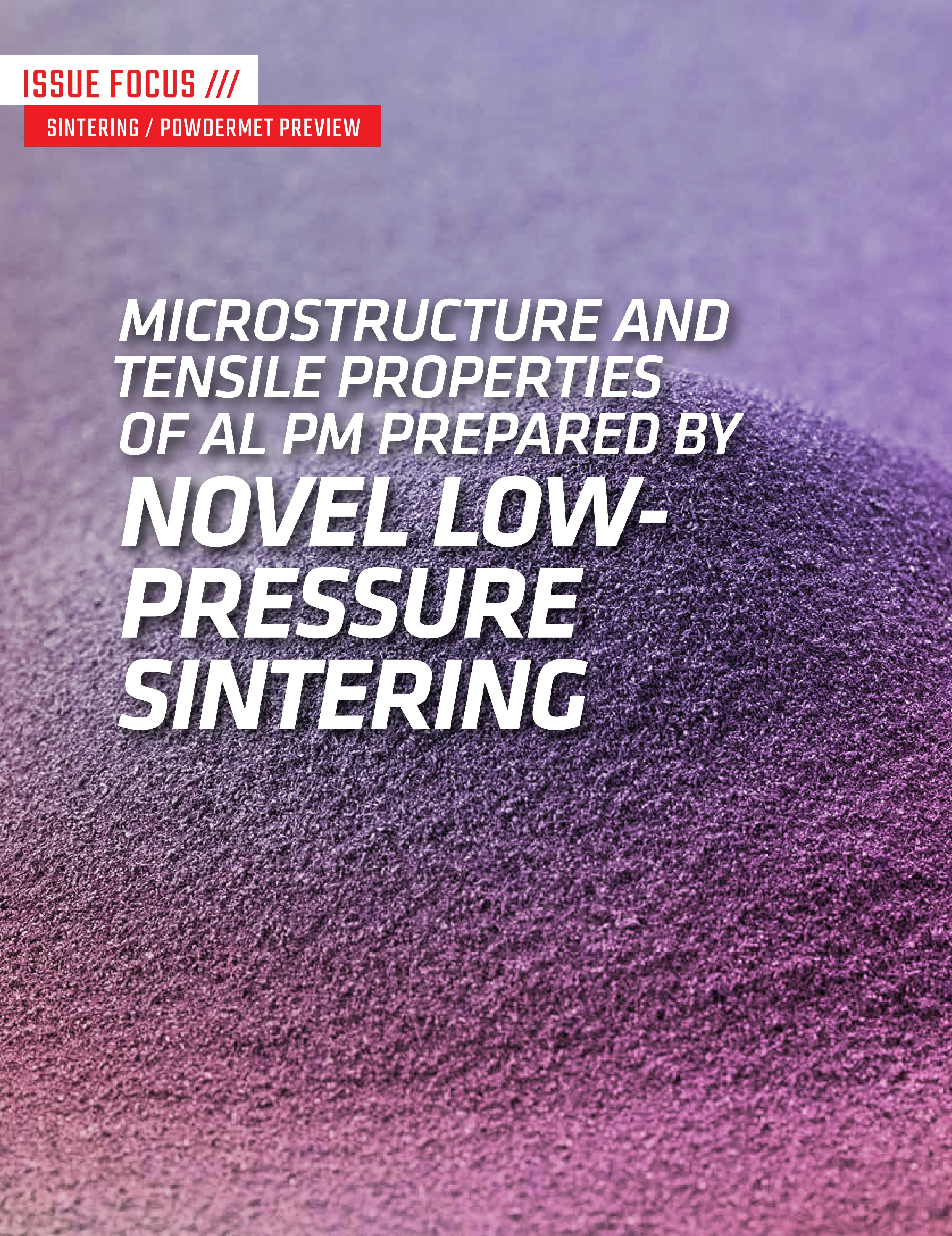

ISSUE FOCUS ///

SINTERING / POWDERMET PREVIEW

MICROSTRUCTURE AND TENSILE PROPERTIES OF AL PM PREPARED BY NOVEL LOW-PRESSURE SINTERING

Results from a study showed it was difficult for pressureless sintering to densify pre-alloyed aluminum powders, but low-pressure sintering could.

By LEI WU, ZHAOJI YU, CHAO LIU, YUNZHU MA, YUFENG HUANG, TAO WANG, LUN YANG, HUANYUAN YAN, and WENSHENG LIU

This article proposes a novel low-pressure sintering process contraposing to characteristics of pre-alloyed aluminum powders and analyzes its feasibility. The low pressure was set to 0.1 MPa in this study. Meanwhile, 0 MPa and 10 MPa were set as the control group. With gas-atomized 2024 aluminum powders as raw material, the microstructure and tensile properties of specimens sintered under three orders of magnitude of pressure (0 MPa, 0.1 MPa, and 10 MPa) at two representative temperatures (525°C and 575°C) were compared. The results showed it was difficult for pressureless sintering (0 MPa) to densify pre-alloyed aluminum powders, but low-pressure sintering could. As the liquid phase formed at supersolidus temperature was squeezed out, the loss of alloying elements such as Cu and Mg, which would play an important role in subsequent heat treatment, during low-pressure sintering was apparently less than that of 10 MPa. The density of aluminum sintered under 0.1 MPa at 575°C was 2.732 g/cm^3 and the ultimate tensile strength was 228.16 MPa with ductility of 12%, which achieved a good balance of plasticity and strength. These findings will bring new insights to the industrialization of aluminum powder metallurgy (APM).

1 INTRODUCTION

Aluminum and its alloys are the most often used light metal due to their attractive properties [1]. Tapping the application potential of aluminum alloy has always been the focus because of exuberant demands in the field of aerospace and vehicle manufacturing. As an advanced manufacturing technology of aluminum alloys, powder metallurgy has unique characteristics: flexible composition design, special material structurally different from cast metal, and cost advantage of near net forming. Based on these, aluminum powder metallurgy (APM) technology is very suitable for manufacturing aluminum-based composite materials and gradient materials. Rahimian et al. [2] studied the effect of temperature, time, and particle size on the preparation of Al–Al_2O_3 by powder metallurgy. Sun et al. [3] employed powder metallurgy to prepare SiC-reinforced pure aluminum composites. A Graphene oxide-reinforced aluminum composite was fabricated by powder metallurgy [4]. Apparently, APM will be a breakthrough for traditional aluminum alloy industry.

Despite owning unique performances, the industrialized development of APM is seriously delayed due to the current unsatisfactory APM technology [5]. The mainstream APM process is divided into liquid phase sintering with element-mixed powders as a raw material [5] and hot pressing with pre-alloyed powders. Although the liquid phase sintering is simple and economical, the inferior mechanical properties of sintered components are usually unable to serve for industrial products, which rely heavily on subsequent machining. Boland et al. [6] mentioned the commercial APM was limited due to the correspondingly narrow scope of mechanical properties. Sweet et al. [7] used powder forge to improve mechanical properties of APM.

As another choice for APM, the components fabricated by hot pressing with the microstructure and mechanical properties similar to those of cast aluminum have near full density and good mechanical properties. However, the inescapable problem is the current hot pressing process for APM always requires high loading pressure (>10 MPa) to ensure high density. Cooke et al. [8] sintered Al powder with 0.4% Sc using spark plasma sintering (SPS) under 50 MPa at 550°C. The relative density of the corresponding aluminum was more than 99.5% and the tensile strength was 226 MPa; Khalil et al. [9] optimized the SPS process for 6061 aluminum and 2124 aluminum and confirmed the best process parameter was 450°C and 35 MPa; Wang et al. [10] adopted hot isostatic pressing (HIP) at 580°C under 130 MPa for 3 hours to obtain the sintered aluminum alloy with a density of 98.9% and tensile strength of 324 MPa.

All of the above cases about hot pressing of aluminum powders rely on complex and expensive sintering equipment, but their low production efficiency is unqualified to satisfy modern industrial production demands. It completely offset the cost advantage of powder metallurgy as a near-net forming technology, leading to the current APM unable to form a significant advantage for the traditional aluminum industry. Actually, for some aluminum base components with simple shapes and small sizes, there is no need for high loading pressure. In other words, the complex hydraulic system could be replaced by the gravity of heavy weight, a kind of low-pressure state, which may be suitable for automatic production in a mesh belt furnace. This approach will greatly improve the production efficiency of APM and significantly reduce production cost. However, to date, there have been few studies on the sintering of aluminum powder under low pressure.

The purpose of this research is a feasibility analysis of low-pressure sintering for aluminum powders in an effort to open up a new field for APM industry. In this work, pressureless sintering (0 MPa) and pressure sintering with 10 MPa were set as control group. The reason for choosing 10 MPa is it is of the same order of magnitude as the pressure used in mainstream hot pressing for APM. Meanwhile, the low pressure was set to 0.1 MPa, which was two orders of magnitude lower than 10 MPa and easily achieved by a heavy weight. The microstructure and tensile properties of aluminum alloys sintered under three different magnitudes of pressure (0 MPa, 0.1 MPa, and 10 MPa) were systematically compared to evaluate low-pressure sintering for APM.

2 EXPERIMENTAL

2.1 Raw materials

In this work, 2024Al nitrogen atomized powders produced by Changsha Tianjiu Co. were used as the raw material, and the chemical composition is listed in Table 1. Figure 1 exhibits the morphology, cross-sectional microstructure, differential scanning calorimetry

(DSC) curve, and particle size distribution of as-received powders. The atomized powders were nearly spherical, and some of them cohered with each other during the solidification of molten droplets (Figure 1a). As indicated in Figure 1b, the cross-section microstructure consisted of dendrite crystals and cellular crystals, which is a typical rapid solidification feature. According to the results of an energy dispersive spectrometer (EDS) in the dendrite crystal (A point) and at the dendrite boundary (B point), the alloying elements of Cu and Mg in the powder were mainly enriched in the dendrite boundary. Figure 1c presents the DSC curve of 2024Al powders analyzed by a NETZSCH STA 449F3 integrated thermal analyzer. It can be seen that a small endothermic peak appears at 507°C, and the temperature corresponding to the peak value of the main endothermic peak, which also is the melt point of this pre-alloyed powder, is 648°C. The small endothermic peak appearing at 507°C indicated there was a phase transition during heating. According to the phase diagram [7], the phase transition actually corresponds to the eutectic reaction, which leads to the formation of a liquid phase in the aluminum. Thus, the solidus of as-received powders was 507°C. Figure 1d shows the particle size distribution of powder particles that the average particle size Dv50 was 68.7 μm.

Element	Cu	Mg	Zn	Fe	Si	Mn	Al
2024Al	4.07	1.51	0.33	0.14	0.094	0.071	Bal

Table 1: Chemical composition of 2024 pre-alloy powder (wt%).

