Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

BURNERS & COMBUSTION / INSULATING MATERIALS

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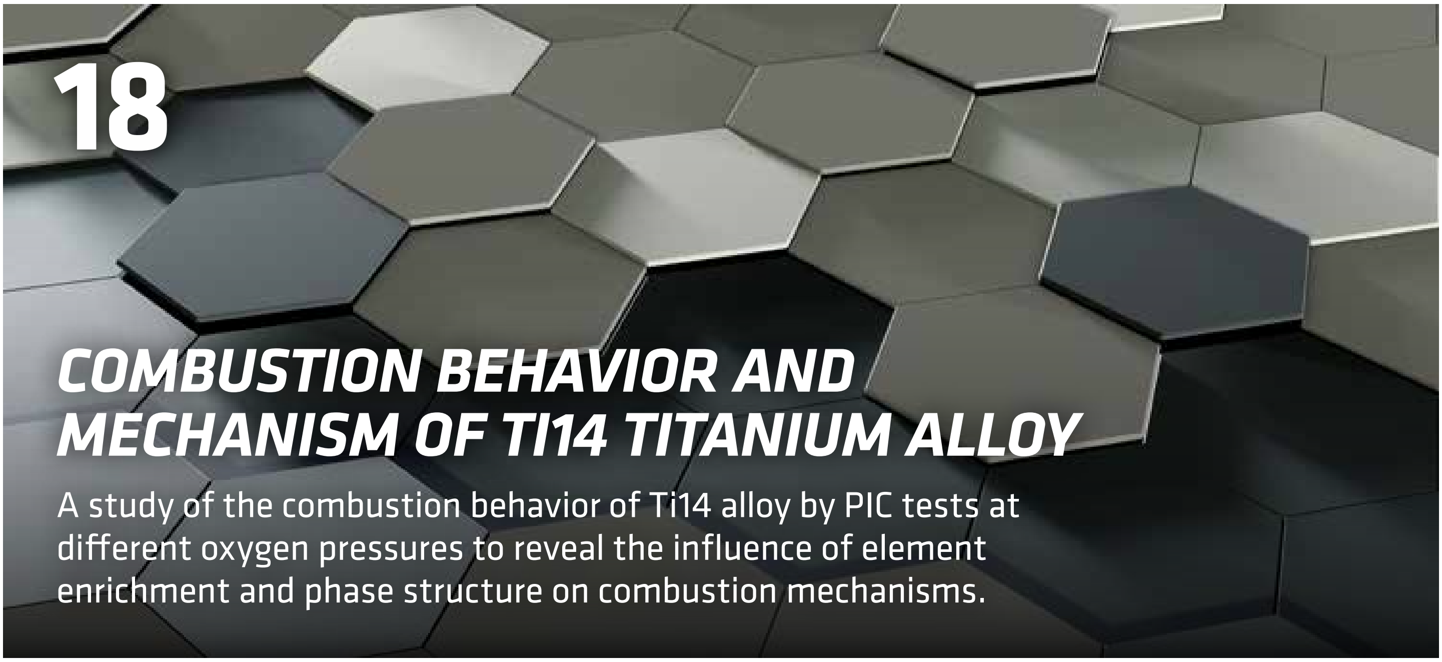
CONTENTS ///



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DEPARTMENTS ///

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FROM THE EDITOR ///

Introducing our new Media Portal

I know 2021 still feels a little like 2020, Part 2, but I think this year will have its own share of surprises — the good kind. But you know what they say: An optimist sees the glass half full; a pessimist sees the glass half empty, and a physicist sees the glass as completely full no matter what his mood is. (I'll give you a minute to process that one.)

While you ponder, I want to share some news about an exciting new feature that we recently launched on our website: *Thermal Processing's* Media Portal.

When you enter the Media Portal through our nav bar, you'll discover what we think of as a "one-stop shopping" tool for heat treaters looking for the newest and latest information social media has to offer.

At the top of the new page, you'll have the opportunity to gain access to posts from Facebook, Twitter, and YouTube from a wide range of heat-treating companies across the U.S. and around the world. Scroll to find a company you're interested in, and click the name. If they have posts on social media, you'll find them immediately. No need to search endlessly across the various platforms. We make sure it's all there for you.

We feel that's pretty cool, but that's not all our Media Portal can do for you. If you're looking for webinars, blogs, and podcasts, we give you access to those as well. And this service is for the companies responsible for webinars, blogs, and podcasts as much as it is for our readers in search of them. If you have a webinar, blog, or podcast, send us a link, and we will make sure readers can access it through our Media Portal.

Check it out, and let me know what you think. If you have suggestions to make it even more user-friendly, send them my way. After all, *Thermal Processing's* ultimate goal is to make sure heat treaters get the best information about the industry that's available.

And, as long as I have you here, check out some of the cool features available in this issue of *Thermal Processing*. We're focusing on burners and combustion, as well as insulating materials.

We're also bringing to you the first in a six-part series of articles from regular contributor Jason Schulze, where he will deconstruct the requirements of the AC7102 standard. A new part of the series will publish every other month through December.

I hope you enjoy this issue, and I hope you get to spend some time with our new Media Portal. We're pretty proud of it, and we think you'll find it very useful going forward.

As always, thanks for reading!

KENNETH CARTER, EDITOR
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David C. Cooper
PRESIDENT

Teresa Cooper
OPERATIONS

The furnace working zone measures 48" W x 48" H x 72" D, includes the SolarVac® Polaris control system, and is AMS2750F compliant. (Courtesy: Solar Manufacturing)

Solar Manufacturing ships furnace to West Coast

Solar Manufacturing shipped an external quench vacuum furnace to a West Coast aerospace manufacturer. The Model HFL-7472-2EQ features an all-metal hot zone, a load weight capacity up to 10,000 pounds, a maximum operating temperature of 2,400°F, and a 2-bar quench system optimized for argon with a 150 HP quench motor and a variable frequency drive. The furnace working zone measures 48" W x 48" H x 72" D, includes the SolarVac® Polaris control system, and is AMS2750F compliant.

The furnace will be primarily used for vacuum heat-treating investment castings for the aerospace industry.

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

Tenova to supply electrolytic tinning line for PERSTIMA

Tenova, a leading company specialized in innovative solutions for the metals and mining industries, has been contracted for a 200,000 ton/year new high-speed electrolytic tinning line with insoluble anodes by Perusahaan Sadur Timah Malaysia (PERSTIMA) Berhad, premier producer and supplier of high-quality tinplate in South East Asia. This cutting-edge technology will be implemented in PERSTIMA's plant in Batangas (Philippines).

The electrolytic combined tin-plating and tin-free steel line will work at 550 meters/minute at entry/exit and 420 at the process section, for annual production of 200,000 tons. The steel strip will be 550-1,000 mm wide and 0.10-0.60 mm thick, and the line will process all the main grades of steel for a product mix that will satisfy the most recent demand of the high-quality market. A minimum tin coating thickness of 1.1 g/m^2 is guaranteed.

The line is equipped with a dedicated section (cells and recirculation equipment) for the production of tin-free steel process as well. Tenova will provide the state-of-the art automation with an enhanced Web-based Level 2 and Roll Management Software to automatically schedule roll activities in the processing line.

"Tenova insoluble anodes technology will permit an easier handling of the process section with highest safety for the operators. Tenova developed an advanced system for the tin-dissolution reactors, achieving very low tin losses in the sludges. This represents a very positive aspect both for economic and environmental reasons," said Giuseppe Zanzi, Tenova Italimpianti & Strip Processing sales manager SEA & India.

"This new project will allow our customer to address the request of higher quality tin-

The Tenova electrolytic line is expected to be put into operation by Q4-2021.

plate and TFS in the region, confirming our position in high-standards tin- plating market, after previous important contracts in Spain and in China, among the others," said Stefano Marelli, Tenova global sales manager South East Asia.

Finally, a further improvement in the quality of the tin plate has been achieved through the development of special edge-masks. These devices prevent the "white edge defects" due to tin overcoating at the edges while processing strips with different widths. In addition, Tenova edge-mask design guarantees easy inspection and access to the cell.

Tenova Insoluble Anode Technology with IGBT Rectifiers globally permits a large operating saving in tin and electrical consumption, guaranteeing the top of quality. The electrolytic line is expected to be put into operation by Q4-2021.

MORE INFO www.tenova.com

L&L ships large, fiber-lined box furnace

L&L Special Furnace Co. recently shipped a highly uniform box furnace to a major aerospace manufacturer in the southeastern United States. The state-of-the-art facility will be opening soon and be a central part of a new heat-treating center for aerospace and military components.

The Model FB666 is a front-loading box furnace with a pneumatic vertical door. Its working dimensions are 60" wide by 60" high by 60" deep. There are a series of castable piers and an alloy grid that supply a very stable work platform for various part sizes and configurations.

The furnace has a high-convection, air-cooled fan for air circulation and excellent uniformity at low temperatures. It was surveyed for performance prior to shipping and obtained certified temperature uniformity of ±10°F from 500°F to 2,000°F. There is also a Venturi cooling system to aid in the cooling of the furnace interior along with an external modulating case cooling blower that provides fresh air intake to keep the furnace case temperature low during operation.

L&L Special Furnace Company's Model FB666 for aerospace components. (Courtesy: L&L)

A manual 2,000-pound loader with rails and incorporated stops allows for the furnace to be easily loaded and unloaded. The loader moves on two low-profile rails and is indexed to the furnace front. Positive stops keep the furnace loader in line and prevent accidental impact with the rear or sides of the furnace.

The furnace is controlled by a Eurotherm program control with overtemperature protection. A 12-channel video recorder and jack panel are included to record all required furnace thermal data. The resistance elements are driven by SSR power controls with biasing for balancing of temperature gradients. There is a stack light that is an audible and visual indicator of current furnace status. The control panel is a modular floor-standing NEMA12 panel with fused disconnect.

Built in accordance with strict customer guidelines for safety, the furnace includes a light shield for operator and furnace interface safety, as well as an access ladder with multiple roof tie-off points for safety latches. It has a secondary shell with a heat shield to ensure very low case temperatures at operating temperatures. The electrical system is completely isolated, with hazardous voltage contained in an enclosure that has a preventive lock for unauthorized access.

The furnace was designed, built, assembled, and tested at L&L's manufacturing facility located just south of Philadelphia.

MORE INFO www.llfurnace.com

Wayland Additive postpones launch events

Wayland Additive postponed both its virtual and physical launch events scheduled for the January 27 and 28 following a statement from U.K. Prime Minister Boris Johnson. The virtual event will now be March 16, 2021, and the physical event will be May 19, 2021, when it is expected there will be a significant degree of relaxation of COVID-19-related restrictions.

Will Richardson, CEO of Wayland Additive, said, "In light of the recent government announcements that have placed the United Kingdom into a third national lockdown, and with travel within the UK and from abroad likely to be severely affected, delaying the physical launch event to a time that should see us better able to operate normally seems the prudent thing to do. As for the virtual event, before Christmas, we were well advanced in producing the creative elements needed for the event with third parties, but now all such activities are impossible to complete safely and in compliance with the new regulations until they are relaxed. It is obviously disappointing to have to delay — both for us as a company and for the many attendees that have registered — but on the other hand we want to ensure that we provide an optimal experience for everyone."

In preparation for the original events, the team at Wayland Additive has been busy finalizing the Calibur3 machines in the newly refurbished production facility at its Huddersfield, UK, site. (Courtesy: Wayland Additives)

In preparation for the original events, the team at Wayland Additive has been busy finalizing the Calibur3 machines in the newly refurbished production facility at its Huddersfield, U.K., site and also preparing an array of parts produced using the patented Neubeam metal Additive Manufacturing (AM) process. In between now and the newly scheduled events, information on these parts and other developments will be revealed in more detail with an eye to making sure that the interested base of industrial users remains well informed as to the possibilities that Wayland's technology opens up.

Peter Hansford, director of business development, said, "In a way, we can make a positive out of a negative now that we have been forced to delay our January events. We will continue to provide information that shows just how advantageous our Neubeam® process is when looking at metal AM applications between now and the events, which will mean attendees are better informed, and will therefore be in a better position to engage with application specific questions at the events. We will of course be able to host individual companies as usual at our premises over the coming weeks in a COVID-secure way, but are determined to make the mass attendance events as comprehensive and useful as possible for all attendees."

Wayland Additive is promoting innovation in metal AM for production applications, which it achieves with the establishment of its proprietary and innovative NeuBeam® process as the go-to solution for a range of manufacturing applications across various industrial sectors. NeuBeam is a groundbreaking metal AM process that effectively neutralizes the electron beam (eBeam) powder bed fusion (PBF) process to offer greater flexibility than laser-based AM processes while overcoming the stability issues many users of traditional eBeam AM systems experience. In addition, the NeuBeam process enables metallurgical requirements to be tailored to application requirements, rather than the previous limitations of the process, to produce optimum results.

Anyone who has already registered for the events will be contacted. All interested parties are still able to register their interest in attending the newly scheduled virtual and/or physical events online.

MORE INFO www.waylandadditive.com

Thermal Care introduces new outdoor chiller

Thermal Care Accuchiller KSE outdoor air-cooled chillers 40- and 120-ton models. (Courtesy: Accuchiller)

Thermal Care has a new outdoor packaged chiller designed with the flexibility to provide process cooling year round, with a wider range of operating conditions than comparable models. Accuchiller KSE Series chillers are fully packaged, integral air cooled outdoor units manufactured to work in the harshest weather environments. Units are factory tested and ready for easy installation — just run piping and power to the unit and it is set for operation.

One of the great features of this new outdoor chiller is the variety of climates where it can be used. Energy saving variable speed EC fans allow the chiller to withstand ambient conditions from 20°F to 125°F. As a bonus, the process fluid circuit allows for more flexibility with a set point temperature range from 20°F to 80°F.

KSE Series chillers come with an advanced outdoor PLC control system with ModBus TCP/IP & RTU and a 7-inch color touch screen similar to the controllers used on Thermal Care's Accuchiller NQ Series portable chillers. This robust control system provides premium performance and extensive diagnostic capabilities with a multitude of communication options making it IIoT ready including OPC/UA, BACnet MS/TP, BACnet/IP and LonWorks. Screen layouts are improved to simplify finding data in an easy-to-follow format. Connecting to Thermal Care's optional CONNEX 4.0 system allows for integrated connectivity and secure remote access to all related connected equipment.

Peter Armbruster, director of sales and marketing at Thermal Care, said, "We have worked on the development of this new product line over the last 15 months and are very pleased with the results. KSE Series industrial chillers are a new approach to outdoor chillers that can withstand the toughest ambient elements while still providing precise control for your process. The standard set point temperature range is from 20°F to 80°F. Competitive units require you to purchase options to achieve this level of control." Armbruster added, "One of the most advantageous aspects of the new KSE product line is that it comes with completely independent fluid and refrigeration circuits for built in backup, highlighting Thermal Care's more than 50 years of chiller design experience for industrial applications."

KSE Series chillers are available from 40 to 720 tons in a combined system. Units come with or without integrated pumping packages in either low or high pressures designs with an optional redundant standby pump. The high-pressure design allows it to support entire plant-wide cooling system needs. Thermal Care also offers a proven line of smaller outdoor packaged chillers available from four to 30 tons.

Founded in 1969, Thermal Care is a developer of leading edge process cooling technology with energy saving and cost efficient product designs. The company provides heat transfer equipment to more than 50 industries and specializes in meeting the specific needs of all customers by offering both standard- and custom-designed industrial process cooling solutions. Thermal Care's broad product line includes portable, packaged, and central chillers, cooling towers, pump tanks, and temperature controllers.