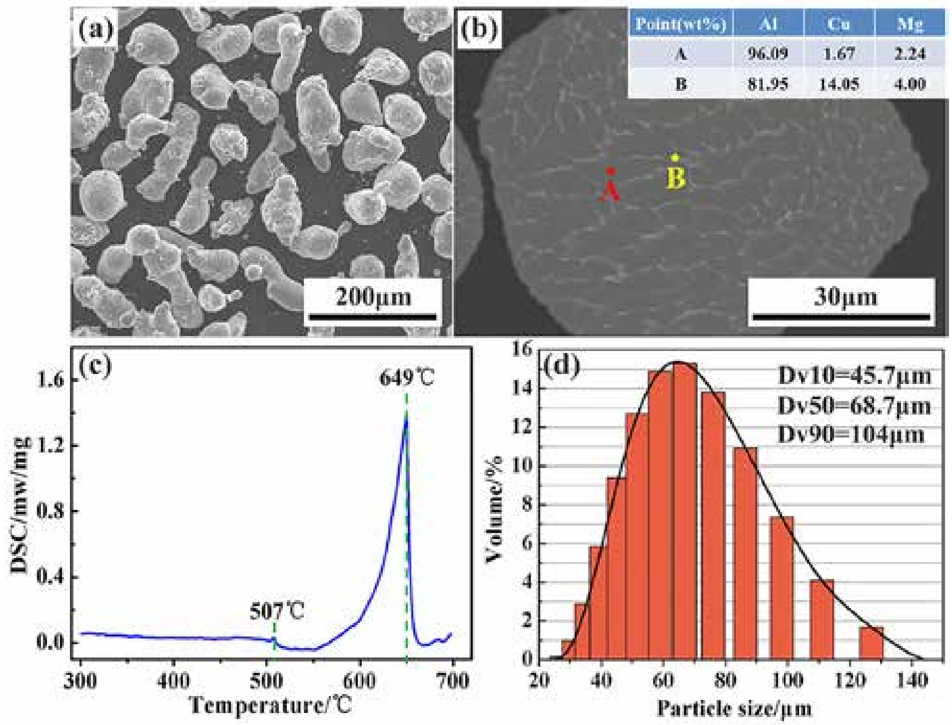

Figure 1: Powder characteristics of 2024 atomized powders: (a) morphology, (b) cross-sectional microstructure (wt%), (c) DSC curve, (d) particle size distribution.

2.2 Experimental techniques

Fixed mass 2024Al pre-alloyed powders were compacted into a disc (40 mm diameter × 2.07 mm thickness) under an axial pressure of 400 MPa. After compacts were inserted into a high-strength graphite mold, the sintering experiments were carried out in a precision vacuum hot-pressing furnace (VVP-60). The sintering pressure was set to three different orders of magnitude: 0 MPa, 0.1 MPa, and 10 MPa, as demonstrated in Figure 2. Of these, the pressure of 0.1 MPa was achieved using a 15 kg iron weight, and the pressure of 10 MPa relied on hydraulic pressure from the hydraulic station. The sintering temperatures were set to 525°C and 575°C, near solidus and above respectively, which represented two kinds of sintering features: almost no liquid phase formation and a small amount. After reaching the set temperature with a heating rate of 10°C/min, specimens were isothermally held for 2 hours, followed by cooling to 200°C at 5°C/min and then furnace cooling. Considering chemical activities of aluminum, the furnace was evacuated to a vacuum of 10^{-3}Pa.

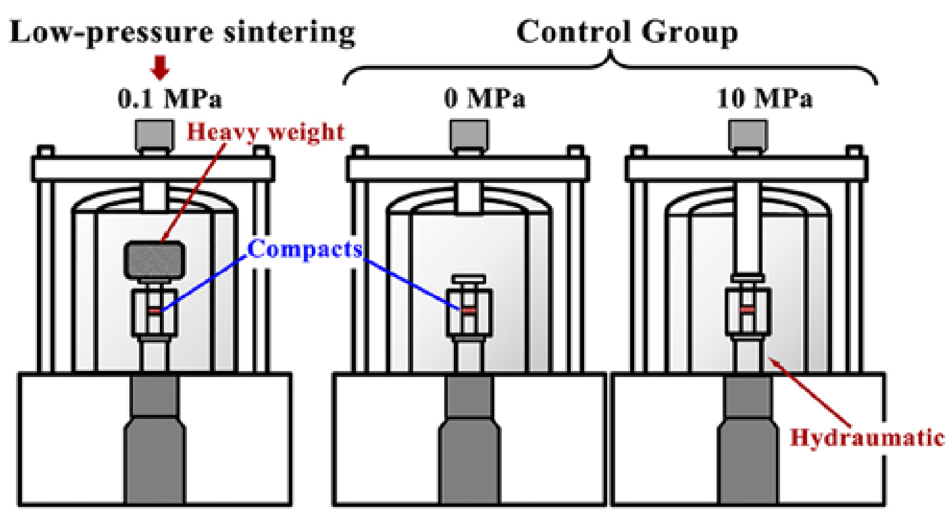

Figure 2: Schematic presentation of low-pressure sintering and its control group in this research.

The density of specimens under different sintering conditions was measured using the Archimedes drainage method with an MSA324S-000-DU balance. The thickness of compacts before and after sintering was respectively measured with a vernier caliper. To observe the microstructure of sintered aluminum, the middle part of the specimens was cut by wire-electrode cutting and embedded in the urea formaldehyde resin. The cross-section of sintered aluminum was grinded with emery-paper and polished with 0.05 μm alumina suspensions. Scanning electron micrographs were captured in backscatter mode using a scanning electron microscope (SEM; model: Quanta 250 FEG, FEI). Surface distribution of main elements such as Al, Cu, and Mg in 2024Al were evaluated by an electron probe micro-analyzer (model: JXA-8530 F). Phase identification was conducted by X-ray diffraction in the range of 20° to 90° at a scan rate of 5°/min with a Bruker Advance D8. High magnification details in sintered aluminum were investigated via a Transmission Electron Microscope (TEM; Tecnai G2 F20). An electronic universal testing machine (Instron 3369) was employed to carry out tensile tests, and the fracture modes were characterized by scanning electron micrographs.

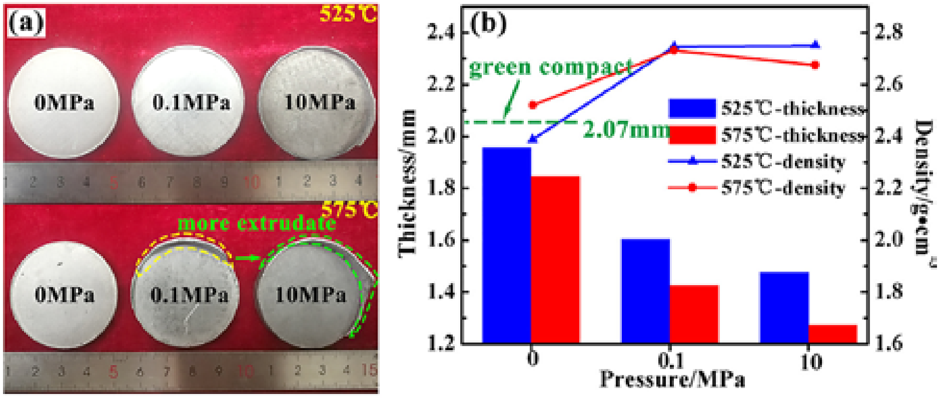

Figure 3: (a) Photograph of sintered compacts at different conditions, (b) the thickness and density of sintered compacts at different conditions.

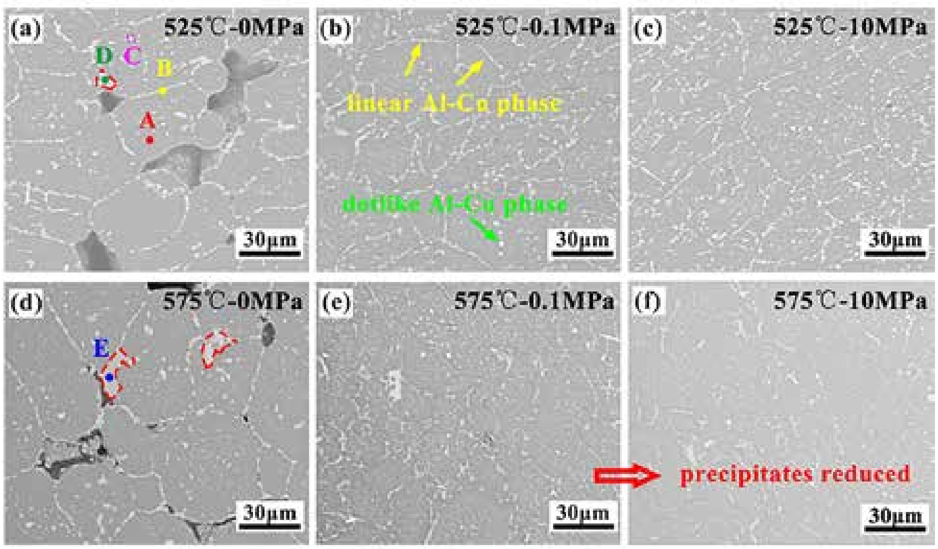

Figure 4: SEM micrographs of sintered aluminum under different pressure states at 525°C and 575°C: (a) 525°C, 0 MPa; (b) 525°C, 0.1 MPa; (c) 525°C, 10 MPa; (d) 575°C, 0 MPa; (e) 575°C, 0.1 MPa; (f) 575°C, 10 MPa.

Position	Al	Cu	Mg	Fe	Mn	Si
A	96.52	1.48	2.00	–	–	–
B	71.61	26.23	1.77	–	–	0.39
C	81.87	14.36	3.21	0.56	–	–
D	79.75	13.80	1.60	4.11	0.74	–
E	72.18	2.01	–	6.30	19.51	–

Table 2: Chemical composition of the characteristic position in Figure 4 (wt%).

3 RESULTS AND DISCUSSION

3.1 Compacts deformation and density

The photograph of compacts sintered at different conditions is shown in Figure 2a. The specimens prepared via pressureless sintering at 525°C and 575°C basically maintained the initial disk morphology of the green compact. As loading pressure, the edge of sintered compacts was extruded out along the fit clearance of the graphite mold in different degrees, especially at 575°C. As indicated by the dashed line in Figure 2a, the edge extrudate of the compact sintered under 0.1 MPa at 575°C is apparently less than that under 10 MPa.

Figure 3b presents the thickness and density of sintered aluminum under different pressure states at 525°C and 575°C. Compared to the thickness of a green compact (2.07 mm), the shrinkage caused via pressureless sintering was very limited. The density of the pressureless sintered aluminum was also much lower than that of the same grade as cast aluminum alloy (2.76 g/cm^3) [11]. Apparently, it is difficult for pre-alloyed aluminum powder to realize densification via pressureless sintering.

After loading pressure, the shrinkage of compacts was obvious, even if the pressure was only 0.1 MPa. The density of aluminum sintered under 0.1 MPa at 525°C rapidly increased to 2.747 g/cm^3, which indicated pre-alloyed aluminum powders could reach densification via low pressure. While further increasing the loading pressure to 10 MPa at 525°C, the gain for density (from 2.747 g/cm^3 to 2.751 g/cm^3) was not apparent. Another noteworthy phenomenon was the density did not always trend positive with the shrinkage on dimensions with the sintering temperature rising to 575°C, even decreased slightly (2.732 g/cm^3 of 0.1 MPa and 2.675 g/cm^3 of 10 MPa). This phenomenon will be discussed in the following section.