MORE INFO www.thermalcare.com

Geberit adds furnaces from Seco/Warwick

An order for two furnaces is the first order for Seco/Warwick from Geberit, the European leader in sanitary products. The finished system is a hybrid model of the Vector® vacuum annealing furnace.

The two furnaces will be tailor-made according to customer requirements. The two single-chamber Vector vacuum furnaces for annealing will be delivered to the Geberit Group's production plant in Ozorków. Both furnaces are adapted to the specific requirements of the customer, increasing the standard dimensions of the furnace working space, 900 x 900 x 1,200 mm to 900 x 900 x 2,400 mm. These changes will allow the manufacturer to double the efficiency of the furnaces in one technological process.

The Vector is the most frequently chosen vacuum furnace for heat treatment, including specialized commercial heat treat and hardening plants from around the world. Customers choose Vector because it is widely used, reliable, characterized by high precision and repeatability of processes. This vacuum annealing furnace is a very efficient and versatile device used in a wide range of materials and metal alloys. It is used for many heat-treatment processes including gas hardening, tempering, annealing, brazing, and degassing.

The Vector is a solution frequently chosen by manufacturers of fittings, especially those made of stainless steel, due to the guaranteed performance of achieving the required metallographic parameters and perfect cleanliness of the surfaces of the processed elements.

"An individual product is an important element and a huge distinguishing feature of the Seco/Warwick offer, allowing the use of tailor-made technology. An individual approach to the furnace design is a project that requires expert engineering knowledge. Seco/Warwick engineers have the knowledge and experience that are needed to adjust the technology and its parameters so that it ensures the safety and failure-free operation of the device, but above all that the solution meets the expectations and needs of the client," said Sławomir Woźniak, CEO of Seco/Warwick Group.

This is the first order from Geberit and the first pair of Seco/Warwick vacuum furnaces that will operate in the Polish production plant.

Geberit begins a new chapter in its history as it invests in heat-treatment processes, building its independence. Additionally, some of the processes carried out in traditional atmospheric furnaces will now be performed in modern Vector vacuum furnaces.

"We chose the Seco/Warwick Vector furnaces due to the guaranteed quality and efficiency but also the high cleanliness of the surfaces of the processed details, which is very important to us, as the elements are displayed in open Geberit sanitary installations, thus aesthetics play an important role," said Mirosław Spasiński, head of the technical department of Geberit in Ozorków.

The key quality parameter of the processed elements are excellent metallographic results, guaranteeing the appropriate strength of the elements and their very high purity after the heat treatment process.

MORE INFO www.secowarwick.com

The two delivered Seco/Warwick furnaces will be adjusted to Geberit's needs by doubling the available working space of the furnace. (Courtesy: Seco/Warwick)

Vastex Industrial offers tabletop infrared oven

Vastex Industrial has introduced a D-100 model infrared conveyor oven for laboratory testing and low volume production applications.

At 46 inches (117 cm) long by 24 inches (61 cm) wide by 24 inches (61 cm) high, the compact unit can be placed on tabletops or wheeled utility carts with tops as small as 24 inches (61 cm) square.

The Vastex D-100 Infrared Conveyor Dryer for laboratory testing and low volume production achieves uniform temperatures to 750°F (400°C). (Courtesy: Vastex Industrial)

Offered in 120V or 240V models, the oven is equipped with a 16 inches (40 cm) square 1,625-watt infrared heater that achieves temperatures to 750°F (400°C). Heater shields maximize edge-to-edge temperature uniformity, while variable controls for both heat intensity and conveyor speed allow fine-tuning of the heating process.

The heating chamber has a fixed infeed width of 19.5 inches (49.6 cm), and an infeed height that can be raised and lowered from two to seven inches (5 to 17.7 cm). The heater can also be raised, lowered, and pivoted using lock knobs on the sides of the heating chamber according to the shape of the items for uniform heating. Heater shields are included as standard to maximize edge-to-edge temperature consistency.

The oven is equipped as standard with an 18-inch (45.8 cm) wide Teflon® coated fiberglass conveyor belt driven by a 50 inch-pound motor, and aligned by a continuously variable tracking device patented by the company. Optional Kevlar® and stainless-steel mesh belts are offered for high-heat and/or sanitary applications.

Larger conveyor/tunnel models are available with belt widths to 54 inches (137 cm), chamber lengths to 162 inches (412 cm) and infrared heaters to 68,400 watts. A three-year warranty against defects and a 15-year warranty on infrared heaters are standard.

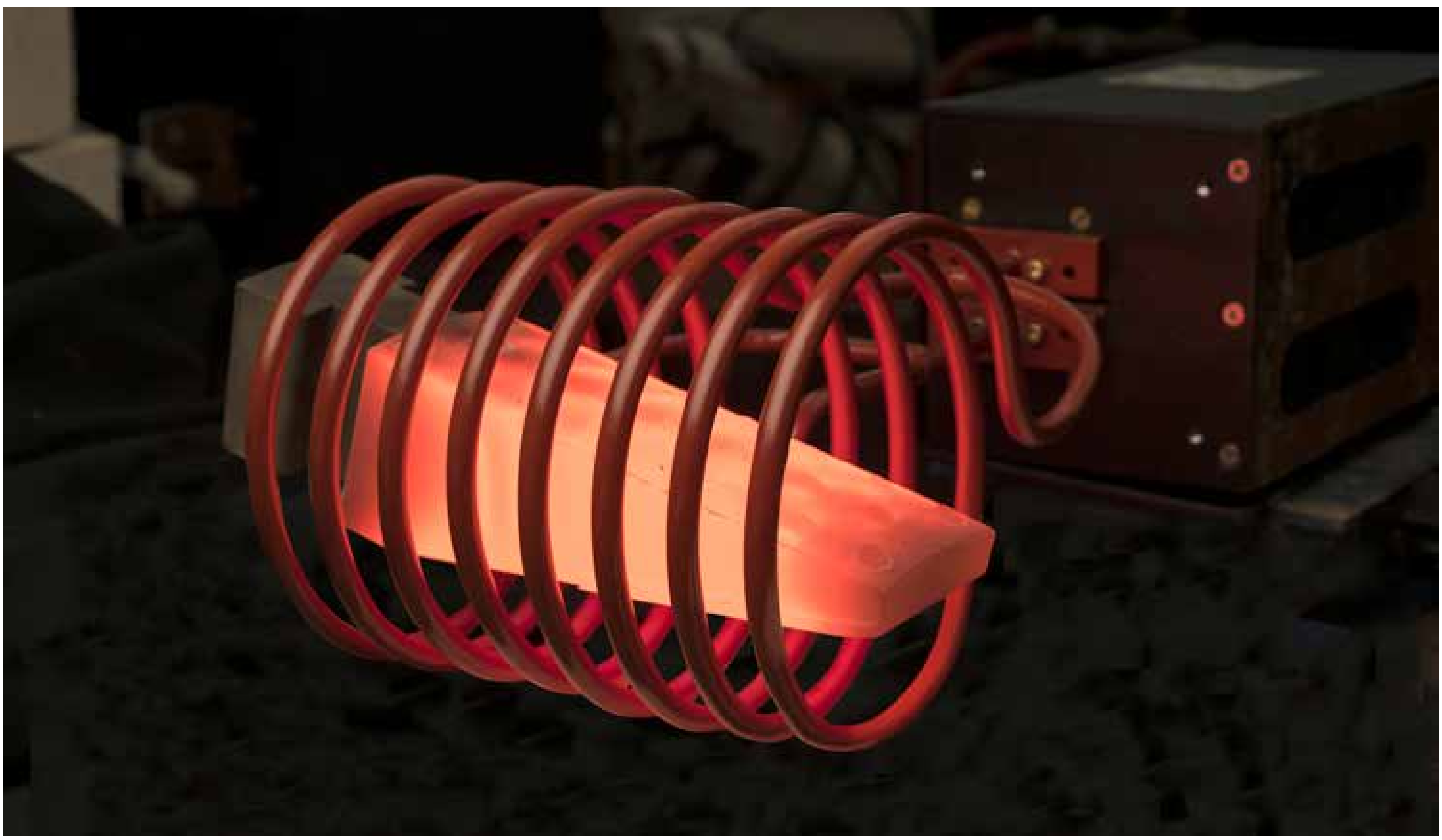
Also offered are cabinet/batch ovens in three sizes with forced, filtered air, adjustable racks and stainless-steel finned strip heaters to 3,100 watts.

MORE INFO www.vastexindustrial.com

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

MEMBER SPOTLIGHT

Ambrell has been all about induction heating since 1986

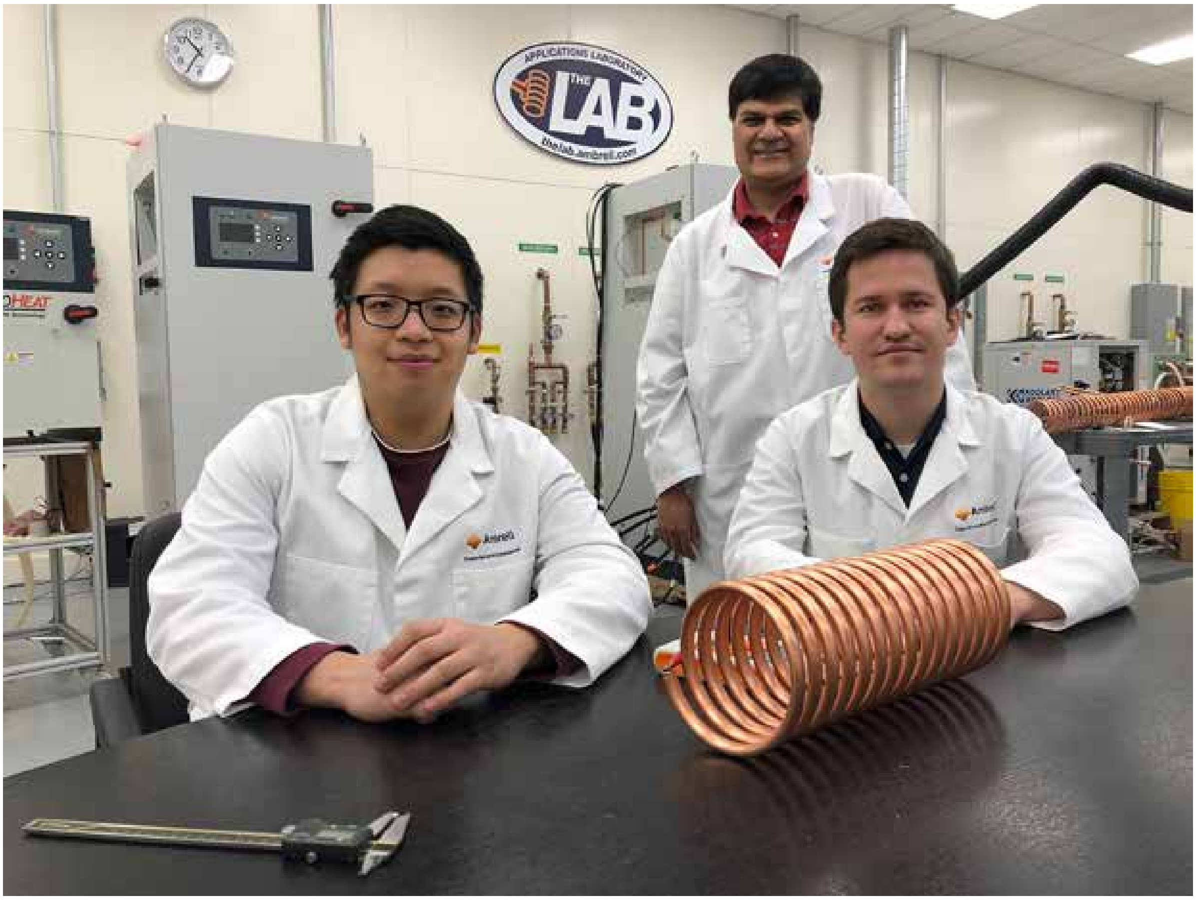


Ambrell's induction heating systems range from 1 to 1,000 kW and are leveraged for a wide array of applications including brazing, soldering, annealing, heat staking, bonding, cap sealing, material testing, shrink fitting, and more. (Courtesy: Ambrell)

Established in 1986, the Rochester, New York-based IHEA member manufactures a range of induction heating solutions. The company has steadily grown from a small startup to an organization with corporate, channel partner, and distributor locations around the world, including sales and support sites in the Netherlands and the U.K. Ambrell serves numerous markets, including automotive, aerospace, energy, forging, heat treating, medical, and semiconductor.

Ambrell's induction heating systems range from 1 to 1,000 kW and are leveraged for a wide array of applications including brazing, soldering, annealing, heat staking, bonding, cap sealing, material testing, shrink fitting, and more. The company also manufactures innovative products such as the flexible EASYCOIL, which is ideal for heating large and oddly shaped parts, and eVIEW software for process data monitoring and logging.

As for services, THE LAB at Ambrell offers complimentary laboratory testing, which offers clients peace-of-mind before making a system purchase. Expert application engineers ensure clients' applications will work in an optimal manner and recommend a system based on their unique requirements. In-person and virtual lab testing are available options, and clients also can simply send in their parts and receive a lab report and video. Ambrell also has a coil-fabrication



THE LAB at Ambrell offers complimentary laboratory testing, which offers clients peace-of-mind before making a system purchase. (Courtesy: Ambrell)

Expert application engineers ensure clients' applications will work in an optimal manner and recommend a system based on their unique requirements.

shop that designs and manufactures coils for countless induction heating applications.

Ambrell, however, is probably best known for its EASYHEAT and EKOHEAT induction heating systems.

EASYHEAT (1-10 kW) systems provide a reliable, compact solution for heating parts with a quick, clean source of heat. They are ideal for repeatable, non-contact heating. The remote workhead is typically located up to 10 feet from the power supply. Equipped to operate over a broad frequency range, EASYHEAT is ideal for heating parts of many geometries and compositions with excellent power control to better than 25W resolution.

The EKOHEAT (10-1,000 kW) system with VPA technology provides versatility while delivering exceptional product performance. The control and power-delivery intelligence is standardized throughout the product line using a common set of circuit components. The same spare board set addresses all models using stored and easily transferred application attributes. All EKOHEAT VPA models are parallel resonant so generators can be more than 30 meters from the application, and each model offers true, high-resolution RF power control.

For ease of use, all systems include wide impedance RF transformers for application matching, and they are armed with an automatic scan feature that sets the appropriate initial frequency and determines the best application RF setup. True digital tuning provides accurate part heating, resulting in excellent repeatability. EKOHEAT VPA systems also offer 100 percent duty-cycle for demanding, automated processes.

Application playback and record means you can record your heat cycle (for up to five weeks) and play it back. The benefit is you can optimize your application and run it in the most efficient manner. In addition, EKOHEAT VPA systems can work together — a 250-kW system and a 125-kW system can be connected to deliver 375 kW.

Ambrell systems are backed by an industry-leading two-year warranty. Systems are manufactured at its new ISO-certified, 80,000-square-foot manufacturing facility in Rochester, New York. This commitment to quality may be why feedback surveys over the previous 24 months indicated 100 percent of customers would buy from Ambrell again.

JUSTIN SIMS
MECHANICAL ENGINEER /// DANTE SOLUTIONS

Models show that the rejection of carbon during ferrite formation has a significant effect on the martensitic transformation when heat treating steel alloys.

Accounting for carbon rejection can head off trouble

The heat treatment of steel alloys is required in almost every industry to acquire the necessary properties for a material given a particular application. These properties include hardness, yield strength, fatigue strength, machinability, weldability, etc., and dictate the selection of the heat-treatment process used. To achieve these requirements, many heat-treatment processes are aimed at producing a mixed microstructure. This includes a ferrite/martensite mixture for dual phase steel heat treatments and processing of TRIP steels to produce ferrite/bainite or bainite/martensite mixed microstructures, to name just a few.