3.2 Microstructure and composition analysis

The microstructures of specimens sintered under different pressure states are presented in Figure 4. The gray matrix is aluminum (α-Al), and the white phases are precipitates formed during sintering. The EDS spectral results of each marked position (A-E) in Figure 4a and d are listed in Table 2, including all kinds of feature regions in sintered aluminum. From point A, the gray aluminum base contains a small amount of Cu and Mg, while the white precipitates are rich in alloying elements such as Cu and Mg (Point B and C). Some coarse blocky precipitates distributed at the triangular position marked by red dashed lines in Figure 4a and d contained more impurity elements such as Fe and Mn than other regions (Point D and Point E). These precipitates are insoluble for the aluminum matrix and have a lower melting point to form liquid during heat treatment in the review paper by Wang and Starink [12]. In the following discussion, these white precipitates are collectively called Al–Cu phases. The morphologies of white Al–Cu phases mainly included linear distribution at the particle/grain boundary and dot-like dispersion inside the powder, as indicated in Figure 3b.

With the change of sintering temperature and pressure, the microstructure of the corresponding aluminum alloys exhibited different characteristics. Figure 4a and 4d show the microstructure of specimens underwent pressureless sintering at 525°C and 575°C respectively, and there were still some pores left in the compacts. These residual pores were neither closed via sintering shrinkage nor filled by liquid formed via eutectic reaction (Figure 4d). That is to say, it is difficult for pre-alloyed aluminum powders to achieve densification by pressureless sintering.

Compared with pressureless sintering, the microstructure of sintered aluminum apparently varied with loading pressure. Under a low pressure of 0.1 MPa at 525°C, residual pores in the compact were closed by the rearrangement and the plastic deformation of aluminum powders (Figure 4b). Every particle was closely combined with each other. Base on this fact, it can be concluded that low-pressure sintering could make pre-alloyed aluminum powders realize high densification. The microstructure of the sintered aluminum under 10 MPa at 525°C was similar to that of 0.1 MPa (Figure 4c). When the temperature rose to 575°C, the decrease in plasticity and the formation of liquid led to more thorough deformation for aluminum powders under the same pressure. Compared with the specimens sintered at 525°C, there was a slight decrease of the linear precipitates at the powder boundary, which were replaced by the coarse blocky precipitates formed at the triangular particle boundary, as seen in Figure 4e. This was related to particle deformation caused by low pressure. The liquid converged to the triangular boundary due to pressing and solidified into coarse precipitates. When the loading pressure further increased to 10 MPa, the most obvious change in sintered aluminum was the content of white precipitates comparatively decreased than that of 0.1 MPa, as indicated by Figure 4f. Combined with the phenomenon of slightly decreased density mentioned earlier, there may be a correlation between both.

In order to clarify this correlation, the area distribution characteristic of element concentration of the edge extrudate formed under 10 MPa at 575°C was analyzed by EPMA technology, and the results are shown in Figure 5. It can be seen that the edge extrudate presented a typical eutectic solidification feature (Figure 5b), which contained a large amount of Cu (Figure 5d) and Mg (Figure 5e). The result illustrated that the Al–Cu eutectic liquid of aluminum alloy formed during supersolidus sintering was easily squeezed out to the edge of compacts by the loading pressure, and this resulted in the loss of alloy elements such as Cu, Mg, and Fe for aluminum alloy. This was the reason why the density of the aluminum sintered at 575°C decreased slightly, that is, some of the "high weight" elements such as Cu, Fe, and Mn were squeezed out with molten liquid.

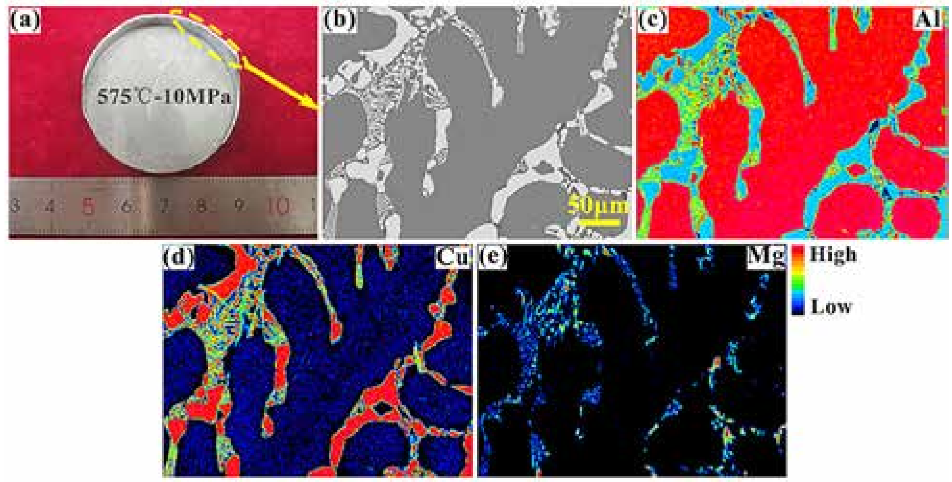

Figure 5: Element maps of the edge extrudate analyzed by EPMA. (a) The compact sintered under 10 MPa at 575°C, (b) SEM micrograph of the edge extrudate, (c) Al map, (d) Cu map, (e) Mg map.

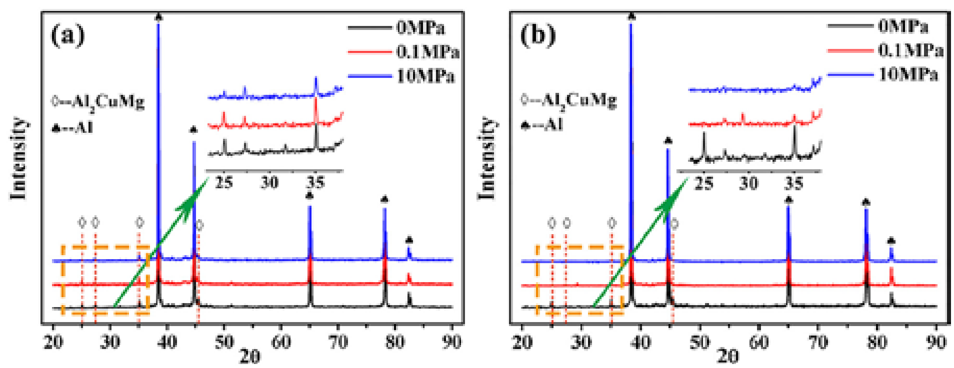

Figure 6: XRD diffraction spectra of aluminum alloys sintered under 0 MPa, 0.1 MPa, and 10 MPa at different temperature: (a) 525°C, (b) 575°C.

Figure 6 shows XRD results of aluminum powders sintered under different conditions. Although there were several combinations of sintering temperature and pressure, the second phase detected in the specimens was only Al_2CuMg (S phase). The phenomenon of precipitates reduced with loading pressure at 575°C was further verified by the XRD results (Figure 6b). The intensity of diffraction peaks corresponding to the Al_2CuMg phase decreased with an increase in pressure, and the peaks almost disappeared when the pressure reached 10 MPa.

Obviously, the pressure is a sensitive factor for aluminum powders sintering at the supersolidus temperature. The formation of the liquid phase led the sintering process to become more complicated. According to the phase diagram, the formation of the liquid phase is mainly because of eutectic reactions. One is the ternary eutectic reaction when the temperature exceeds 507°C:

$$L \rightleftharpoons \alpha(Al) + \theta(CuAl_2) + S(Al_2CuMg) \qquad \textbf{Equation 1}$$

Another is the binary eutectic reaction when the temperature exceeds 550°C:

$$L \rightleftharpoons \alpha(Al) + \theta(CuAl_2) \qquad \textbf{Equation 2}$$

Mi and Grant [13] considered the functional relationship of the liquid phase fraction with temperature during sintering is

$$f_l = \left(\frac{T - T_s}{T_l - T_s}\right)^{(1/(1-k))} \qquad \textbf{Equation 3}$$

f_l is the liquid fraction; T_l is the liquidus temperature; T_s is the solidus temperature, and k is a partition coefficient. Wang et al. [10] demonstrated k was 0.66 in hot isostatic pressing of 2A12 aluminum alloy, which has the same chemical composition as 2024 aluminum alloy. The curve obtained according to this functional relationship between sintering temperature and the fraction of the liquid phase is shown in Figure 7. When the sintering temperature was 525°C, there was only less than 1% liquid in the sintered aluminum; while the temperature rose to 575°C, the liquid fraction rapidly reached 11.47%. The liquid phase distributed at the grain boundaries and prior particle boundaries will cause a rapid-softening, even collapse for aluminum powders, as reported by Momeni et al. [14]. Despite this, as mentioned earlier, pressureless sintering was unable to achieve densification for pre-alloyed powders with liquid phase produced at 575°C. But the yield strength reduction of aluminum powders caused by the temperature rising and liquid phase easily resulted in high densification via low pressure. The Al–Cu phases such as Al_2Cu (θ phase) and Al_2CuMg (S phase) are still the main strengthening phases for heat-treatment strengthening of 2024 aluminum alloy [15,16], and the loss of alloy elements Cu and Mg will weaken the strengthening for sintered compacts. Apparently, this adverse effect in low-pressure sintering was relatively less than that of 10 MPa. That

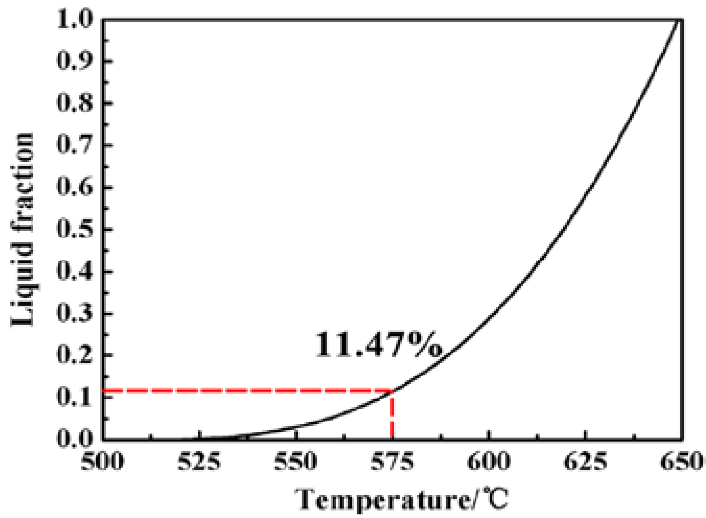

Figure 7: Relationship between liquid phase quantity of 2024 aluminum and temperature.