Of these microstructures, the inclusion of ferrite helps improve machinability, ductility, impact strength, etc. and is becoming a popular processing option. The formation of ferrite involves the rejection of carbon into the surrounding austenite matrix, due to the low solubility limit of carbon in ferrite. Increasing the carbon in the surrounding austenite results in modified martensitic and diffusive transformation behavior. This article will examine, through the use of experimental data and modeling using the DANTE heat treatment simulation software, the effects of carbon rejection during ferrite formation on transformation behavior.

Figure 1 shows strain versus temperature test data gathered from dilatometry experiments conducted on a European-grade, low-alloy carbon steel. Only the cooling portion of the test is shown. The blue curve begins at the austenitization temperature and is quenched to room temperature to form a fully martensitic microstructure. The orange curve begins at the austenitization temperature and is quenched to 715°C and held for a short ammount of time and then quenched to room temperature, for a microstructure consisting of ferrite and martensite. The effect on the martensite starting temperature (M_S), seen in Figure 1, is significant; the carbon rejected during the ferrite transformation lowered the M_S by 100°C. The lowering of the M_S locally can have significant effects on the final part hardness, distortion, and residual stress.

Figure 2 shows DANTE heat treatment simulation results for the steel alloy AISI 4120, which is available in the DANTE material database, quenched from the austenitizing temperature to 700°C, held for a prescribed amount of time, and then quenched to room temperature. The three holding times were chosen to produce a mixed microstructure consisting of ferrite and martensite. The 100-second hold produced 14 percent ferrite, the 130-second hold produced 33 percent ferrite, and the 200-second hold produced 49 percent ferrite; with martensite constituting the remaing phase. Figure 2 clearly shows the shift in M_S due to the rejection of carbon during the partial ferrite transformation, with a lowering of the M_S as more ferrite is formed and more carbon is added to the surrounding austenite matrix.

The carbon in the austenite matrix as a function of process time for the three simulated hold times are shown in Figure 3, with time

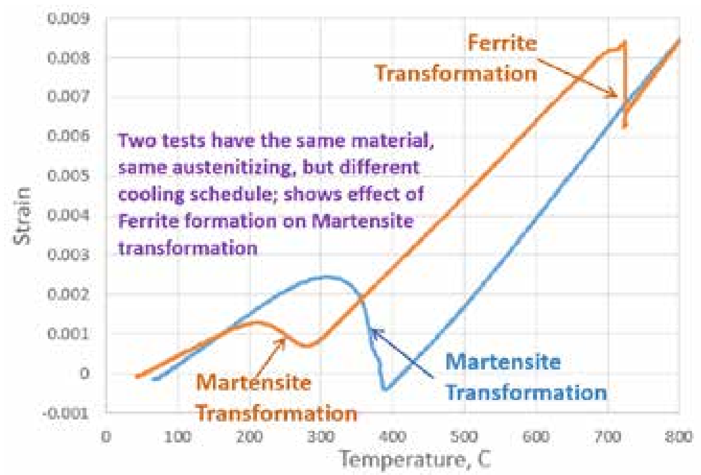


Figure 1: Test data of martensite starting temperature shift caused by rejection of carbon into the austenite matrix during partial ferrite transformation.

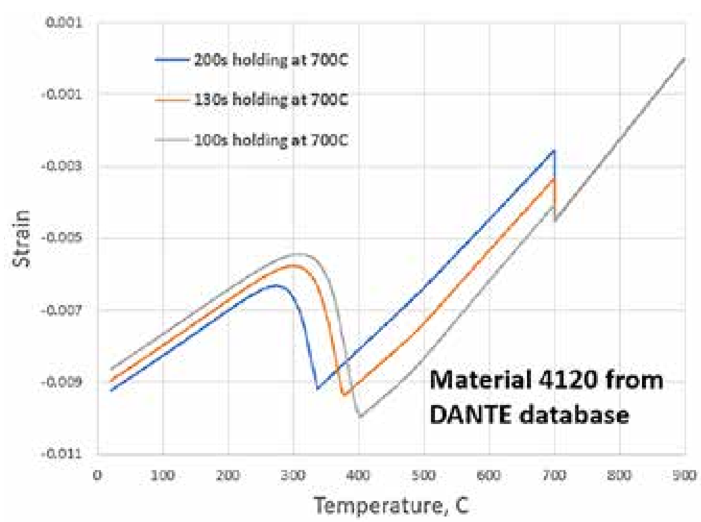


Figure 2. Martensite starting temperature shift caused by rejection of carbon into the austenite matrix during partial ferrite transformation as a result of different isothermal hold times.

zero equaling the start of quenching from the austenitizing temperature. Holding for 100 seconds, obtaining 14 percent ferrite, results in an additional 0.02 percent carbon in the surrounding austenite matrix. This is an insignificant increase and does not significantly affect the M_S or diffusive transformation timing. However, when 49 percent ferrite is formed, by holding at 700°C for 200 seconds, the carbon in the surrounding austenite is essentially doubled, to 0.38 percent. Therefore, an increase in the carbon in the austenite matrix from 0.2 percent to 0.38 percent resulted in a reduction of the M_S by

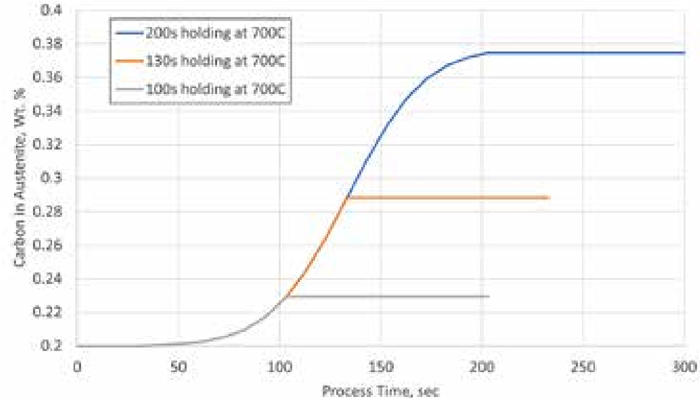


Figure 3. Carbon in austenite as a function of process time.

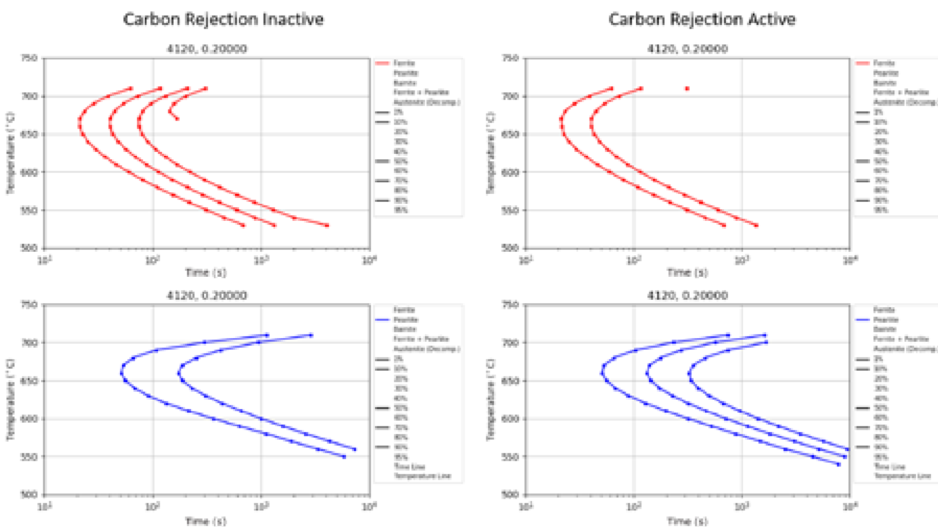


Figure 4. TTT plots showing ferrite (top) and pearlite (bottom) when ignoring carbon rejection (left) and considering carbon rejection (right).

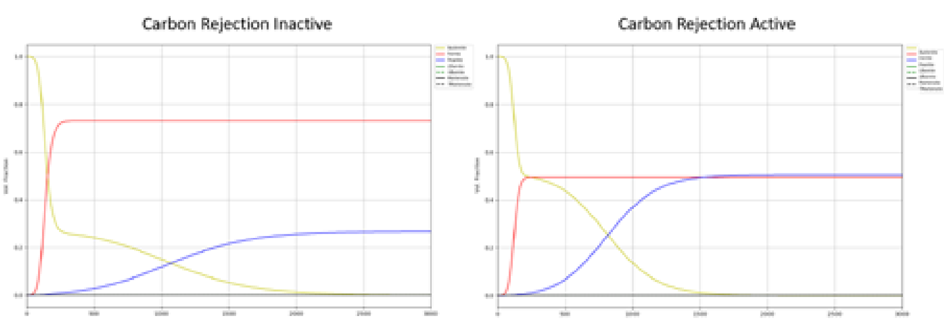


Figure 5. Phase percent vs. time showing ferrite (red curve) and pearlite (blue curve) formed when ignoring carbon rejection (left) and considering carbon rejection (right).

75°C, which can be significant if processing times and temperatures are based on the original carbon available.

The previous discussion only examined the effect of carbon rejection from ferrite formation on the martensitic transformation. However, the rejection of carbon also influences pearlite formation and futher ferrite formation. Figure 4 shows TTT diagrams generated using DANTE's TTT-Generator software and using AISI 4120 data contained in the DANTE material database. Figure 4's left side shows the TTT diagram for ferrite (top left) and pearlite (bottom left) for AISI 4120 if carbon rejection during ferrite formation is ignored. Figure 4's right side shows the TTT diagram for ferrite (top right) and pearlite (bottom right) for AISI 4120 if carbon rejection during ferrite formation is considered. Figure 4 clearly shows that if the rejection of carbon is ignored, more ferrite can be formed over a shorter time, forming 70 percent at 700°C. With more ferrite formed, there is less austenite available for the pearlite transformation, resulting in a reduced amount of pearlite, 10 percent at 700°C, when compared to the TTT diagram in which carbon rejection was condisdered. By contrast, considering carbon rejection, 10 percent ferrite and 50 percent pearlite is formed at 700°C. This can have an effect on the final hardness of the component.

Another way to view the effect of carbon rejection on the ferrite/pearlite transformation is to examine the ferrite and pearlite formed for a given process at a given point. Figure 5 shows DANTE's Mat-Simulator software results for a process by which the material, AISI 4120, is quenched from the austenitizing temperature to 700°C and held for three hours and then quenched to room temperaure; only the first hour is shown since the transformations were already complete. The red lines represent ferrite, the blue lines represent pearlite, and the yellow lines represent austenite. The left side of Figure 5 shows that approximately 70 perecent ferrite is formed, with approximately 30 percent pearlite, if carbon rejection during the ferrite transformation is ignored. Accounting for the rejection of carbon from ferrite formation, shown on the right side of Figure 5, there are equal parts ferrite and pearlite. The difference in phase constituents will have an effect on the hardness of the component.

In conclusion, the rejection of carbon from the formation of ferrite should be considered in practice and in heat-treatment simulation. It has been shown, through experimental data and DANTE models, that the rejection of carbon from ferrite has a significant effect on the martensitic transformation, particularly the martensite starting temperature. DANTE models were also used to explore the effects of carbon rejection on the ferrite and pearlite transformations. It was shown that by accounting for the rejection of carbon, less ferrite, and more pearlite, can be formed for a given isothermal process. The local increase in carbon resulting from the rejection of carbon as ferrite is formed can lead to locally varying hardness and mechanical properties, ultimately affecting the final performance of the component. With the ability of the DANTE heat-treatment software to account for the rejection of carbon, simulation can now be used to evaluate this effect on final properties and help engineers and designers avoid post-production issues.

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Natural aging of aluminum occurs when the solid solution obtained after quenching starts to form precipitates immediately at room temperature.

Heat treatment of aluminum, Part V

After quenching and any straightening, the supersaturated solid solution of aluminum wants to reach equilibrium. It does this through the process of precipitation hardening. Precipitation hardening is the mechanism in which the hardness, yield strength, and ultimate strength dramatically increase with time at a constant temperature (the aging temperature) after rapidly cooling from a much higher temperature (solution heat-treat temperature). This rapid cooling or quenching results in a supersaturated solid solution, providing the driving force for precipitation. This phenomenon was first discovered by Wilm [1], who found that the hardness of aluminum alloys with minute quantities of copper, magnesium, silicon, and iron increased with time after quenching from a temperature just below the melting temperature.

During aging, the metastable solid solution resulting from quenching will precipitate. This is done in a controlled manner to control the size and shape of the precipitates. There are two types of aging: natural aging and artificial aging. Natural aging is allowing precipitation to occur at room temperature, while artificial aging is the result of applying elevated temperature to achieve the desired precipitation.

There are many different types of aging available to aluminum alloys. These different processes are designated as "Tempers" and are illustrated in Table 1.

Precipitation hardening is dependent on several factors. The change in solid solubility with temperature is a primary factor, although this feature alone does not make an alloy capable of being precipitation hardenable. Precipitation hardening from the metastable solid solution is strongly influenced by kinetic factors such as diffusion, even with a large decrease in the solid solubility limit. The elements Cu, Mg, Si, and Zn, which are the principal solutes involved in the precipitation-hardening reactions, have relatively high rates of diffusion in aluminum.

Temper	Designation
T1	Cooled from an elevated temperature shaping process and naturally aged.
T2	Cooled from an elevated temperature-shaping process, cold worked, and naturally aged.
T3	Solution heat treated, cold worked, and naturally aged.
T4	Solution heat treated and naturally aged.
T5	Cooled from an elevated temperature-shaping process and artificially aged.
T6	Solution heat treated and artificially aged.
T7	Solution heat treated and artificially over-aged.
T8	Solution heat treated, cold worked, and artificially aged.
T9	Solution heat treated, artificially aged, and cold worked.
T10	Cooled from an elevated temperature shaping process, cold worked, and artificially aged.

Table 1: Temper designations for heat-treated aluminum.

GENERALIZED PRECIPITATION SEQUENCE

In heat-treatable aluminum alloys (and many other precipitation hardening systems), the supersaturated solid solution transforms along a multistage reaction path. This path first produces Gunier-Preston zones, followed by one or more metastable transition precipitates. After enough time at temperature, the equilibrium precipitate forms.

In many aluminum alloys, the precipitation sequence begins with the nucleation of small, fully coherent phases known as Guinier and Preston zones (discovered independently by Guinier and Preston from x-ray diffraction studies) [2][3]. Guinier-Preston (GP) zones are solute-rich clusters resulting from phase separation or precipitation within a metastable miscibility gap in the alloy system.

GP zones are the first to nucleate because of their small size and coherency with the matrix. The GP zones typically take the shape of small spherical particles or disk-shaped particles that are about two atomic layers thick and several nanometers in diameter. The GPZ generally align perpendicular to the weakest direction of the aluminum crystal structure [4].

As Gunier-Preston zones grow, the incoherency with the matrix increases. Eventually a transition phase nucleates from the GP zones. These precipitates have an intermediate crystal structure between the aluminum matrix and the equilibrium phase. A typical reaction sequence for Al-Cu systems is written as:

$$\alpha_0 \rightarrow \alpha_1 + GPZ \rightarrow \alpha_2 + \theta" \rightarrow \alpha_3 + \theta' \rightarrow a_{eq} + \theta$$

where θ′ and θ″ are transition precipitates and θ is the equilibrium precipitate. As each new precipitate forms, the matrix (α) becomes more and more depleted in copper.

To maximize strengthening, aging is typically carried out to the precipitation between any intermediate phases. Reactions carried out beyond maximum strengthening are termed overaged, because the beneficial effects of precipitation strengthening are lost as the precipitates grow larger in size and spacing.

Eventually, as the transition precipitates grow, the matrix coherency decreases. At the maximum mismatch, the equilibrium precipitate will form. With the loss of mismatch or coherency strain,

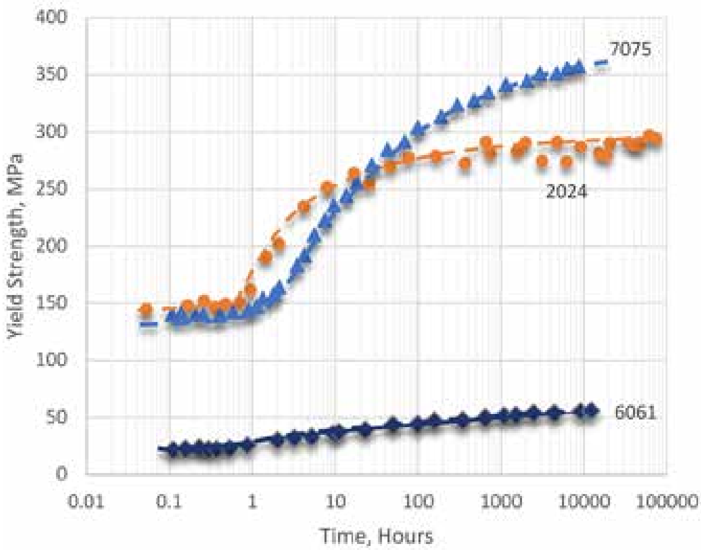

Figure 1: Response of 2024, 6061, and 7075 to natural aging at room temperature.

In heat-treatable aluminum alloys (and many other precipitation hardening systems), the supersaturated solid solution transforms along a multistage reaction path.

strengthening diminishes. As the equilibrium precipitate further grows, strength is decreased.

NATURAL AGING

The solid solution obtained after quenching starts to form precipitates immediately at room temperature. This process is termed natural aging, and the hardening during natural aging is attributed almost entirely to the homogenous precipitation of solute-rich GP zones.

Rates of natural aging vary widely among the different alloy types. However, the degree of precipitation that exists after virtually stable equilibrium is reached is less than can be induced by precipitation heat treating (or artificial aging) for a proper time and temperature. Consequently, the full-strength capability of an alloy usually is not attained by natural aging. Even so, the mechanical properties of alloys in the T3 and T4 series of tempers are essentially stable and are adequate for many uses. With alloys in the T3 and T4 series of tempers, a substantial degree of precipitation hardening occurs within a relatively short time at room temperature. Examples of response during natural aging for several common alloys are shown in Figure 1.

Alloy 2024 age hardens quite rapidly at room temperature. Most of the strengthening occurs within a day at room temperature, and hardening is almost completed after about four days. This alloy is widely used in the naturally aged tempers: T4, T3, and T36. Another alloy often used in the naturally aged condition is 6061. Alloy 6061 ages more slowly, but the alloy age hardens to a substantial degree at room temperature within four days after quenching. It may be used in the T4 temper, but it is more frequently given a precipitation heat treatment (T6 temper) of artificial aging. Alloy 6061 continues to age slowly for an indefinite period, although for practical purposes the mechanical properties become stable after several months.

Alloys such as 7075 and 7079 age harden rapidly at room temperature to a substantial degree within several days after quenching and continue to increase slowly in strength for several years. Temper designation W is used to indicate solution heat-treated material that does not reach substantially stable mechanical properties during a reasonable period of natural aging. Because alloy 7075 and other 7xxx series alloys continue to age harden indefinitely at room temperature, they are very seldom employed in the W temper.

The strength of naturally aged alloys can be augmented by cold working. For example, the stretching or roller-leveling operations employed in producing 2024 flat sheet introduce appreciable strain hardening (over 1 percent effective reduction). The resultant higher tensile and yield strengths are recognized by specifications, and the T3 temper designation identifies this product. Additional strain hardening, to 5 to 6 percent, develops higher strengths, reflected in the higher values specified for 2024-T36. Other examples of alloys that are cold worked after natural aging to produce commercial T3-type tempers, are 2011, 2014, and 2219.

CONCLUSION

In this short article, we have described the basics of natural aging. In the next column, we will be discussing artificial aging of aluminum.

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

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Mitigating risk is a critical step in separating commercial and aerospace processing.

When different processes co-exist

I'm a quality director at Byington Steel Treating, Inc. (BST). We are a commercial heat-treat shop with accreditation to perform NADCAP/AMS (aerospace) processes. Similar to people in the same position as me, I must ensure that all of our processes and procedures meet contractual, regulatory, and statutory requirements flowed down from our customers. This is applicable to jobs that are aerospace and jobs that are standard commercial work. That being said, there is a risk of blending the two procedural activities and creating the possibility of processing a job incorrectly. Why would there be risk? There is risk because there are far more requirements when processing to an aerospace standard versus processing a commercial job where standards are not applicable. This is a daily occurrence that I navigate with extreme scrutiny because of the potential impact of incorrect processing. This column will focus on ways to mitigate the risks associated with being a commercial shop that also provides aerospace processing.

Let's start from the beginning. Get familiar with your procedures. Whether you're new to quality or are a veteran of many years, there is something that is universal to us all: Our procedures define what activities need to be performed and how they should be carried out. It's important to understand that your procedures govern how you perform each set of processing activities, and they are realized through work instructions. In simpler terms, do what you say and say what you do through your procedures. What is tried and true for myself is starting at the procedural level and building my processes at that point. Once you understand what commercial or aerospace processing is required, you can build your processes through your procedures.

You've verified your procedures and they all meet your intended requirements. Now it's time to figure out a way to separate the two processing procedures. It's clear that commercial work is not the same as aerospace because of the detailed requirements that aerospace processing entails. The same applies with commercial work having requirements that aerospace processes do not. Just because commercial work might not have the same requirements as aerospace, it doesn't mean that you should pay less attention to it or put a high value on quality. As quality representatives for our companies, we should all strive for the highest level of quality and integrity for all work.

A situation I see often is a commercial job requiring certain conditions with no standards applicable and aerospace jobs requiring the same condition where standards are applicable. In order to avoid the problem of performing it incorrectly, you must make certain your commercial and aerospace processes are clearly distinguishable from one another. You've already defined your requirements and procedures for both commercial and aerospace, now what? How do you make these processes distinguishable from each other with the only difference being a standard?

This was problematic for me in the early stages in my role within the company. I was having issues with jobs getting mixed up between commercial and aerospace processes. After fighting with myself on possible solutions and making the problem more complex than it needed to be, I went to the basics of how our work instructions are generated and found something that blew my mind. The software we use to create work instructions archives our processes under its name. After realizing this, the remedy was a simple one. Change the name of the processes. I simply added an AMS/NADCAP to the beginning of the process name that I designated as aerospace processing.

The standards that govern aerospace processes can be simple, but they can also be difficult depending on what standard you are using.

Whenever a job required aerospace process controls, our production team could simply type AMS/NADCAP and all the archived processes under aerospace would populate. Since those processes were already verified and vetted by me and engineering, they were ready to go. All that was needed was to vet the commercial processes the same way and give specific names to those commercial processes.

The bottom line? Whether you have a system that uses software or a unique system that's tailor-made for your business, give your processes specific names so whoever generates work orders for your company can easily distinguish a commercial process and an aerospace process. This will minimize the risk of selecting an incorrect process for commercial or aerospace work.

Now that we have separated our commercial and aerospace processes, how can we verify the processes to all of the relevant requirements? I mentioned earlier that I already verified and vetted my aerospace processes, so I will limit this portion to that. The standards that govern aerospace processes can be simple, but they can also be difficult depending on what standard you are using. There are too many factors to name that contribute to the complexities of aerospace processing, but some stick out more than others. Take my word when I say that some of those key differences can send you down the rabbit hole of process building — things such as, but not limited to — thicknesses, materials, and tolerances. What I am trying to say is that virtually no process is the same. Naturally, there will be variations even when you are using the same standard from one job to another.

There are many ways to mitigate this, but there are three things that come to mind when I think about process conformance to aerospace standards.

» Set controls that allow you to perform a process check to the applicable standard prior to processing.

» Set process controls to check for post process conformance.

» Make sure you have a competent team that supports you and understands the technical nature of aerospace standards.

Setting a process control for pre- and post-processing is as simple as procedurally requiring a review as part of your work instructions. Remember, say what you do and do what you say. If you say it in your procedures, do it. If you do it on the shop floor, write it into your procedures. You can require a review for pre-processing before the heat-treatment operation and require a review right after the final heat-treat operation. This will force your process to stop at review pre-process and post-process. It will minimize a non-conforming process hitting the floor, but also stop an escape when performing a post process check.

I am a firm believer that you're only as good as the team around you. Surrounding yourself with competent individuals who understand aerospace standards can go a long way in your goal to efficiently produce high quality conforming product.

There is a variety of ways to combat the risk of a commercial heat treater with accreditation to process aerospace. I have outlined a few things that have worked best for my company. It's important to remember that there is no right or wrong answer to mitigate this risk. In the end, whatever works for your company is the right thing to do. One thing that is certain is that it all begins with your procedures. Do what you say and say what you do.

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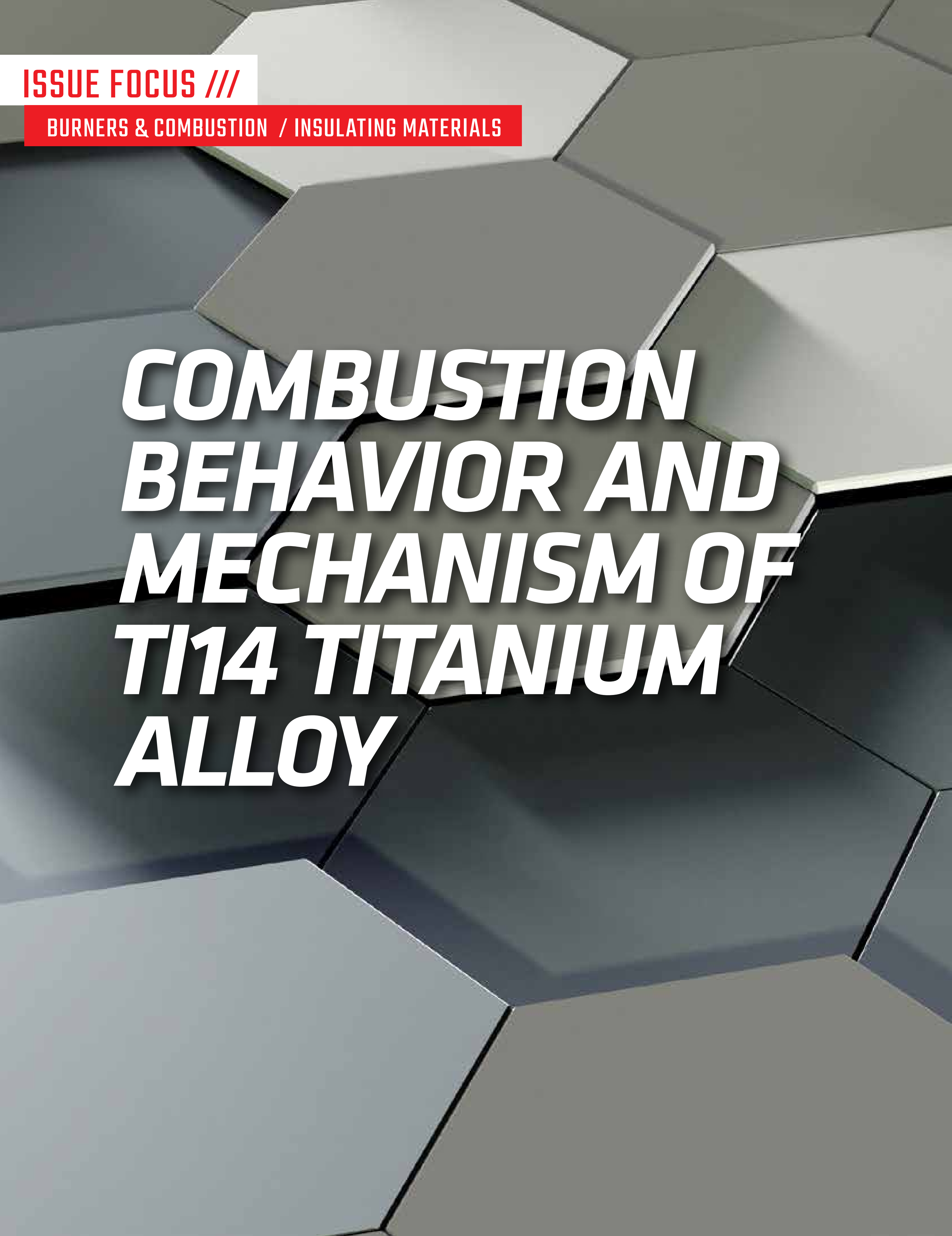

COMBUSTION BEHAVIOR AND MECHANISM OF TI14 TITANIUM ALLOY

This paper studies the combustion behavior of Ti14 alloy by PIC tests at different oxygen pressures to reveal the influence of element enrichment and phase structure on combustion mechanisms.

By LEI SHAO, GUOLIANG XIE, HONGYING LI, WANRAN LU, XIAO LIU, JIABIN YU, and JINFENG HUANG

The combustion behavior and mechanism of Ti14 titanium alloy are studied by promoted ignition combustion tests at different oxygen pressures. The burning velocity increases at higher oxygen pressures and also increases with longer burning times instead of a constant at the same pressure. The Cu atoms are found enriched in two zones — i.e., the heat-affected zone and melting zone during the combustion process — which can prevent the diffusion process of oxygen atoms. The different combustion behavior of Ti14 and Ti-Cr-V alloys is basically controlled by the characteristics of phase structures and chemical reactions.

1 INTRODUCTION

Titanium alloys have broad applications in aviation industry because of the excellent properties such as high strength, low density, and high-corrosion resistance [1,2]. However, they can be ignited by high-speed friction and particle impact under the conditions of high pressure and temperature due to the low thermal coefficient and high-combustion heat, known as a "titanium fire" accident [3]. The applications of titanium alloys are limited by the "titanium fire" accident since the burning velocity of titanium alloys is so fast, needing only four to 20 seconds, that it can hardly be terminated once the combustion reaction starts.

To avoid this problem, many researchers are developing burn resistant titanium alloys. There are two typical types of burn resistant titanium alloys: One type is Ti-Cr-V system alloys, and another is Ti-Cu system alloys. The burn resistant mechanism of Ti-Cr-V alloys is that adding some V and Cr (above 13 wt %) to Ti matrix, the burning product V_2O_5 is volatile and takes away a great deal of heat by volatilization process during combustion. Furthermore, the element Cr can form a dense and continuous oxide layer Cr_2O_3 in the combustion process, and it can prevent the Ti matrix from oxidizing. Therefore, the Ti-Cr-V system alloys avoid combustion to some extent [4–7]. The Alloy C, Alloy C^+, and Ti40 are Ti-Cr-V system alloys [8–10]. Different from the Ti-Cr-V alloys, the Ti-Cu system burn-resistant alloys are based on the principle of friction. The copper shows wonderful thermal conductivity, and it can transfer heat rapidly from friction to avoid the local heat concentration, which makes it difficult to reach the ignition point [11–13]. The friction conditions are improved by changing dry friction into wet friction with liquid lubrication due to the melting of the Ti_2Cu phase, leading to the friction heat decreasing sharply [14–16]. Therefore, the addition of Cu into titanium alloy is reported to improve the burn resistance. Several Ti-Cu system alloys have been developed, such as BTT-1, BTT-3, and Ti14 [17–20].