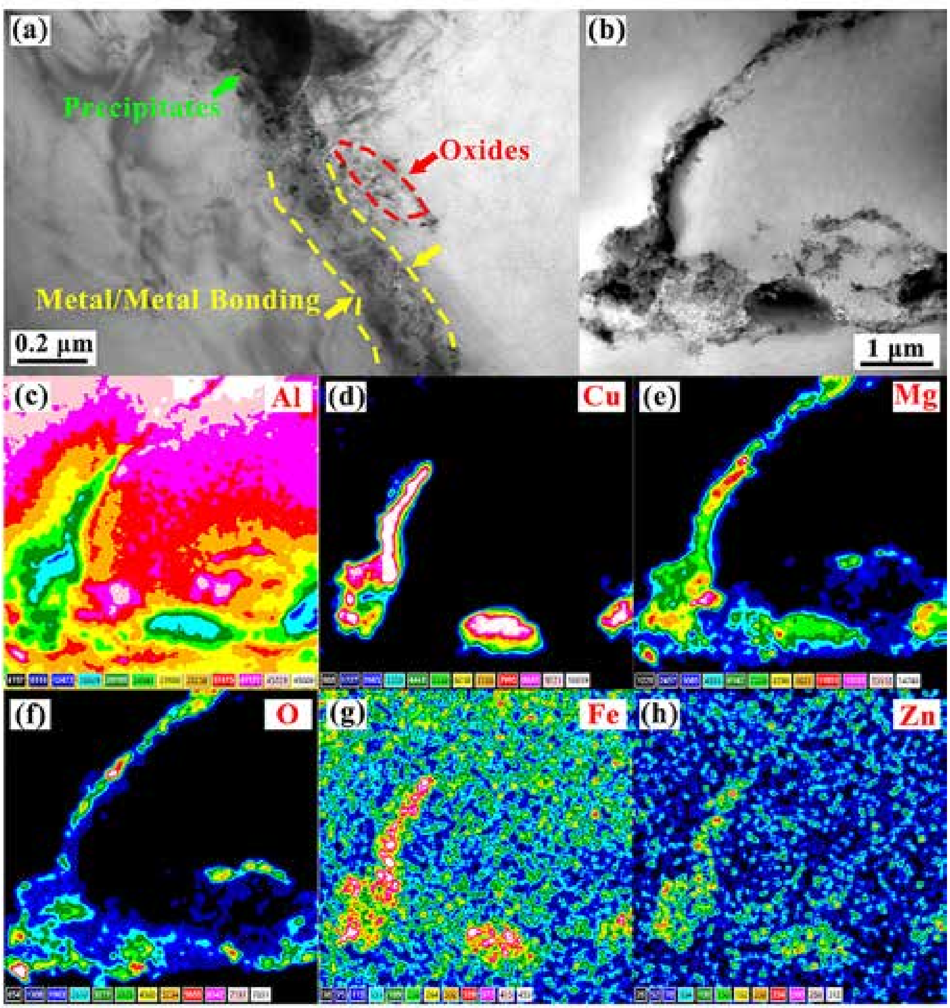

Figure 8: TEM analysis of prior particle boundary of the aluminum sintered under 0.1 MPa at 575°C: (a) and (b) are bright field images of two types of PPB; EDS-acquired elemental maps of (c) Al, (d) Cu, (e) Mg, (f) O, (g) Fe, (h) Zn in (b).

is to say, the low-pressure sintering is more suitable for pre-alloyed aluminum powders at supersolidus temperature.

To gain further insight on microstructure characteristics of low-pressure sintered aluminum, the specimen obtained under 0.1 MPa at 575°C was investigated at higher resolution using TEM. Figure 8 presents the prior particle boundary (PPB) of low-pressure sintering aluminum that can be directly used as an important reference to evaluate the quality of APM. According to the difference in morphology, it is easy to identify the PPB is an irregular transition zone with width less than 0.2 µm between two particles (Figure 8a). The main part of it is the directly metal/metal bonding formed through particles contacting, annotated by a yellow dash line, which is one of the two typical bonding interfaces in the sintered aluminum while the other is a metal/oxide layer/metal bonding interface [17]. Apparently, the effect of this metal/metal bonding on improving the mechanical properties for APM is more critical. From Figure 8a, there were still some Al–Cu precipitates at the boundary and small clusters of oxides crushed by compression distributed in the right particle. The whole boundary reflected a good conjunction between aluminum particles.

Comparing with Figure 8a, Figure 8b shows another more complicated prior particle boundary formed at the triangular junction of aluminum powders with the maximum width close to 1 µm. To further clarify the chemical composition of the boundary in Figure 8b, elemental maps of Al, Cu, Mg, O, Fe, and Zn were obtained by EDS map scanning and presented in Figure 8c–h respectively. It can be seen this coarse transition zone apparently had a complex composition of oxides and precipitates. However, no micro-voids and cracks were observed in this irregular region, which indicated a fully dense transition zone at the triangular particle boundary could be established via low-pressure sintering at 575°C. Besides, the black linear precipitation in Figure 8b, which was rich in alloying element Cu, Mg, Fe, and Zn, was consistent with the feature of liquid solidification and it just reflected the characteristic of low-pressure sintering for pre-alloyed aluminum powders at the supersolidus temperature, that is, a substantial part of liquid phase remained in the sintered structure instead of squeezing out.

Another notable phenomenon is the continuous distribution of heterogeneous oxygen along the PPB and the enrichment of magnesium with the similar distribution of oxygen. As mentioned earlier, the difficulty of APM is always that the stubborn oxide layer on the surface of powders is hard to remove. Many studies have shown adding a small amount of magnesium is an effective means to improve the sinterability of aluminum powders. Coincidence is the 2024Al atomized powders used in this research just contained 1.51wt% Mg (Table 1). That is to say, Mg atoms dissolved in the aluminum transferred to the edge of the powder with the temperature reaching 573°K [18] and would react with the prior aluminum oxide layer above 773°K as follows [19]:

$$3Mg + 4Al_2O_3 \rightarrow 3MgAl_2O_4 + 2Al$$

Equation 4

When the Mg concentration in the region is high enough (4%–8%), reaction 2 tends to occur.

$$3Mg + Al_2O_3 \rightarrow 3MgO + 2Al$$

Equation 5

Xie et al. [20] study shows when the mass fraction of Mg is in the range of 1.0–2.0 %, two reduction products, $MgAl_2O_4$ and MgO, tend to form. The fresh Al atoms produced by the deoxidization reaction and the shear stress caused by the phase volume change with the new formation of $MgAl_2O_4$, MgO led to the destruction of the aluminum oxide film and the formation of a new metallic bond between particles. However, compared with pressureless sintering mentioned earlier, it can be inferred the densification of pre-alloyed aluminum powders could not be achieved only depending on the reaction of Mg atoms. Therefore, the key to achieve metallurgical bonding between aluminum powders still relied on the direct compression of powders caused by low pressure.

Figure 9 exhibits some crystal characteristics inside the powder after low-pressure sintering. Plenty of dislocations remained in the aluminum after sintering and formed dislocation tangles as the movement hindered by rod-like precipitates (Figure 9a). Figure 9b shows a grain boundary and Al–Cu phase precipitated along it, which was apparently different from the morphology feature of PPB analyzed before. It indicated aluminum powder was still composed of several grains after sintering, and the precipitated phases in the powder were evenly dispersed in the grain and at the grain boundary. Due to the furnace cooling mode of aluminum alloy after sintering, the precipitates inside the powder are mainly rod-shaped and finer needle-shaped, as seen in Figure 9c. According to the EDS map scanning for Figure 9c, the precipitates in the crystal mainly were Al_2CuMg (S phase) and Al–Cu phase enriched with Mn and Fe. In addition, there is no obvious oxidation inside the powder (Figure 9h), compared with PPB. Obviously, the aluminum alloy sintered under low pressure had unique crystal structure characteristics different from that of cast aluminum alloy and determined the unique mechanical properties of aluminum powder metallurgy alloy.

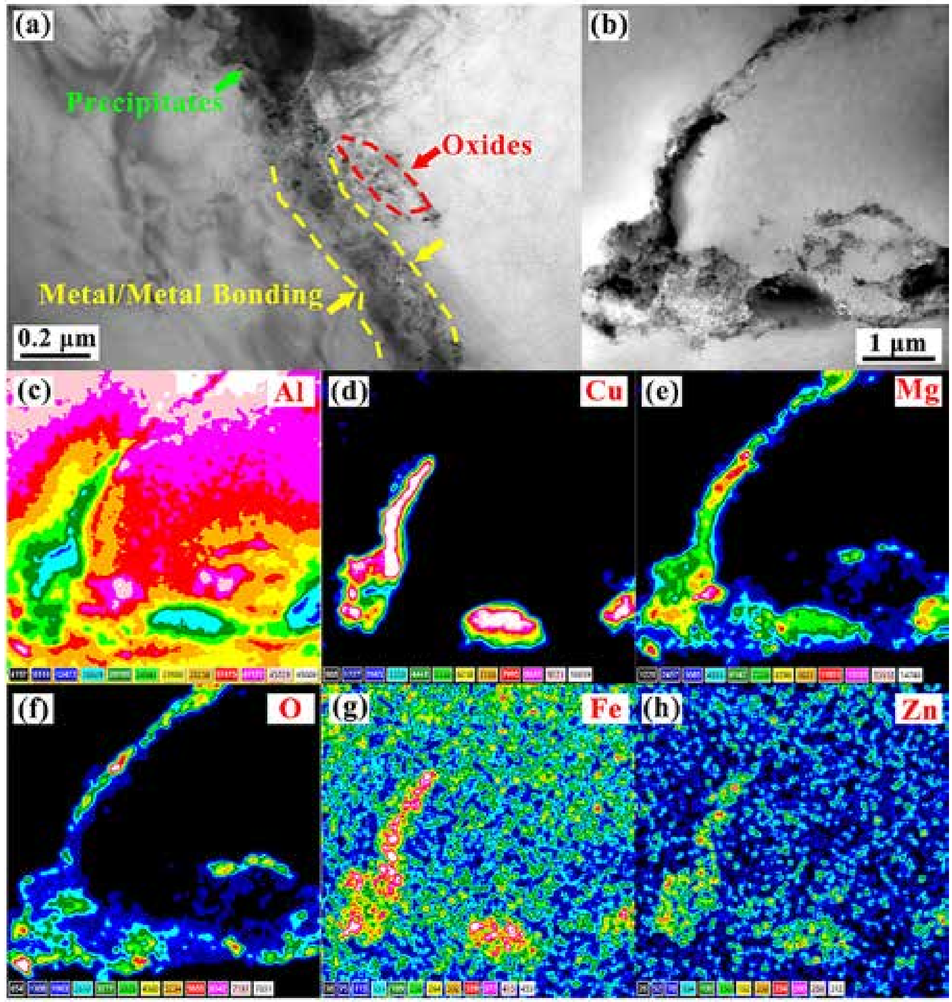

Figure 9: TEM analysis inside powder of the aluminum sintered under 0.1 MPa at 575°C: (a) dislocation, (b) grain boundary, (c) precipitates are bright field images respectively; EDS-acquired elemental maps of (d) Cu, (e) Mg (f) Mn, (g) Fe, (h) O in (c).

3.3 Tensile properties and fracture characteristics

Figure 10 shows the tensile properties of aluminum prepared under different sintering conditions and the comparison with other literatures. Figure 10a and c present the average ultimate tensile strength (UTS) at 525°C and 575°C respectively. It can be seen that the UTS of pressureless sintering aluminum was far inferior to that of pressure sintering at the same temperature, while the UTS of the aluminum alloy sintered under 0.1 MPa at 525°C was 153.46 MPa and further reached 226.18 MPa with the temperature rising to 575°C, which was already superior to that of cast 2024-T1 aluminum alloy as specified in ASTM B595. For higher loading pressure (10 MPa), the tensile strength of sintered aluminum was always higher than that of low-pressure sintering. But the UTS gap between 226.18 MPa and 233.64 MPa was close at 575°C. For powder metallurgy aluminum with powder as a structural unit, the mechanical property mainly depended on the bonding state between powders. The loading pressure not only increased the relative density of the sintered aluminum,

It was difficult to achieve densification of pre-alloyed aluminum powders prepared via pressureless sintering. However, low-pressure sintering was suitable.

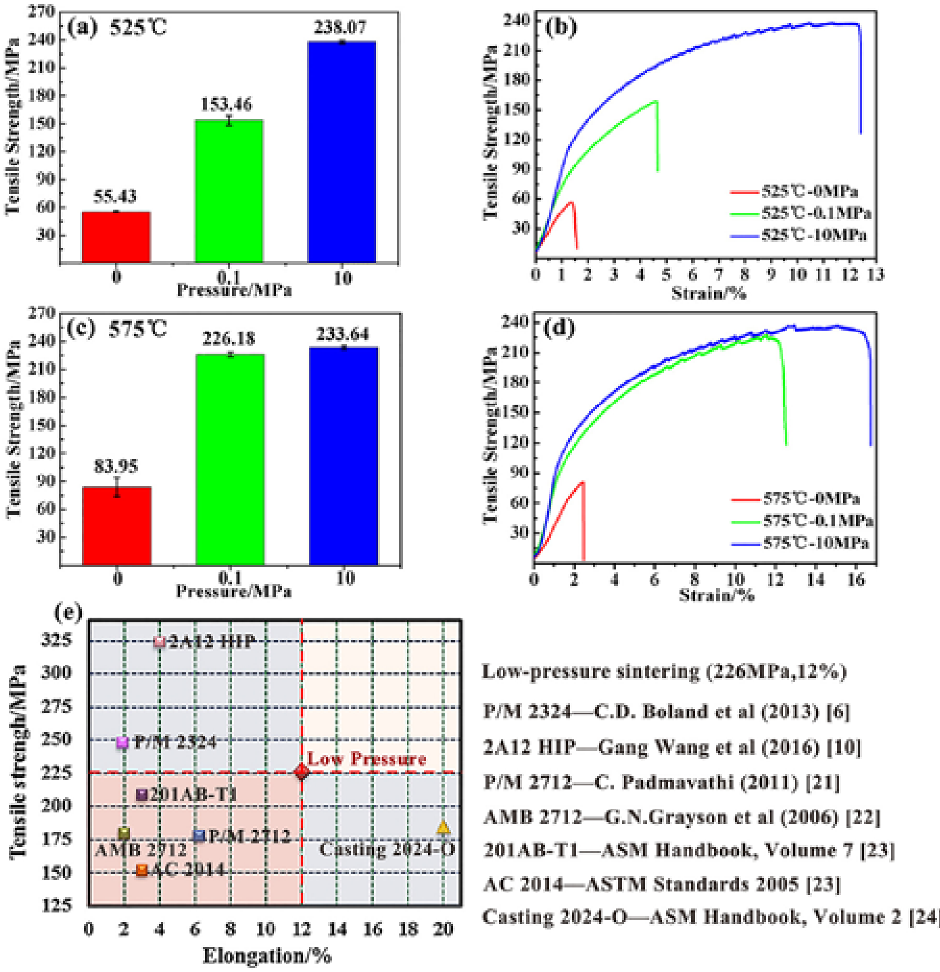

Figure 10: Tensile properties of aluminum alloys sintered under different pressure states: (a) the UTS at 525°C; (b) the stress–strain curves at 525°C; (c) the UTS at 575°C; (d) the stress–strain curves at 525°C; (e) Comparison with other literatures.

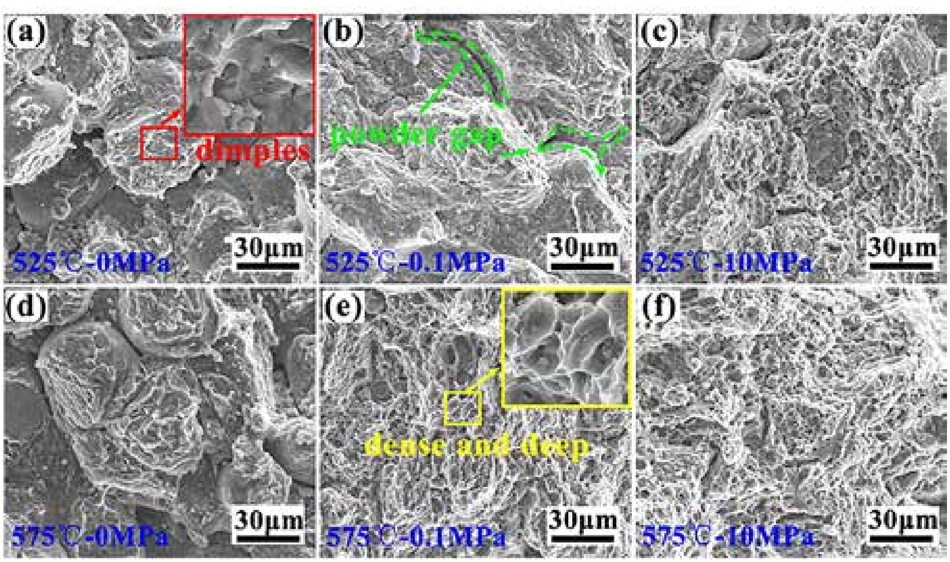

Figure 11: Fracture morphology of aluminum alloys sintered under different conditions: (a) 525°C, 0 MPa; (b) 525°C, 0.1 MPa; (c) 525°C, 10 MPa; (d) 575°C, 0 MPa; (e) 575°C, 0.1 MPa; (f) 575°C, 10 MPa.

but it also destroyed the initial oxide layer on the surface of the particles, which promoted the metallurgical bonding between the aluminum powders. Apparently, the higher the pressure meant the better tensile properties.

According to the stress–strain curves of all the specimens (Figure 10b and d), the plasticity of sintered aluminum also exhibited the similar rule of the tensile strength. Among them, the elongation of the aluminum sintered under 0.1 MPa at 575°C was almost 12%. A comparison of low-pressure sintering 2024 aluminum with other literatures is exhibited in Figure 10e [6, 10, 21, 22, 23, 24]. Apparently, the ductility of low-pressure sintering aluminum is superior to other similar aluminum PM alloys, and the tensile strength is also higher than that of casting 2024 aluminum at the O state, which means the low-pressure sintering helps APM achieve a good balance between ductility and strength.

Combined with tensile properties mentioned earlier for low-pressure sintering of pre-alloyed aluminum powders, the key to obtaining good mechanical properties is a suitable sintering temperature. In this study, the suitable temperature was 575°C, which caused a significant decrease to yield strength of the powders and generated a small amount of liquid. Therefore, the low pressure is sufficient to close the residual pores and make the particles fully contact to destroy the oxide layer during sintering. In addition, according to the similar tensile properties of the aluminum sintered under 10 MPa at 525°C and 575°C respectively (238.07 MPa and 233.64 MPa), it can be assumed the mechanical properties of sintered aluminum will reach an extreme value if the bonding at the prior particle boundary is sufficient.

Figure 11 shows the fracture morphology of aluminum alloys that were sintered under different conditions. The fracture morphology of the pressureless sintered aluminum shows powders were not fully in contact with each other (Figure 11a and d), and the fracture left dimples at the powder connect surface, as indicated by a local magnification in Figure 11a. This indicated the failure mode was peeling along the powder boundary for pressureless sintered aluminum. After loading pressure, the plastic deformation of Al powders caused the compact to be tight over the entire surface. The fracture morphology of the specimen sintered under 0.1 MPa at 525°C was mainly composed of shallow dimples and tearing ridges (Figure 11b), which indicated the failure mode was mainly a quasi-dissociation fracture. Also, there were some powder gaps left at the fracture surface, as indicated by the green dashed line, which means the powder bonding was not strong enough under 0.1 MPa at a low temperature (525°C). With an increase in temperature, the consolidation between powders was firm and dimples at the fracture surface were distinctly more dense and deeper than that of 525°C, as seen by a local magnification in Figure 11e. The fracture mode of the low-pressure sintering aluminum obtained at 575°C was a typical plastic fracture, which consisted of compacts sintered under 10 MPa (Figure 11c and f).

4 CONCLUSIONS

From the above study on the microstructures and tensile properties of aluminum alloys that were sintered under different pressure states, the main conclusions are as follows:

» It was difficult to achieve densification of pre-alloyed aluminum powders prepared via pressureless sintering. However, low-pressure sintering was suitable.

» Due to squeezing out of liquids at supersolidus temperature, the loss of alloying elements such as Cu and Mg via low-pressure sintering was relatively less than that of 10 MPa, which was more beneficial for subsequent heat treatment.

» Although the structure and composition of the prior particle boundary were quite complicated, including precipitates and oxides, there were no micro-voids and cracks at the boundary, which indicated a good metallurgical bonding between aluminum powders formed via low-pressure sintering.

» A suitable temperature condition was the key for low-pressure sintered aluminum to obtain a good mechanical performance. The 2024Al powders sintered under a low pressure of 0.1 MPa at 575°C had a density of 2.732 g/cm^3 and a ultimate tensile strength of 228.16 MPa with ductility of 12%, which achieved a good balance of ductility and strength.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CASE STUDY

PARTNERING WITH THE MEDICAL INDUSTRY

The Vector ordered by SECO/WARWICK's partner operates well in many precision industry branches, such as aviation, automotive, and medicine. (Courtesy: SECO/WARWICK)

SECO/WARWICK has been involved with supplying key equipment for the advancement of medical applications, including a Vector® vacuum furnace to be used to manufacture X-ray and radiotherapy equipment.

By MACIEJ KORECKI

The high-tech medical industry is one of the most demanding in terms of standards, procedures, and technical parameters that must be met by the equipment involved in the production process. This is not surprising, because the complex components integral to medical equipment (e.g. RF components and components for X-ray tubes) must be characterized by maximum precision. They take part in processes that ultimately determine not only the treatment quality, but also human life. This is the reason when choosing the equipment for their hardening plant, medical equipment manufacturers are primarily guided by quality and reliability.

Equipment such as SECO/WARWICK's Vector vacuum furnace can be used to carry out heat-treatment processes during medical equipment production. The product is intended for annealing and brazing processes.