Ti-Cu system alloy is one of the most promising burn resistant alloys because of its lower costs and density than Ti-Cr-V alloys and extremely excellent workability. Several works have been conducted to study the combustion behavior of Ti-Cu alloy [14,17,18], whereas the burning velocity and combustion mechanism of Ti-Cu alloys is still unclear, especially the elements diffusion and phase transitions during combustion. Ti14 alloy is developed as a representative Ti-Cu system alloy for the applications in aircraft industries. In this paper, the combustion behavior and mechanism of Ti14 alloy are studied by the promoted ignition combustion (PIC) tests [21]. The non-isothermal oxidation, combustion velocity, and microstructure after combustion are studied, and the combustion mechanism of Ti14 alloy is discussed.

Element	Ti	Al	Cu	Si
at %	86.35	2.25	10.72	0.68
wt %	84.46	1.24	3.91	0.39

Table 1: Chemical composition of the samples.

2 MATERIALS AND METHODS

2.1 Material Preparation

Alloy ingots Ti14 with a nominal composition of Ti-1Al-13Cu-0.2Si was fabricated by vacuum arc melting. Those ingots were melted five times to ensure the chemical homogeneity, then heat treated at 810°C for 0.5 hours followed by water quenching to room temperature. After that, the ingots were hot rolled into 5 mm thick plate at 810°C and finally cut into rods with the dimension of Φ3.2 × 70 mm. Table 1 presents an analysis of the chemical composition of the experimental alloys.

2.2 Experimental Methods

The PIC tests were carried that were wildly used in oxygen-enriched atmosphere, and the test procedures were described in detail in References [22] and [23]. The quartz tubes with the internal diameter of 3.2 mm and the length of 20 mm were put on the samples at the position corresponding to the sample lengths of 10, 20, 30, and 40 mm, for the determination of burning rate in different stages. Argon gas is simultaneously pumped into the chamber to quench the sample. The burning time was measured of different combustion lengths to calculate the burning velocity. The equipment of the PIC test and the combustion process are shown in Figure 1. The PIC tests were carried out at the oxygen pressure from 0.2 MPa to 0.5 MPa, and each test was repeated three times to ensure the reliability of the experimental date.

2.3 Microstructural Characterizations

The samples after combustion were cut in half into long longitudinal sections, polished, and etched in a solution of HF:HNO_3:H_2O = 1:3:6 for microstructure observation. The phase formation of combustion product was determined by X-ray diffraction (XRD) using a Huber-2 goniometer with a Cu target (TTR3, Rigaku, Tokyo, Japan). The microstructure characterization of combustion areas was conducted by optical microscopy and scanning electron microscopy (SEM) with operating voltage of 20 keV (Supra 55, Zeiss, Oberkochen, Germany), equipped with energy-dispersive spectrometry (EDS). The chemical compositions of different areas of the specimen are determined by an electron probe microanalyzer (EPMA) (JXA-8100, JEOL, Tokyo, Japan). The non-isothermal oxidation experiments were also carried out using thermogravimetry (TGA) (SDT Q600, NSK, Tokyo, Japan) with accuracy of 0.01 mg for the comparison. The specimens were heated from room temperature to 1,300°C at the heating rate of 10°C/min, which were under a flowing gas mixture of nitrogen (80 mL/min) and oxygen (20 mL/min) during heating.

3 RESULTS

3.1 Non-Isothermal Oxidation

The non-isothermal oxidation results of Ti14 alloy containing DSC (differential scanning calorimetry) and TGA curves are shown in Figure 2. The thermograms in Figure 2a show two exothermic peaks near 740°C and 840°C, respectively. The first peak is probably attributed to the clustering of atoms and formation of Guinier–Preston zones. The second peak may be due to the precipitation of Ti_2Cu as the final phase. Two endothermic peaks at higher temperature is also visible near 985°C and 1,024°C. The peak at 985°C corresponds to the melting point of Ti_2Cu phase and second endothermic peak at 1,024°C is due to α/β phase transformation. The TGA carve of Ti14 from room temperature to 1,300°C is plotted in Figure 2b. The mass gains of the sample do not change at lower temperatures; however, the oxidation process is severely accelerated at 970°C as reflected by the variation of the mass gains.

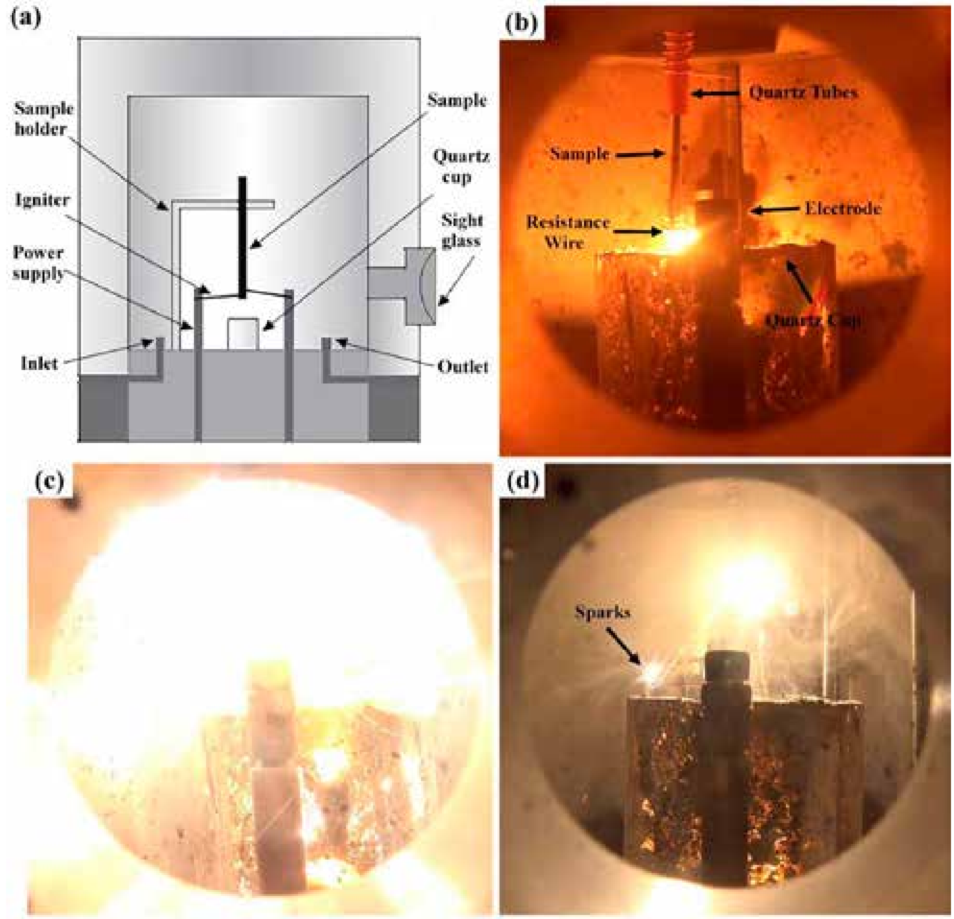

Figure 1: Illustration of promoted ignition combustion equipment (a), and the combustion process of titanium alloys (b) to (d), (b) thermo-oxidation, (c) ignition, and (d) flame expansion, respectively.

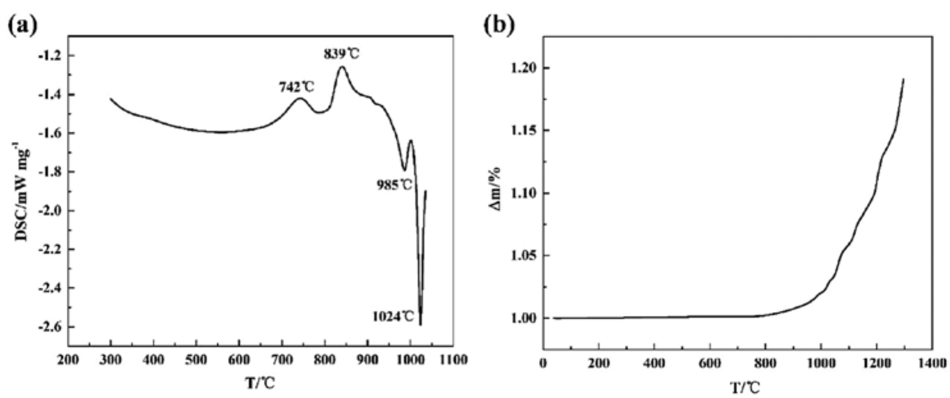

Figure 2: Differential scanning calorimetry (DSC) (a) and thermo gravimetric analysis (TGA) (b) of Ti14 alloy.

3.2 Combustion Characteristics

The combustion process is shown in Figure 1b-d; three stages can be distinguished from the PIC tests observation of the Ti14 alloy combustion process, i.e., thermo-oxidation, ignition, and flame expansion. The combustion process of Ti14 is similar to that of Ti-Cr-V alloys, which were described in detail in a previous study [22]. However, some unique phenomena of Ti14 are observed during the combustion that are different from Ti-Cr-V alloys, such as several sparks of droplets splashing into the environment for Ti14 alloy. This phenomenon may be caused by the different solid solubilities of oxygen in different phases formed during the combustion process of titanium alloys.

The relationship between the burning length and time is listed in Figure 3a. It can be seen from the picture that the burning length has a parabolic relationship with the burning time at the same oxygen pressure. Moreover, it can be suggested by the variation of the slopes of length-time curves representing the burning velocity, that the burning velocity is not a constant but changes with the burning time. The burning velocity at different pressures is shown in Figure 3b. As can be seen from the chart, similar changing trends of burning velocity are found at different oxygen pressures, and the velocity is found increasing at the higher oxygen pressures. It is worth noting that the burning velocity increases with longer burning time at the same oxygen pressure, suggesting the combustion of Ti14 alloys is a self-accelerate reaction. The burning velocity of Ti14 corresponding to the 10 mm in length is 2.31 mm/s, then increased to 6.16 mm/s corresponding to the length of 40 mm at the oxygen pressure of 0.2 MPa. The variation of burning velocity at the same oxygen pressure may be attributed to the high combustion heat of titanium alloys. A huge amount of combustion heat is generated when the sample

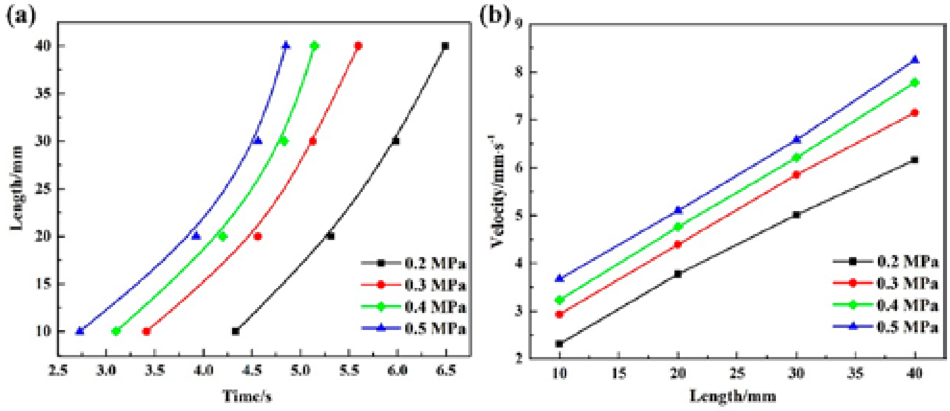

Figure 3: Burning length–time relationship (a) and burning velocity of different length (b).

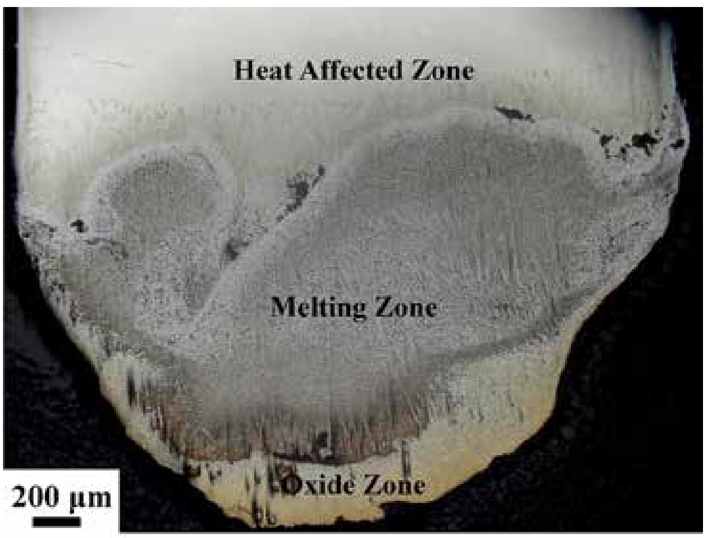

Figure 4: Overall morphology of Ti14 alloy, containing oxide zone, melting zone, and heat-affected zone.

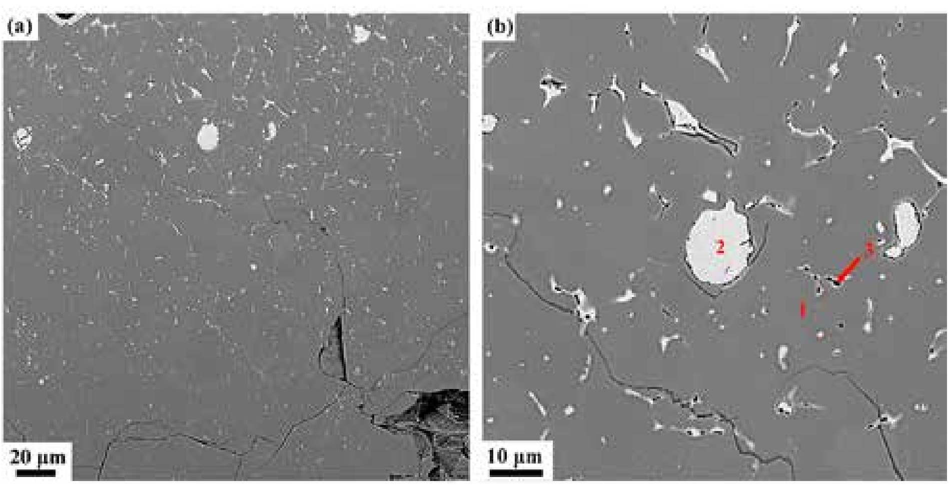

Figure 5: Microstructures of the oxide zone of Ti14 alloy, (a) overall morphology of oxide zone, (b) typical oxide zone, and 1, 2, and 3 marks are three different phases, and their compositions are shown in Table 2.

ignites; as the combustion process continues, the heat accumulates gradually and eventually leads to accelerating velocity.

3.3 Microstructure and Composition Distributions of the Combustion Areas

The combustion behavior of titanium alloys is different from that of copper alloys [23]. Once it is ignited, the sample of titanium alloys burn completely due to its high combustion heat. There are three different morphologies of Ti14 alloy after combustion; those are: oxide zone, melting zone, and heat-affected zone, as shown in Figure 4. The oxide zone is the burning product located in the outermost layer of the sample. The melting zone is formed as a result of intensive temperature influence, inhibited by the oxide zone already formed. In the heat-affected zone located farthest from the heat source, the microstructure is also affected by the heat from the melting zone, leading to the coarsening of grains but no phase transformations.