The Vector ordered by SECO/WARWICK's partner operates well in many precision industry branches, such as aviation, automotive, and medicine. The company sells a lot of devices for soldering processes used in industrial production. This time, the partner specializes in soldering complex elements that require very high precision.

MEDICAL INDUSTRY AND HEAT TREATMENT

The medical industry uses heat treatment to a very large extent. One of the SECO/WARWICK's partners is a surgical instrument manufacturer. Various hardening, tempering, and soldering processes are carried out to produce these types of parts.

"In surgical instrument production, properties such as strength, hardness, and corrosion resistance are taken into account," said Adam Adamek, Vacuum Segment Sales Team Manager at SECO/WARWICK. "The high quality of the processed elements can only be obtained by processing in vacuum furnaces. For surgical instruments, it is very common to perform hardening and tempering in one cycle in a vacuum furnace."

VARYING HARDENING TEMPS

Different materials require different hardening temperatures, for example: 980°C for the X20Cr13 steel grade or 1,050°C for the X39Cr13 steel grade. Then the tempering process is carried out at a temperature of 240°C to 300°C, which allows the material to obtain a hardness at approximately 45 HRC or even above 50 HRC. To achieve a sufficiently high quality, a high vacuum level is needed in order to obtain the perfect surface quality.

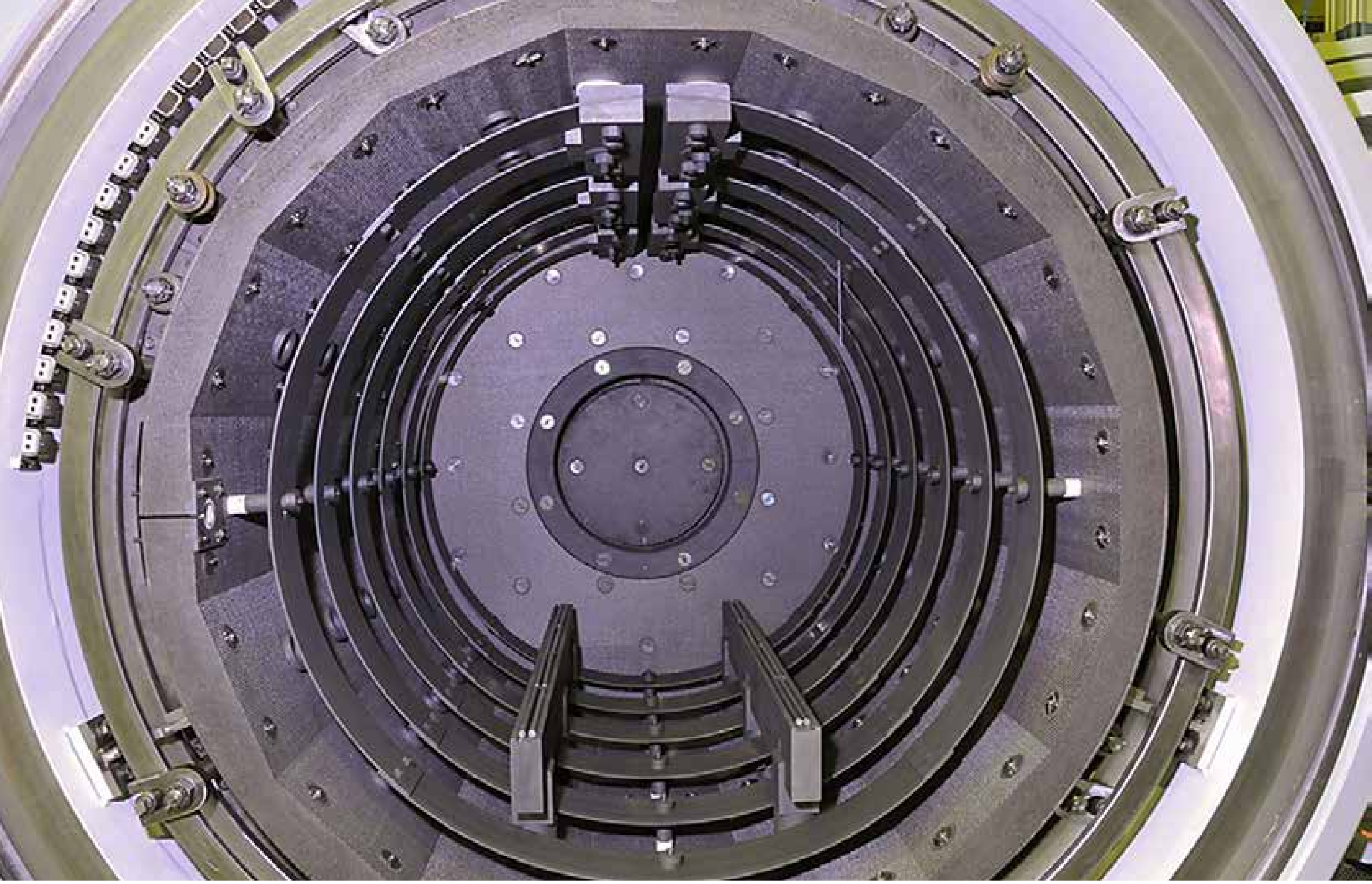
Tempering should be carried out immediately after hardening in the same furnace, without opening the door, thus minimizing the risk of oxidation. The ±5°C temperature distribution uniformity in the working zone is also very important. It determines the austenitization temperature accuracy of the entire load and each individual detail. Therefore, not only are the properties of the furnace itself crucial, but also the operator's experience in the load distribution. Failure to meet the temperature condition may result in a failure to reach the austenitization temperature or in overheating, which has an impact on the result of hardness, grain growth, and carbide separation.

Forged dies are also needed to produce surgical instruments. Scalpels, scissors, and other surgical instruments are forged from corrosion-resistant steel. Atmospheric furnaces are used to heat the dies before forging.

The Vector can be used in various technological processes: hardening, tempering, annealing, brazing, and sintering. (Courtesy: SECO/WARWICK)

The correct course for the entire process determines the appropriate tool life achievement, usually counted in thousands of cycles. High strength, ductility, hardness, resistance to abrasion at high temperatures, and thermal fatigue are the important parameters for forging dies used for manufacturing surgical instruments. Hardening processes should be carried out in vacuum furnaces with a high-pressure gas hardening system. Vacuum helps to avoid problems with decarburization and oxidation of the tool surface. In order to reduce deformation and the risk of tool breakage, the die hardening furnace should be equipped with an isothermal cooling function.

Another important element of the furnace equipment is convection heating, which enables the tempering process immediately after hardening, but it also results in the load's effective uniform heating at low temperatures (reduction of thermal deformation).



SECO/WARWICK's Vector vacuum furnace can be used to carry out heat-treatment processes during medical equipment production. (Courtesy: SECO/WARWICK)

3D PRINTING IN THE MEDICAL INDUSTRY

Year by year, 3D printing technology plays a greater role in the dental, medical, and ophthalmic industry, because the medical industry, which produces implants, more and more often produces them with the incremental method. Vector 3D furnaces using annealing processes are perfect to produce these elements.

SECO/WARWICK'S EXPERIENCE IN THE MEDICAL INDUSTRY

Apart from the examples described, SECO/WARWICK has a very large portfolio of customers from the medical industry. An interesting example is a company producing venous stents. This customer uses the Vector HV furnace to anneal the components needed to manufacture the stents.

Another SECO/WARWICK partner — Karlsruher Institut für Technologie — uses heat-treatment furnaces for the elements needed to build gyrotrons. Gyrotrons are used in nuclear magnetic resonance imaging and in magnetic resonance microscopy for medical diagnoses. In this case, the VR retort furnace with vacuum purging is used.

VECTOR® FOR THE MEDICAL INDUSTRY

In the SECO/WARWICK Group portfolio, the Vector® is by far the most versatile vacuum furnace. The Vector can be used in various technological processes: hardening, tempering, annealing, brazing, and sintering. Its characteristic feature is the low consumption of power and process gases while maintaining high efficiency processing. This most popular solution in the vacuum segment has already found its way to manufacturers of aircraft landing gear along with tool and die extrusions used for aluminum or dental implants.

SECO/WARWICK furnaces from the Vector line prove themselves not only in the brazing processes involved in simple element mass production, they are also perfect for soldering and annealing in the high-tech industry, where the focus is on small precision elements, and the production process itself has many variations related to the selection of materials and shapes of soldered elements.