In the oxide zone, the burning product shows a lot of cracks that benefit the oxygen transportation and against the burn resistance, as shown in Figure 5a. Those cracks may be attributed to the thermal stress in the cooling process. It can be seen from Figure 5b there are three different phases distinguished in the oxide zone, i.e., the gray matrix phase (phase 1), the white phase (phase 2), and the black particle phase (phase 3). The gray matrix is probably composed of Ti and O and appears to be titanium oxide based on the chemical composition by EPMA listed in Table 2. The composition of phase 2, mainly consisting of Cu and a little Ti and Al, may be the result of phase 2 not burning completely. Phase 3 is found surrounded by phase 2, containing more amount of Ti. X-ray diffraction is conducted to investigate the phase formation of oxide zone, as shown in Figure 6. According to the XRD, phase 1 may be made up of TiO, Ti_2O_3 and TiO_2, and the phase 2 is a mixture of Cu and Cu_2O. The XRD is not reflected in phase 3 may be because of the little content of it.

The detailed microstructures of the melting zone are shown in Figure 7; some pores and three different microstructures are found, i.e, the black dendrite structure (phase 4), the gray cellular structure (phase 5), and the white intergranular structure (phase 6). In the cooling process, the solubility of oxygen in liquid alloy is reduced, and the O atoms desolate from the solid solution to form the O_2 molecules. The cooling process is so quick that some O_2 molecules do not have enough time to escape and form those pores. Phase 4 is possibly sub-oxides of titanium according to the elements content listed in Table 3. Phase 5 contains more Cu but less Ti and O than phase 4, and the intergranular structure (phase 6), which is an extreme enrichment of the Cu element. There is an obvious interface between the oxide zone and melting zone, and in the interface, the Cu content is pretty high according to the EDS mapping shown in Figure 8.

In the heat-affected zone, grains became coarser than the matrix, and some white net-like structures (phase 7) are found. The Cu content in phase 7 is about twice as Ti. Phase 8 is close to the nominal composition with a little of O, as listed in Table 4. A clear interface is also found between the melting zone and heat-affected zone, and the EDS line scan and mapping scan are performed across the interface as shown in Figure 9. It can be seen from Figure 9 that, in the interface, the Cu content

Region	Composition Ti	Cu	Al	Si	O
1 (at %)	47.82	0.04	0.28	–	51.86
1 (wt %)	73.16	0.08	0.28	–	26.51
2 (at %)	6.10	88.87	4.06	0.20	0.77
2 (wt %)	4.81	93.08	1.81	0.17	0.20
3 (at %)	85.36	2.13	2.38	0.25	9.88
3 (wt %)	91.81	3.04	1.44	0.16	3.55

Table 2: Chemical compositions of different phases in the oxide zone.

Region	Composition Ti	Cu	Al	Si	O
4 (at %)	70.26	0.52	0.30	0.04	28.88
4 (wt %)	86.96	0.85	0.21	0.03	11.94
5 (at %)	64.50	29.20	3.20	0.51	2.59
5 (wt %)	60.72	36.48	1.70	0.28	0.81
6 (at %)	30.04	54.68	13.42	0.13	1.73
6 (wt %)	27.11	65.48	6.82	0.07	0.52

Table 3: Chemical compositions of different phases in the melting zone.

increases sharply, which means the Cu element is enriched in the interface between the melting zone and heat-affected zone.

4 DISCUSSION

According to the TGA results, Ti14 alloy oxidizes violently when the resistance wire heats the alloy to 970°C and releases a tremendous amount of heat. Then, the titanium alloy is ignited when the heat accumulates up to the ignition point. According to the reference [24], the flame temperature of titanium alloy is about 2,930°C, which is above its melting point. Therefore, the titanium alloy begins to melt into the liquid phase during the combustion process. The quantity of dissoluble oxygen in liquid alloy is found to be much higher than that in solid alloy, which causes the more intensive response. The combustion reaction continues until it burns completely. The equilibrium microstructures of Ti14 alloy consist of Ti_2Cu and α phases. The Ti_2Cu phase shows the low melting point at about 985°C, and it melts in the thermal oxidation process before ignition, which absorbs a lot of heat to hinder the ignition process. During the combustion, the temperature of the alloy is heated to 1,740°C, and the peritectic reaction: L + α → β would probably occur in the alloy with 1–13.5 at % oxygen according to the Ti-O phase diagram. The maximum solid solubility of O in β phase is 6 at %, so the supersaturated oxygen atoms will desolate and assemble into oxygen molecules. Finally, those oxygen molecules escape from the melted alloy and cause the sparks to splash into the environment. As the combustion progresses, more oxygen takes part in the reaction, and the second peritectic reaction: L + α → TiO occurs when the oxygen content exceeds 35 at % at 1,770°C or higher temperatures. A part of the TiO continues to react with O and to form the Ti_2O_3 and TiO_2. This analysis is consistent with the XRD and EPMA results.

Standard formation of free energy (ΔG^θ) for metallic oxide reflects the stability of oxide, and the value of ΔG^θ can be obtained from the oxygen potential diagram. It is well known that the affinity between the metal and oxygen is stronger and the corresponding oxide is more stable if the value of ΔG^θ is more negative. It can be seen from the oxygen potential diagram that the ΔG^θ of Ti is much more negative than that of Cu, which means the affinity between Ti and O is stronger and Ti reacts with O preferentially during combustion. Therefore, the metallic oxides generated by the reactions between Ti and O are found in the outermost region of the sample to form the oxide zone. Because of the preferential reaction of Ti and O, the Cu element is consequently enriched in the interface between the oxide zone and melting zone as shown in Figure 8. Those oxygen atoms are difficult to diffuse through the Cu enrichment zone due to the low dissolved oxygen of the Cu element, and it hinders the oxygen diffusing to the melting zone. In the heat-affected zone, the microstructures of the Ti14 matrix are found coarsened due to the combustion heat. The Ti_2Cu phase shows the low melting point, which is about 985°C. During the combustion, the Ti_2Cu phase melts first in the matrix and forms the white net-

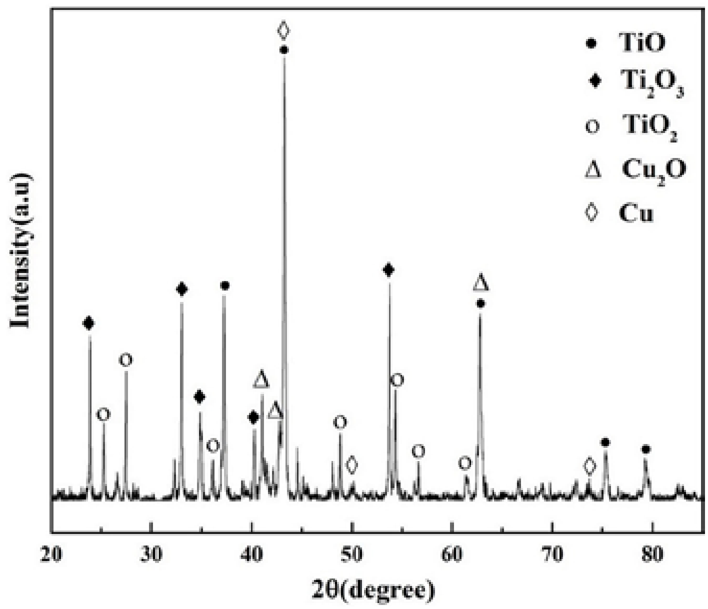

Figure 6: XRD analysis results of oxide zone after combustion.

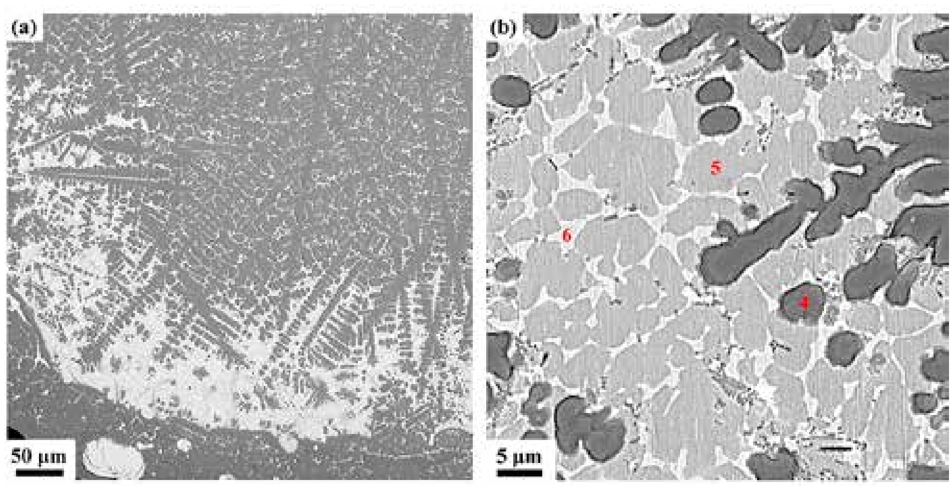

Figure 7: Typical microstructures of the melting zone of Ti14 alloy, (a) overall morphology of melting zone, (b) typical melting zone, and 4, 5, and 6 marks are three different phases, and their compositions are shown in Table 3.

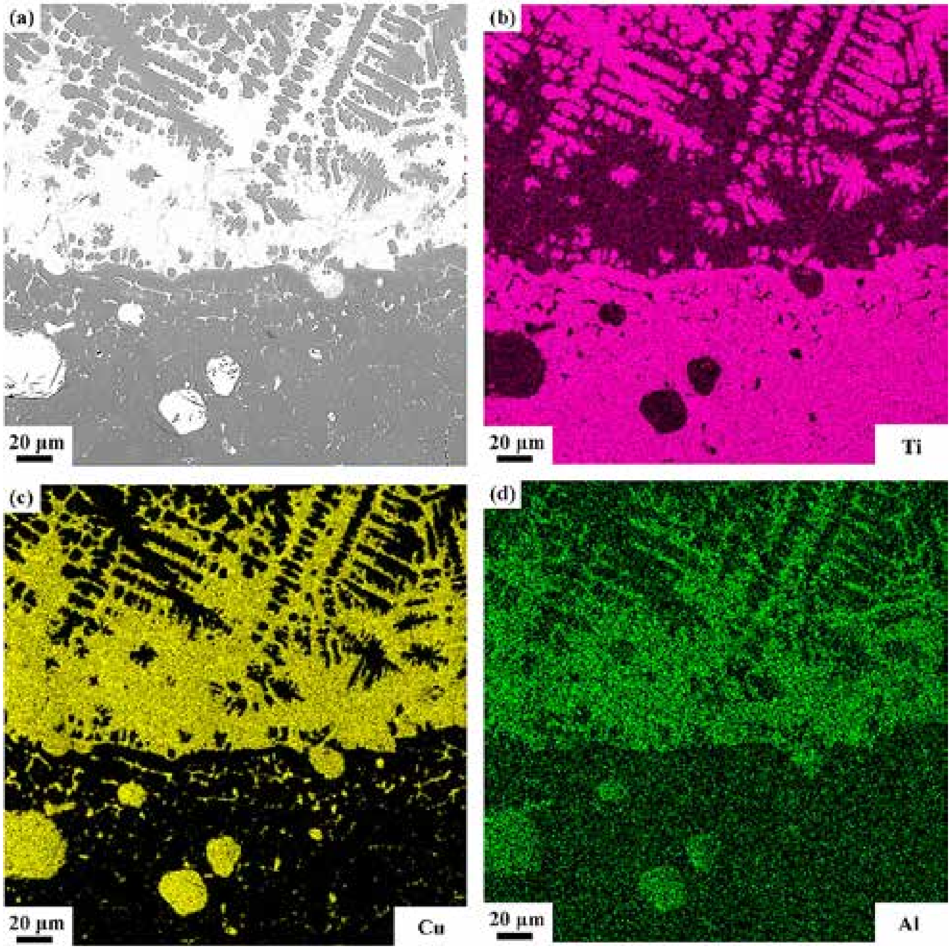

Figure 8: SEM photograph of typical microstructure of oxide zone and melting zone (a), and the corresponding mapping-scan of EDS analysis, containing (b), (c), and (d) for Ti, Cu, and Al atomic distributions, respectively.

	Composition				
Region	**Ti**	**Cu**	**Al**	**Si**	**O**
7 (at %)	66.67	28.88	1.28	0.54	2.63
7 (wt %)	62.36	35.85	0.67	0.30	0.82
8 (at %)	82.29	9.25	2.11	0.40	5.95
8 (wt %)	83.99	12.53	1.21	0.24	2.03

Table 4: Chemical compositions of different phases in the heat-affected zone.

like structures in the heat-affected zone as shown in Figure 9. The EPMA results show that phase 7 is the Ti_2Cu phase, which agrees with the analysis. There is another Cu enrichment zone in the interface between the melting zone and heat-affected zone caused by the Ti_2Cu phase preferential melts. It can prevent the O diffusing to the matrix further and shows good burn-resistant effect to some extent.

The combustion behaviors of Ti14 is similar to that of the Ti-Cr-V system alloys, which was reported in the previous study of the author [22]. They both have an element-enriched zone between the oxide zone and melting zone, which is enriched with Cr and V for Ti-Cr-V alloys and Cu for Ti14 alloys. The element enriched zone shows the low combustion heat of the matrix since the combustion heat of Cr, V, and Cu (2,608 cal/g, 3637 cal/g, and 317 cal/g, respectively) is lower than that of Ti (4717 cal/g). Less heat is released when the flame extends to the element-enriched zone, and the burning velocity is slowed down. Moreover, the Cu element is considered more powerful than Cr and V in the terms of burn resistance due to its lesser combustion heat and lower solubility of oxygen. However, there are some differences of combustion behavior between Ti-Cr-V and Ti14 alloys. The Ti-Cr-V alloys show the single β phase structure, and Ti14 alloy shows the double phases structure which contains α and Ti_2Cu phases at service temperatures. The solid-liquid interface moves forward through the grain boundary for Ti-Cr-V alloys as reported in [22], whereas Ti14 alloys in a different way. The Ti_2Cu phase melts firstly into liquid phase due to the low melting point before the ignition, which causes the hindrance of ignition since the heat transfer is promoted by the liquid phase. The peritectic reaction ($L + \alpha \rightarrow TiO$) as mentioned earlier, is considered as the key factor to control the burning velocity, since this reaction may occur in the solid-liquid interface leading to the solid-liquid interface moving forward. Therefore, the different combustion behavior of Ti14 and Ti-Cr-V alloys is basically controlled by the characteristics of phase structures and chemical reactions.

5 CONCLUSIONS

This paper studied the combustion behavior of Ti14 alloy by the PIC tests at different oxygen pressures to reveal the influence of element enrichment and phase structure on combustion mechanisms. The following conclusions can be drawn:

» **1:** The burning velocity of Ti14 alloy is found increasing at the higher oxygen pressures and increasing with longer burning time at the same pressure instead of a constant, suggesting that the combustion of Ti14 alloy is a self-accelerating reaction.

» **2:** The combustion reaction area of Ti14 alloy is found containing three different zones, i.e., oxide zone, melting zone, and heat-affected zone. The Cu atoms are found enriched in two zones — i.e., the heat-affected zone and melting zone during the combustion process — which can prevent the diffusion process of oxygen atoms.

» **3:** The combustion behavior is related to the phase structure. The occurrence of peritectic reaction: $L + \alpha \rightarrow TiO$ is deduced in the solid-liquid interface during the combustion process by the analysis of the chemical composition and phase contents of the reaction area, regarded as the key factor that decides the moving velocity of the solid-liquid interface.

AUTHOR CONTRIBUTIONS

Data curation, J.Y.; Formal analysis, L.S.; Investigation, L.S.; Methodology, H.L., W.L. and X.L.; Supervision, J.H.; Writing — original draft, L.S.; Writing — review & editing, G.X. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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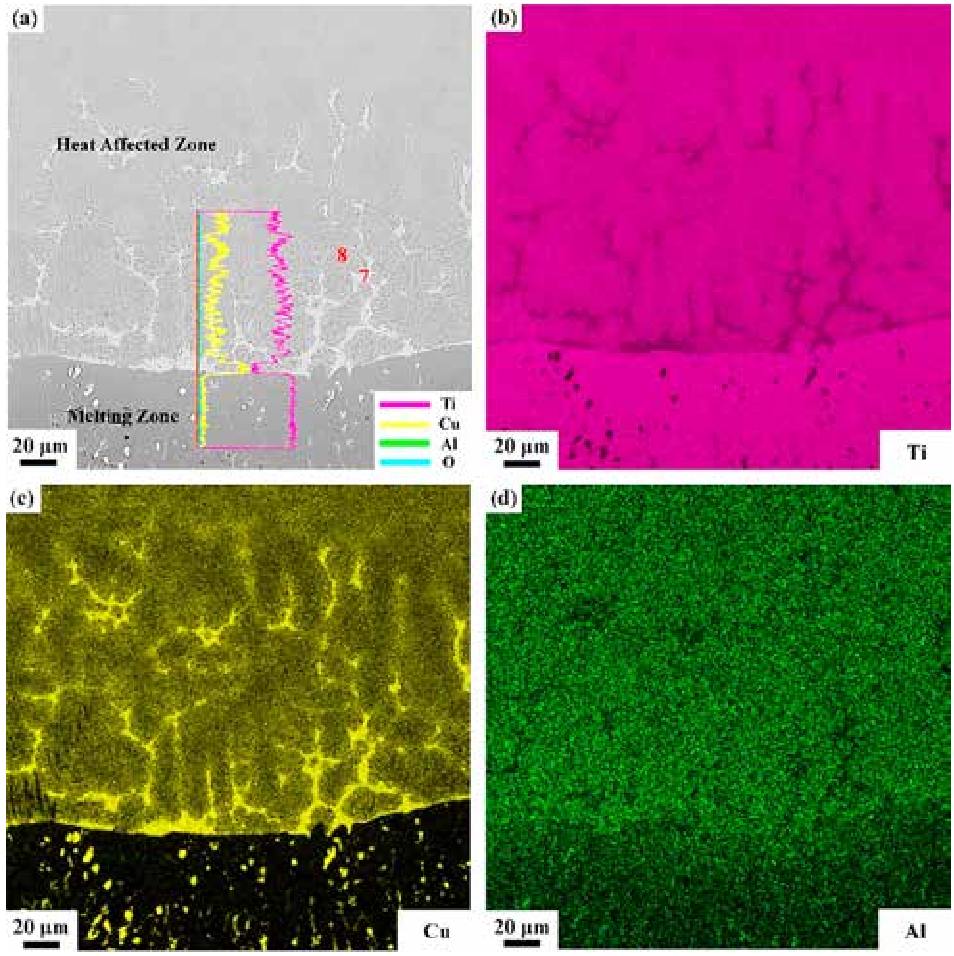

Figure 9: SEM photograph of typical microstructure of the heat-affected zone and melting zone and the corresponding line-scan of EDS analysis (a), the mapping-scan containing (b), (c), and (d) for Ti, Cu, and Al atomic distributions, respectively.

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INNOVATION FOR SAVING ENERGY AND IMPROVING OUTPUT

Unifrax's Durablanket product line is produced with the aid of proprietary technology adapted from a spinning based fiberization process for AES wool. (Courtesy: Unifrax)

New insulating blanket technology allows for improved handling, as well as increased durability and tensile strength for use in the most extreme operating environments.

By ALLAN DAVIES

The harsh economic climate of 2020 had a direct impact upon ferrous and non-ferrous metal producers, as well as those companies involved in the post production processes of these metals. The demand had fallen sharply in almost all markets worldwide. However, as we move forward into 2021, the signs are encouraging for both sectors as confidence returns and demand starts to expand once again.

Those companies who deal realistically with the current situation, and plan ahead, will be best positioned to be lean and competitive in the future. Firms will be looking to succeed in what has become even more competitive markets by seeking new business opportunities while working more efficiently and reducing costs.

High-temperature insulation solutions are still a much-needed product in the heat-treat industry. All of the main industrial sectors benefit from their use. To that end, Unifrax, a world leader in high-temperature insulation products, has developed a lightweight, thermally efficient lining solution for furnaces traditionally used in steel production.

BREAKTHROUGH IN ALUMINA-SILICATE INSULATION

Since the 1960s, Fiberfrax Durablanket insulation products have been known for their performance, versatility, and handling, forming the basis of energy-efficient lining systems for heat-treatment furnaces where high-temperature applications place extraordinary demands on insulating components. The reduction of fuel usage combined with extended service life of the furnace lining solutions engineered by Unifrax has seen end users benefit from lower-operating and product costs, as well as improved output and enhanced metal quality.

Now, using advances in manufacturing innovation learned from the development of the company's market-leading Insulfrax® range, Unifrax's Durablanket product line is produced with the aid of proprietary technology adapted from a spinning based fiberization process for AES (alkaline earth silicate) wool. Durablanket LT and LT Z is a breakthrough RCF (refractory ceramic fiber) product that delivers outstanding thermal performance for temperatures up to 2,450°F.

This new production technology also means Durablanket LT and LT Z offers improved handling for safer, quicker, and easier installation, as well as increased durability and tensile strength that allows it to perform for longer, even in the most extreme operating environments.

As a result, it is suited for a wide range of applications, including:

- Billet slab/reheat furnaces.
- Heat-treatment furnace linings.
- Furnace door linings and seals.
- Boiler insulations.
- Pipe and duct insulation.
- Chemical process heaters.
- High-temperature seals and gaskets.

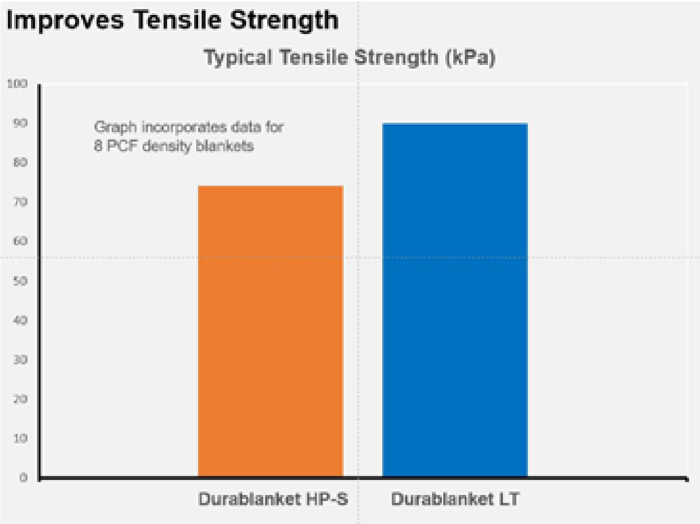


Figure 1

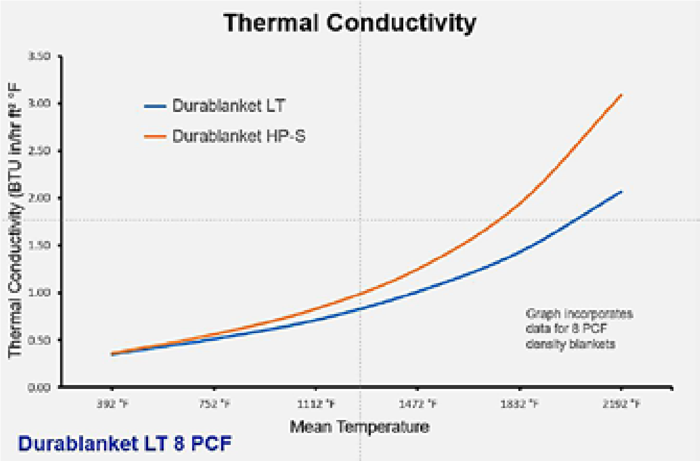


Figure 2

STRENGTH THAT'S EASIER TO HANDLE

The proprietary manufacturing process used by Unifrax for the production of Durablanket LT and Durablanket LT Z results in a blanket with a higher index of interlocking fibers and a reduced shot content that makes it easier to form and handle while providing class-leading tensile strength. This high tensile strength — 80 kPa for Durablanket LT — means Durablanket LT is harder to pull apart, making it more robust during installation and much more resistant to stress due to the expansion of casings and components under extreme heat. (See Figure 1)

INCREASED THERMAL PERFORMANCE

Having 20 percent lower thermal conductivity compared to the next

Durablanket LT and LT Z are available as Anchor-Loc® modules. (Courtesy: Unifrax)

FEATURES

- Exceptional insulating characteristics (low thermal conductivity)
- More fibers (higher fiber index)
- Reduced shot content and particle size
- Less surface shot and "dustiness"
- Improved handling and tensile strength
- Smoother and softer feel

BENEFITS

- Reduced insulation thickness and weight = Choice of energy savings or material cost savings
- Improved energy savings
- Lower cold face temperatures
- Cleaner workspace and operator satisfaction
- Easier installation, saving time and waste
- Less skin irritation

best available RCF blanket material means real energy savings in all applications within the ferrous, non-ferrous metals in particular, as well as the power industry. It also translates into payback periods within just several months of service.

In addition to energy savings, Durablanket LT's low thermal conductivity performance can be leveraged through a reduction in blanket weight and/or thickness, creating more available space in furnaces and ovens. For example, at 96 kg/m3, Durablanket LT provides the same insulation performance as a standard 128 kg/m3 blanket product, which can result in a weight saving of up to 25 percent. (See Figure 2)

ENERGY SAVINGS AND SUSTAINABILITY

One of the key challenges customers face is rising worldwide energy prices. Across industries of every kind, customers are looking to reduce their energy consumption as much as they can. Added to this, the demands on these same industries to reduce emissions in line with local regulations and international agreements make Durablanket LT and LT Z a natural choice when it comes to increasing thermal efficiency, reducing costs, and honoring CSR (corporate social responsibility) commitments to achieve sustainability. Durablanket LT and LT Z can reduce energy costs by 15 to 20 percent on average. (See Figure 3)

MORE FIBER

Durablanket LT has a high fiber index — higher than the standard RCF blanket. Unlike fiber, shot (un-fiberized particulate), a by-product of the fiber-manufacturing process, is not an efficient blocker of thermal radiation. The fiber properties of Durablanket LT have been optimized to minimize the shot content and reduce the size of shot. The result is superior thermal performance. This is also enhanced by producing a blanket with a softer feel and improved handling. (See Figure 4)

LONGER LIFETIME

About 30 percent more fiber per unit mass and fewer large shot particles allow the remaining small shot to be "locked away" from the surface, resulting in minimal free particles in the fiber matrix. Fiberfrax Durablanket LT and LT Z blankets provide a longer lifetime in high-vibration/high-temperature environments.

BLANKET AND MODULE FORMATS

Durablanket LT and LT Z are available as a needled blanket product, or as Anchor-Loc® modules. These insulation modules combine fast installation with a robust, thermally efficient, lining solution for high-temperature furnace applications. In either format, it is easy to work with. Little dust is given off during installation, and thanks to

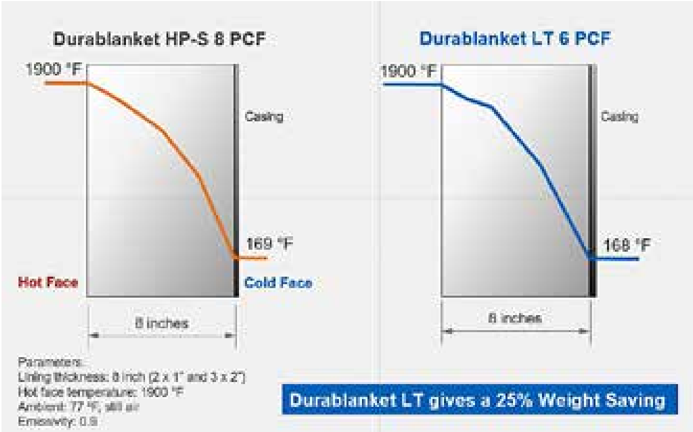


Figure 3

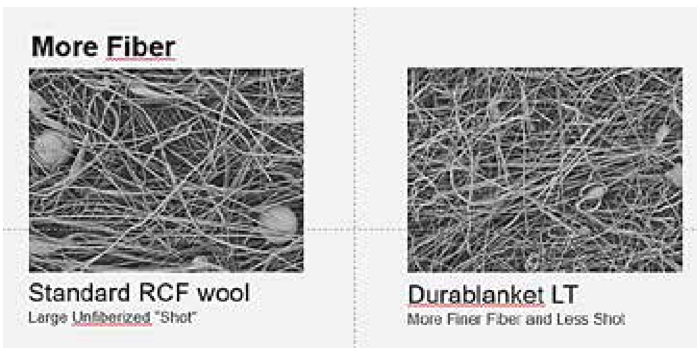


Figure 4

its smoother, softer surface, there is less likelihood of skin irritation.

FERROUS/NON-FERROUS APPLICATIONS

Durablanket products have been used successfully for decades in applications for ferrous and non-ferrous metals, power generation, and other industries worldwide. Now, Durablanket LT and LT Z deliver even better thermal performance and an even longer service life.

Unifrax has one of the broadest ranges of in-house manufactured, high-temperature insulation wool found worldwide and is committed to maintaining the long Durablanket legacy of quality and performance.