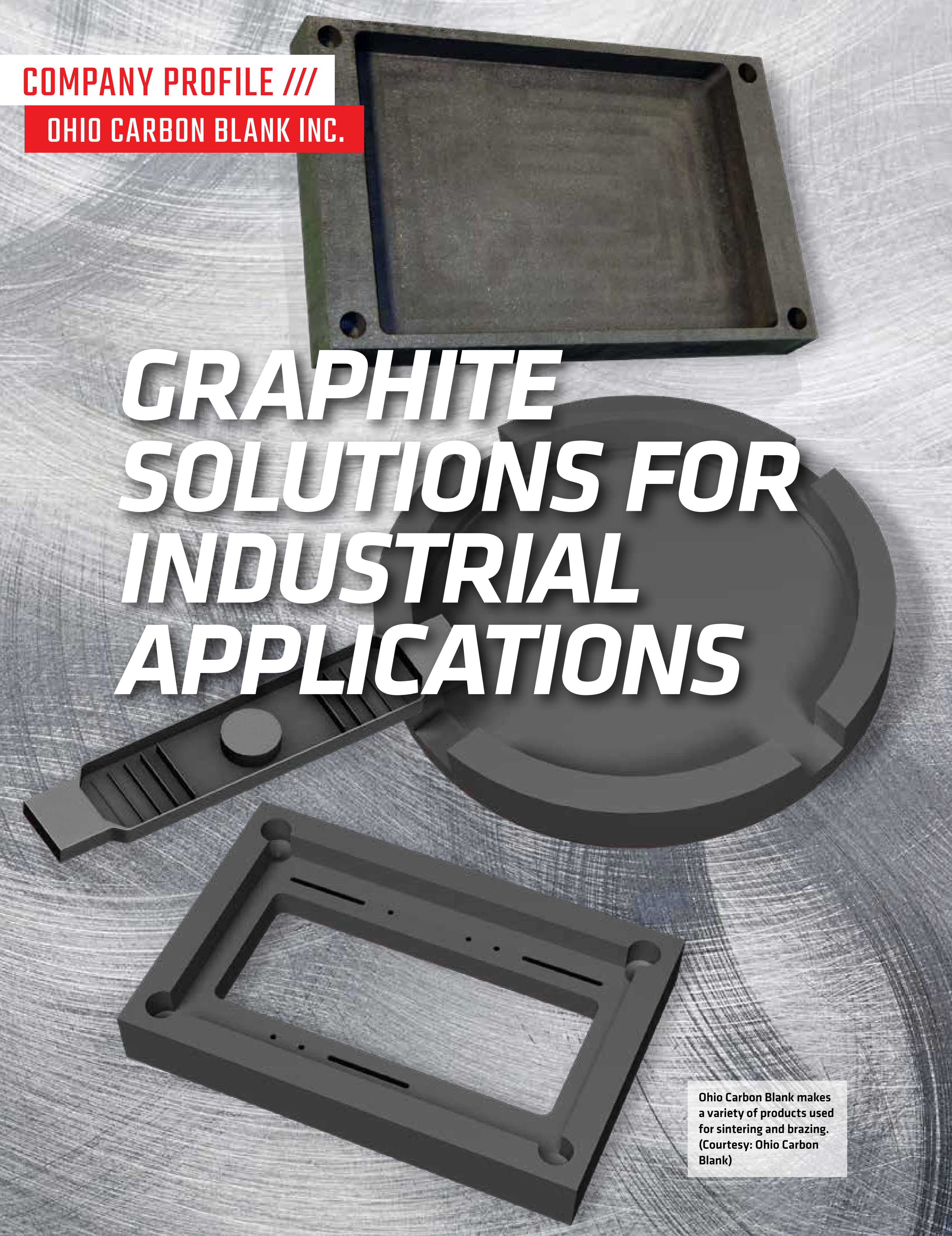
ABOUT THE AUTHOR

Maciej Korecki is vice president, Business Segment Vacuum Heat Treatment Furnaces for SECO/WARWICK S.A. He is involved in the research and development of vacuum heat treatment equipment and technology and their implementation into a new area of industrial applications. He is an inventor and promoter of the "single-piece flow" vacuum heat treatment method. Korecki graduated from the University of Zielona Góra in 1988, where he received his Master's Degree in electrical engineering. He completed his Ph.D. at the Łódź University of Technology in 2008 with his thesis on the theoretical and experimental methods of design for vacuum furnaces. He has authored numerous international patents on behalf of SECO/WARWICK and regularly presents technical papers at international conferences on a variety of topics, specializing in vacuum heat treatment technology. He began his career at Elterma in 1988 as a service engineer for vacuum furnaces. He then joined SECO/WARWICK in 1991 as a service engineer and then service manager on the Vacuum Team. In 2005-2009, he served as an R&D Director, leading the team that developed new equipment and processes, such as low-pressure carburizing and high-pressure gas quenching. He served as Director of the Vacuum Team in Europe from 2009-2012. Then he has become the Vice President of the global Vacuum Product Group.

COMPANY PROFILE ///

OHIO CARBON BLANK INC.

GRAPHITE SOLUTIONS FOR INDUSTRIAL APPLICATIONS



Ohio Carbon Blank makes a variety of products used for sintering and brazing. (Courtesy: Ohio Carbon Blank)

Ohio Carbon Blank Inc. offers graphite products and CNC machining for the EDM and mold-making industries, including heat treating, glass industry, and many others.

By KENNETH CARTER, Thermal Processing editor

When parts need to be brazed, sintered, or heat treated, they often need a suitable substrate, holder, or fixturing to hold them in place as they are exposed to the high temperatures frequently associated with vacuum-furnace applications. But who supplies these high-temperature materials, and who makes these niche products?

Ohio Carbon Blank is one of the major players. It has been making custom graphite plates for brazing and sintering applications, as well as custom fixturing for welding and heating-treating applications for more than 10 years. In addition to specialty plates, trays, and fixturing, Ohio Carbon Blank also manufactures heating elements and various other internal components for these vacuum furnaces.

Ohio Carbon Blank has been providing graphite materials and specialty graphite machining services for more than 40 years. From the ’80s to the early 2000s, Ohio Carbon Blank was a leader in the electrical discharge machining industry, providing precision ground blanks and finished electrodes for those needing to machine intricate details into exceptionally hard, difficult-to-machine materials.

Over the years, however, the company has evolved, expanding materials and investing in new machinery and advanced inspection capabilities. A number of high-speed, precision CNC machines give Ohio Carbon Blank expanded capabilities, as well as improved efficiencies to tackle nearly any sized job. When it comes to graphite machining, OCB has many years of experience grinding, milling, turning, drilling, and tapping graphite. As a result, the company is often referred to as the graphite machining experts.

“Due to increasing demand from the vacuum furnace industry, we have been producing more and more custom plates, trays, and fixtures for these particular vacuum-furnace applications; products machined-to-print that furnace operators can safely put into their furnaces and not risk damage or deformity,” said Paul Geoffrion, sales manager at Ohio Carbon Blank Inc. “That includes heat treating, brazing, welding, and sintering, too. We have clients that use graphite for the sintering trays because it simply lasts longer than the ceramic counterparts. At the end of the day, graphite tends to be more economical and cost efficient.”

‘QUICK TURNAROUND’

“Our goal is to be the primary supplier for CNC machining of items for thermal management and many other industries,” he said. “That means we offer rapid turnaround of machined-to-print products at competitive prices. Our current lead times are seven to 12 days, as opposed to many other suppliers that are six to eight weeks.”

That quick turnaround is a guiding principle with Ohio Carbon Blank, and Geoffrion emphasized it’s one the entire company takes seriously. Ohio Carbon Blank has gone to great lengths to grow and be competitive.

“We have multiple CNC machines to manufacture orders to our customers’ requirements,” he said. “We have the inspection equipment and expertise to ensure customer requirements are satisfied.

Ohio Carbon Blank recently added a new Keyence inspection machine that can help speed up the inspection process. (Courtesy: Ohio Carbon Blank)

“Our philosophy is to give our customers good quality made-to-print products that are shipped within the quoted lead time. We maintain a 95 percent or greater ‘on-time shipping’ standard that is part of our ISO 9001:2015 requirement. We can work with any freight company to ship our customers’ orders. We’ve been ISO certified for over 20 years, which has helped us streamline and make our processes more efficient. We’re always striving for continuous improvement as well.”

According to Geoffrion, getting a job completed quickly is essential, but equally important is Ohio Carbon Blank’s ability to get a quote out as fast as possible.

“Our capabilities for quoting custom jobs include a very knowledgeable engineering department and an experienced CNC department,” he said. “We can typically turn quotes around in a day or two, depending on complexity and number of drawings. We try to get things done quickly and efficiently for our customers. We know that time is money.”

Making sure a customer has what they need when they need it is

Ohio Carbon Blank has 40 years of graphite machining experience. (Courtesy: Ohio Carbon Blank)

crucial, according to Geoffrion; communication with the customer is key.

"They'll give us drawings of a fixture or an item they may want, and we work with them to ensure that the print reflects exactly what they need, including any specified tolerances, etching, or any special handling requirements," he said. "If they have a challenging application, we can recommend materials that may be better suited than what they might be currently using."

> *"We're into an array of fields now. Graphite is very unique and versatile. It's a fascinating material."*

EXPERT ADVICE

That's an important feature to have when a customer calls for a quote. Geoffrion and his team can often suggest a more straightforward or economical solution.

"A customer will send a print that has squared pockets, and we've gone back to the customer and said, 'If we use a rounded end mill here and have a radius at the bottom, that would save machining time, and in turn, save you money. Would that be acceptable for you?'" he said. "That's opposed to us having to order a custom tool or maybe spend extra time. It might be more cost-effective to use a tool we already have on hand. We have done things like that in the past, especially when customers may not know the design process."

Ohio Carbon Blank has a variety of materials to meet just about any heat-treating application need, according to Geoffrion.

"And if our customer needs a specialty grade of graphite material, we can usually acquire it," he said. "We've evolved as industry and applications have evolved. We are expanding our CNC department with new equipment for more diversity."

EFFICIENT PART INSPECTION

According to Brian Strollo, sales and marketing engineer, the company recently added a new Keyence inspection machine that can help speed up the inspection process.

"That machine is very effective and has 3D-video capability, so basically, it can look at a part and identify whether the part is within tolerance immediately," he said.

Geoffrion also praised the inspection machine and its capabilities.

"This newly acquired machine provides accurate readings for our inspection data sheets and is a great compliment to our existing line of inspection devices," he said.

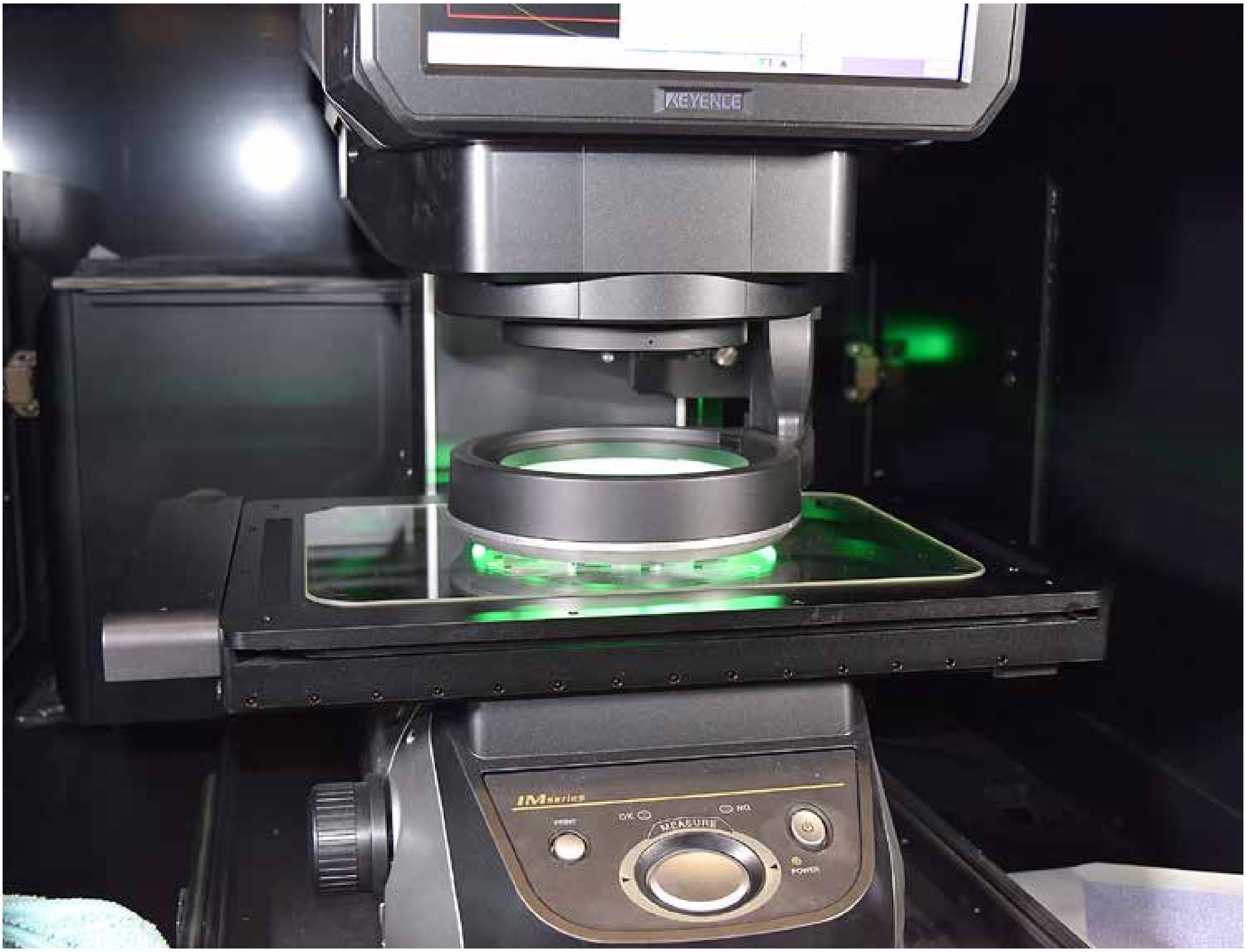
GRAPHITE: A MULTI-FACETED MATERIAL

Although graphite is a valuable material for heat treating, it is also used in many other applications as well. Strollo said the company is involved in many fascinating new applications, well beyond the conventional uses; i.e. electrical discharge machining, mold making, die castings, and typical thermal management applications.

"We're into an array of fields now," he said. "We have companies that use our graphite materials for human tissue growth; some use graphite as a substrate material to grow diamonds, and now we are using graphite in modern batteries, sensors, and various electronics, too. Graphite is very unique and versatile. It's a fascinating material."

ONLINE QUOTES AND ORDERING

Many of Ohio Carbon Blank's customer needs involve standard size rounds, rectangles, hexes, etc., according to Geoffrion, and making sure customers can get parts and get them quickly falls on Ohio



Ohio Carbon Blank has advanced inspection capabilities. (Courtesy: Ohio Carbon Blank)

Carbon Blank's unique online quoting and ordering system for these types of standard items.

"Customers can log in, get quotes for materials and order them online immediately — immediate pricing, immediate order placing," he said. "Now, that does not support custom machine-to-print items; it's used just for general shapes such as rectangular, rounds, squares, or hexagonal items. Our Graphimator® is a patented piece of software, and we are the only company among our competitors to have that."

Geoffrion said Strollo was instrumental in the development of this unique ordering system. His expertise has allowed the company to continue improving and maintaining the functionality of the Graphimator®.

"It allows orders to be placed with a variety of surface finishes and tolerances," he said.

And Geoffrion said the company will be launching a new website soon.

"It will have a smoother interface and allow customers to upload drawings or send RFQs right through the website," he said. "Another unique feature that Ohio Carbon Blank and the Graphimator® offers is a 'bulk upload' in CSV format for orders with a high number of line items."

40-PLUS-YEAR HISTORY

Ohio Carbon Blank opened its doors in 1979 after owner Scott Boncha saw the need first hand, according to Geoffrion. Boncha had been working in a machine shop that ran electrical discharge machines where they were hand grinding and making all of their own electrode blanks for the EDM process.

"It's time-consuming and messy, so he got the idea of opening a machine shop where he could manufacture those EDM blanks," Geoffrion said. "It was a niche business, and that had been the bulk of our work. But in the last 10 or so years, we've branched into non-EDM applications and industries for the vacuum-furnace industry, among others. We supply to anybody who has a need for graphite."

Additionally, Strollo stressed a point of pride that Ohio Carbon Blank has been able to continue to supply customers despite the challenges many have faced.

"We have not only endured, but in some cases, we have even grown," he said.

Strollo also pointed out that the company seeks to become more involved in other areas such as the steel industry, aerospace, and defense as Ohio Carbon Blank moves into the next decade.

"There is always a high demand for strengthened materials and heat treating," he said.

MORE INFO www.ohiocarbonblank.com

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ADVERTISER INDEX ///

COMPANY NAME	PAGE NO.

KENDALL DEVANE /// REGIONAL SALES MANAGER /// THERMAL PROCESSING MAGAZINE

"My No. 1 goal is to familiarize myself as much as I can about what a client's needs are and how they want to use those needs to make an impact on the heat-treat industry."

Thermal Processing welcomes its newest sales representative to its staff, Kendall DeVane. He has 20 years of experience in sales and promises to bring his unique style and acumen to making sure advertisers get the best possible exposure with our readers.

What about the heat-treat industry most excites you?

It might sound like an odd fit, but I actually come from a background in the golf industry. During my time primarily teaching and fitting clubs, I became fascinated by how the various metals perform — whether they're used primarily by themselves in an application or blended into an alloy. I've had the pleasure of watching how clubs are actually manufactured, so learning more about how they are cast, forged, or milled has always intrigued me.

That being said, I simply like to learn how products are made, from beginning to end, and being involved in the heat-treat industry in this new capacity will allow me to learn a lot.

How do you approach a potential client who you feel should be advertising in *Thermal Processing*?

Any new or existing client almost always has their own unique approach to how they see their products or services. But with any potential client, I want to make sure I know what they are looking for and the direction they want to take their marketing agenda.

In order to do that, my No. 1 goal is to familiarize myself as much as I can about what a client's needs are and how they want to use those needs to make an impact on the heat-treat industry.

I try to achieve this goal by making sure I'm always available to make the client-sales rep relationship a collaborative effort where we can work together to develop the best marketing strategy available in order to let our readers know that client is making the best products and supplying the best services that they can, yielding the greatest results.

What part of your sales background has most prepared you for interacting with the heat-treat industry?

It's important as a sales rep to realize that, even though I expect the best results for both me and my client, I also realize that every relationship isn't going to be perfect. As a matter of fact, sometimes it might not be a good fit at all. However, sometimes those bumps in the road can lead to an even better understanding of the client, which can translate into a huge boon in sales for whatever the client may be offering.

One of the best sales reps I have ever had the pleasure of working with used to tell me that it was his job to present everything he could, in the best way possible, and it was the client's job to make a decision. He simply explained the benefits and features of each product. That is a philosophy that I have adopted with those I am working with. If you truly believe in the product you represent, presentation and explanation often can take the place of selling.

Ultimately, in my opinion, the results a client can get by working with *Thermal Processing* will speak for themselves while bringing them back for more collaborations.

As you learn more about the many aspects of heat treating, what do you see as the No. 1 need when it comes to businesses sharing what they can do with the industry at large?

From my perspective, we have to be able to find the most efficient ways to connect with the greatest number of heat-treaters possible.

As with many things in life, it can all boil down to communication. That is something I have become most impressed with during my brief time with *Thermal Processing*.

The magazine offers such a great array of choices that enable our customers to get the word out to the industry about their amazing products and services — no matter if the platform they choose involves print, digital, or, ideally, a combination of the two.

Personally, I enjoy being hands-on with the community storefronts, allowing us to share company information, websites, and all the social media a client has at their disposal to make sure they're not shouting into a vacuum, but getting in touch with the heat treaters in need of what they can offer.

What parts of *Thermal Processing* do you feel have most surprised you about the heat-treat industry, and why?

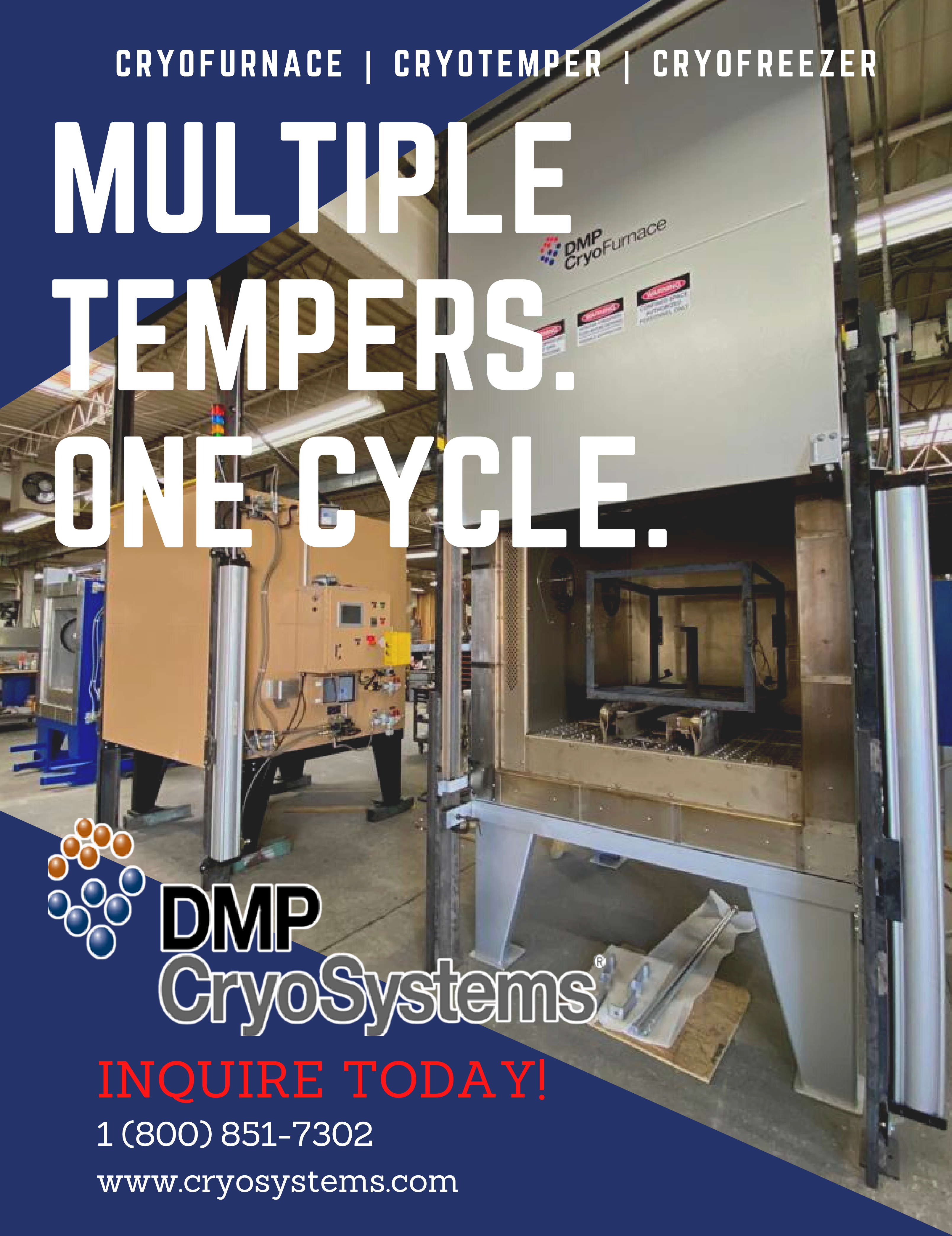
Bottom line: I have become firmly enthralled by this incredible industry, and I really didn't see that coming.

I find myself voraciously reading articles and watching videos in order to learn how something is created, as well as all the processes involved from start to finish.

After that, I often go back and reread or re-watch to see if I might have missed something.

I want to learn all I can about every aspect of this industry, and I have been truly blessed to be able to learn from the staff here. I'm also learning from the very companies I represent as they patiently work with me and explain what they can do for the heat-treat industry, because I know what they do is important to the fabric of our everyday lives. And for all that and much more, I'm very grateful.

MORE INFO kendall@thermalprocessing.com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