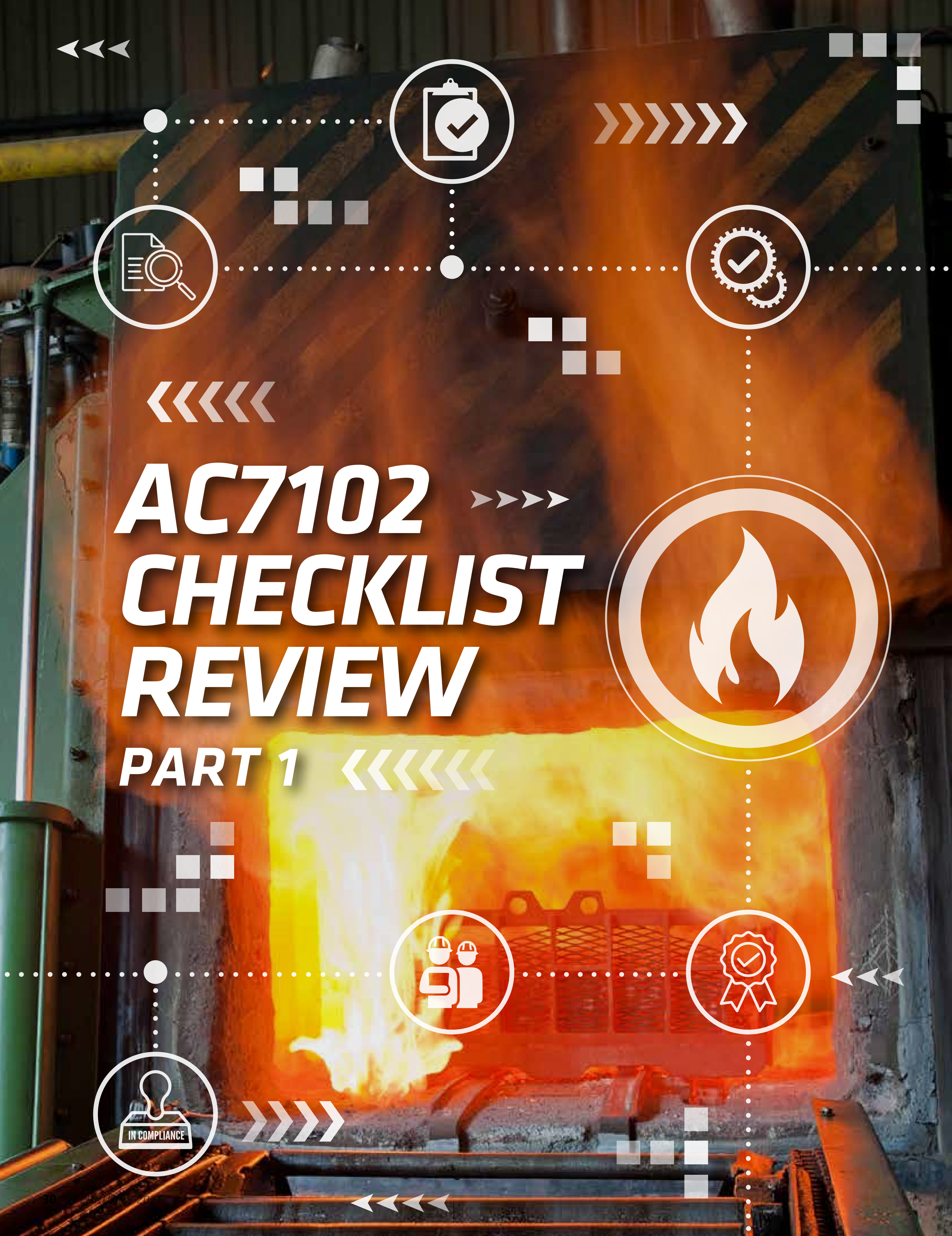
The Unifrax product portfolio encompasses traditional ceramic fiber (RCF), to low bio-persistent (LBP) products and non-classified polycrystalline materials (PCW) classified at 2,912°F. Unifrax recently added Insulfrax 1300 HT to the Insulfrax family of calcium magnesium silicate products. This provides end users additional material choices spanning the entire classification and use-temperature range required across several major industrial sectors including the production, processing, and finishing of ferrous and non-ferrous metals.

ABOUT THE AUTHOR

Allan Davies is a Unifrax product manager. Unifrax is a global leader in high-performance specialty products used by many industries in a diverse group of applications. Its products provide substantial improvement in thermal performance, save thousands of dollars in energy costs, and can help reduce the operations environmental footprint. Unifrax is committed to producing high-quality products that help its customers save energy, reduce pollution and improve fire safety. For more information, go to www.unifrax.com or email info@unifrax.com.

AC7102 CHECKLIST REVIEW

PART 1



Understanding the Nadcap checklists is key when performing internal audits as well as general conformance.

By JASON SCHULZE

EDITOR'S NOTE ›› This is the first of a six-part series of articles that will deconstruct the requirements of AC7102. Each article will appear every other month through 2021.

Throughout my consulting work, questions regarding Nadcap heat-treat checklists are often presented. These questions range from interpretation to job audits to applicability. In this series, I will examine select Nadcap heat treat checklists as well as the top-10 NCRs, according to PRI.

AC7102 is the baseline checklist in the heat-treat commodity. Suppliers obtaining Nadcap accreditation in heat treat must include this checklist regardless of the heat-treat process being performed. Additional checklists are added depending on what thermal processes a supplier wishes or is required to include in their scope. In this article series, we will address the following checklists seen in Figure 1.

AC7102 – FORMAT

The format of AC7102 can be split into 10 main sections (less the job audits), which may make it easier to identify and account for requirements. We will address select items from select categories. It is important to note that questions that have a (UXY) designation next to them must be answered by all suppliers, regardless if that specific UXY designation is applicable. (See Figure 2)

SECTION 1 – AUDIT REQUIREMENTS

Section one begins by addressing the self-audit (aka internal audit) that suppliers must complete prior to the Nadcap audit. This section references OP1105 (Nadcap Operating Procedure), which can be found on the eaudit.net website within the documents section. It is important to understand and read Nadcap operating procedures as they will apply to all suppliers seeking accreditation or who already have accreditation. The self-audit must include the Nadcap checklists, which apply to the suppliers prospective or current scope of accreditation as stated in question 1.1.1 (& 3.5.2). In fact, para 3.5.2, which is essentially a repeat of 1.1.1, is No. 10 on the list of the top 10-findings for AC7102.

Section one also requires that, during the self-audit, the supplier identify procedure and paragraph number for each checklist question that requires it. An example of this would be question 3.6.4: "Are there procedures that address the use and placement of load thermocouples when required by specification or customer requirements?" You will notice this paragraph is referencing the word "procedure," which should be an indication that a procedure and paragraph must be referenced. Another indication may be when a question uses the phrase "do documents exists."

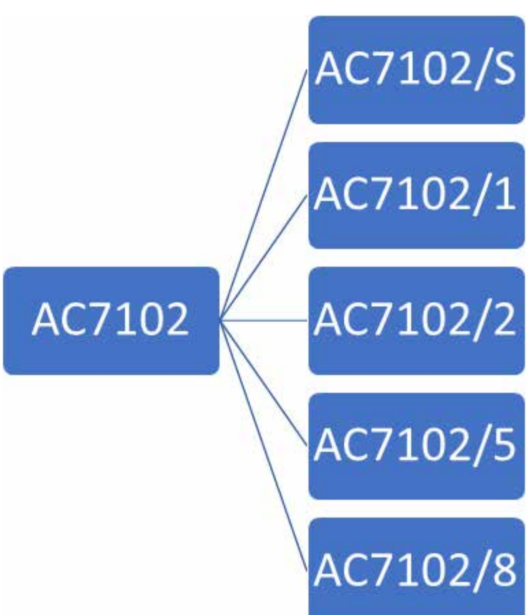


Figure 1

The self-audit is the best check and balance for suppliers, making it important to have good procedures and practices in place regarding the self-audit. When I perform internal audits for suppliers, I typically identify the procedure, revision of the procedure, and paragraph for each question, regardless if certain phrases are used. This can account for several things: 1) if there is a question during the Nadcap audit, you can reference what is written and 2) if a certain topic is not applicable, your procedures will prohibit the topic within internal procedures instead of leaving it open ended. An example of this would be question 5.4, titanium cleaning. Let us assume titanium is not in the scope of your audit, and you choose to just mark N.A. without identifying in your procedures that titanium is not processed. This has the potential to cause a leak in the contract review process if titanium work is quoted.

QUESTIONS 1.1.1.1 THROUGH 1.1.4

The next section is questions 1.1.1.1 through 1.1.4. These questions are within the top 5 findings and due to this, we will address these questions.

Questions 1.1.1.1: "Did the auditee perform a self-audit as above, including all applicable job audits?"

This happens to be No. 3 on the top-10 findings. The self-audit must be completed in full, as it applies, with all job-audit. Let us assume AC7102, AC7102/8, and AC7102/2 are part of your scope of accreditation. AC7102/2 is for aluminum heat treating and lists 2-job audits at the end of the checklist. The question will be asked: Do I need to fill our all 10-job audits on AC7102 (baseline checklist) including the 2-job audits in AC7102/2? Or can I substitute the 2-job audits in AC7102/2 and subtract those two job audits from the main checklist AC7102 and only perform 8-job audits within AC7102? This is a common question regardless of the addition checklist accompanying AC7102. The answer to this question is: If you have an additional checklist aside from AC7102 baseline that has job audits, those job audits may be subtracted from the 10-total required within AC7102.

Question 1.1.2: "Were all of the non-conformances identified by the auditee's self-audit addressed by their corrective action system prior to this Nadcap audit?"

This question would apply if a supplier marked "NO" to any checklist questions, including additional slash checklists. Heat-treat auditor advisory HT-16-003 was issued in 2016 addressing how this should be done.

Question 1.1.3: "Did the auditee provide the following documents to the auditor 30 days prior to the audit?"

This question relates to what must be submitted to the auditor/eaudit.net 30-days prior to the audit. This question is No. 2 on the top-10 findings. The question lists six categories: 1) list of equipment, 2) list of purchases and services, 3) list of prime customers and specifications, 4) list of heat-treat specifications, 5) copy of general internal procedures applicable to heat treat, and 6) a copy of the organization chart. I would recommend suppliers make a template that lists these items and have the list verified by quality to ensure all items requested are captured in the document submitted to PRI.

QUALITY SYSTEM REQUIREMENTS

The portion of this section that should get the most attention is question 3.4.1.

Question 3.4.1: "Are all corrective actions from the previous Nadcap audit still implemented?"

It is vital that suppliers verify their previous corrective actions during the self-audit. If a Nadcap auditor establishes that previous corrective actions are not implemented and/or not maintained, the supplier will receive two major findings: 1) against the supplier's quality system and 2) against the original finding. Receiving a non-sustaining finding will also affect a supplier's merit status.

Question 3.9.2 "Are consumable goods, such as process atmospheres, quenchants, salts, thermocouples, and materials for test samples, ordered and accepted according to an in-house document or to a specific standard?"

This can be linked directly to question 4.1.1. Suppliers must have documented procedures addressing how consumables are received, inspected, and released. Thermocouples are the easiest example of this. If a shipping clerk is performing the review of the thermocouple certification, there should be evidence of training, as required in question 4.1.1.

PERSONNEL

There are two questions in this section that I see may be lacking at times: question 4.1.1 and question 4.2.2.

Question 4.1.1: "Are there training procedures that assure personnel performing contract review, job planning, heat treating, and associated quality and test functions are competent to perform assigned tasks?"

Within this question, there are five items that need to be accounted for. The mistake often made is the assumption that this question applies only to the furnace operators themselves, when, in fact, it applies to the five categories listed.

Question number 4.2.2: "Do records indicate that the evaluations are performed at documented frequencies and the results reviewed with employees in a program of continuous improvement of personnel?"

The part of the question that can be missed at times is the end "… continuous improvement of personnel." Procedures should state and describe how this is accomplished.

PROCESS CONTROL TESTING

This section can be misinterpreted or not understood in general at times. It is actually very simple: Account for any process control testing that is performed (not including pyrometry), document the testing requirement, frequency, and in necessary results. This acts as a tracking tool. Another name for this may be a process control matrix or a control plan. Those with a background in quality or quality engineering may recognize the term "process control plan." I have also seen this information assembled into a spreadsheet that would be something of a specification listing that includes testing and frequencies.

During the Nadcap audit, the auditor will look to get four tests documented. This could range from mechanical testing, hardness, and furnace burn-outs to titanium (Alpha Case) testing. This portion of the checklist must also be completed by your staff during the internal audit.

Figure 2

FURNACE CONTROL AND MAINTENANCE

Question 9.1.2.1: "Does the internal procedure specify the method for determining heat-up rate, start of soaking time, end of soaking time, and cooling rate?"

This is No. 6 on the top-10 findings. Let's look at each requirement separately. Determining heat-up rate may either be customer flow down or by a default requirement within the internal procedures, such as "unless otherwise specified, ramp rate shall be 25-45°F per minute." Start and end of soak are critical. This may come from an applicable AMS/SAE specification and/or customer requirements. Suppliers must define how to determine start and end of soak. An example of this may state "start of soak shall be when all furnace and load thermocouples have reached the soak temperature including the minimum tolerance." The actual definition of both the start and end of soak will depend on requirements flowed down from your customer.

VACUUM FURNACES

This section has one question that is on the top-10 list.

Question 11.2.1.2: "Calibration of vacuum instruments, flowmeters, dew point meter(s), and the related master gauges as appropriate."

In my experience, the common deficiency lies with the vacuum-calibration portion of this question. Since the revision of AMS2769, vacuum calibrations have become more controlled. If GE's P10TF3 applies to your operations, it changes even more still. Vacuum calibrations should be in accordance with the specifications flowed down to your operations to ensure conformance.

JOB AUDITS

The job audit section is not included in the 10-main sections I discussed earlier, although it is critical to understand and complete during the internal audit.

The job audit section has a total of 1 job audit, 8 short jobs, and 2 long jobs. Simply put, short jobs consist of a single temperature/treatment (i.e. anneal, age, etc.), while long jobs consist of a 2-stage process (i.e. solution-age, austenitize-harden, etc.). Additionally, it is expected that suppliers (and auditors) attempt to include all materials processed within the job audits.

A challenge I have seen is when suppliers perform more focused thermal processing. For example, a captive heat treater may only heat treat titanium, which would consist of only short jobs with no long jobs to offer. This would be something that should be discussed with the staff engineer prior to the internal audit to ensure compliance. It is also important to mention jobs that are deemed EC, or export controlled. Throughout the job-audit section, there is a nomenclature (EC). This signifies that, if the job you are documenting is export controlled, no information should be placed in those fields, only "EC." This is watched closely by PRI, so be careful when documenting job audits where export control applies.

SUMMARY

Understanding the Nadcap checklists is key when performing internal audits as well as general conformance. Each question should be examined closely as there may be more than one requirement within a single question. Our next topic will focus on AC7102/1.

ABOUT THE AUTHOR

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COMPANY PROFILE ///

BRISKHEAT

INCREASING PRODUCTIVITY, REDUCING DOWNTIME, LOWERING MAINTENANCE COSTS

Valve with a cloth heating jacket and LYNX™ temperature control module. (Courtesy: BriskHeat)

BriskHeat manufactures flexible surface heating elements and controls/accessories for applications for industries including petrochemical, semiconductor, food processing, biotech, aviation, steel, laboratory, power generation and more.

By KENNETH CARTER, Thermal Processing editor

Customers are often lauded as the driving force of a company, and that important business focal point is certainly no exception to BriskHeat. But beyond that, a strong force that guides the experts behind BriskHeat's unique products are — put simply — the cool things the company has done.

"We have this image of our employees — particularly people who build the product and don't visit customers — we like to have them understand the stories that make us unique," said John Li, senior vice president of sales. "We envision our employees sitting with their kids saying, 'You know what, when the space shuttle went up, we helped that happen because we fixed the tiles.' Or, for example, sustainability. One of our biggest projects of all time was for Clipper Wind, which is a series of wind turbines for energy all around the country. What we did for them is we created a kit when they would need to repair those blades made of composites. They could carry the power up to the top of the wind turbine and do the repair on top instead of having to bring the blades down. And those blades are huge."

INNOVATION DRIVE

That enthusiasm from the top down at BriskHeat is what has continued to drive the innovation of heat treating for more than 70 years, in which the company divides heat into four specific applications, according to Li.

"One of those is process heating, which is what a lot of your customers in the magazine are dealing with," he said. "It's different types of heating for process."

This would involve processes that include heating components for vacuum bake out, heating gas-containing vessels to prevent gas condensation, or heating to reach a particular temperature for an application, according to Li.

"That's the first type," he said. "The second type is what we call viscosity control. Sometimes it can be for a process, but it's very specific to thick fluids and fixed substances that have to be heated to make them flow better."

As an example, Li said viscosity control could be used in a food processing facility that uses molasses or a shortening. It could be a petrochemical facility heating crude oil or heating other thick oil compounds that must be heated to either prevent them from sticking in the pipes or to increase flow. Freeze protection would also fall into this category.

The third application is condensation prevention.

"That's gas work," Li said. "We do a lot of work with companies that are using gas for a process, and it starts out in a storage facility and gas tanks of some type. They have to transport that gas to where the gas is actually prepared for production."

When the gas is sent through the pipes, it must be heated to prevent condensation while maintaining the gas at certain pressures to ensure it stays in gaseous form. This application also includes heat to prevent moisture condensation, according to Li.

The final heat application is considered miscellaneous since it doesn't really fit into any of the previous three categories.

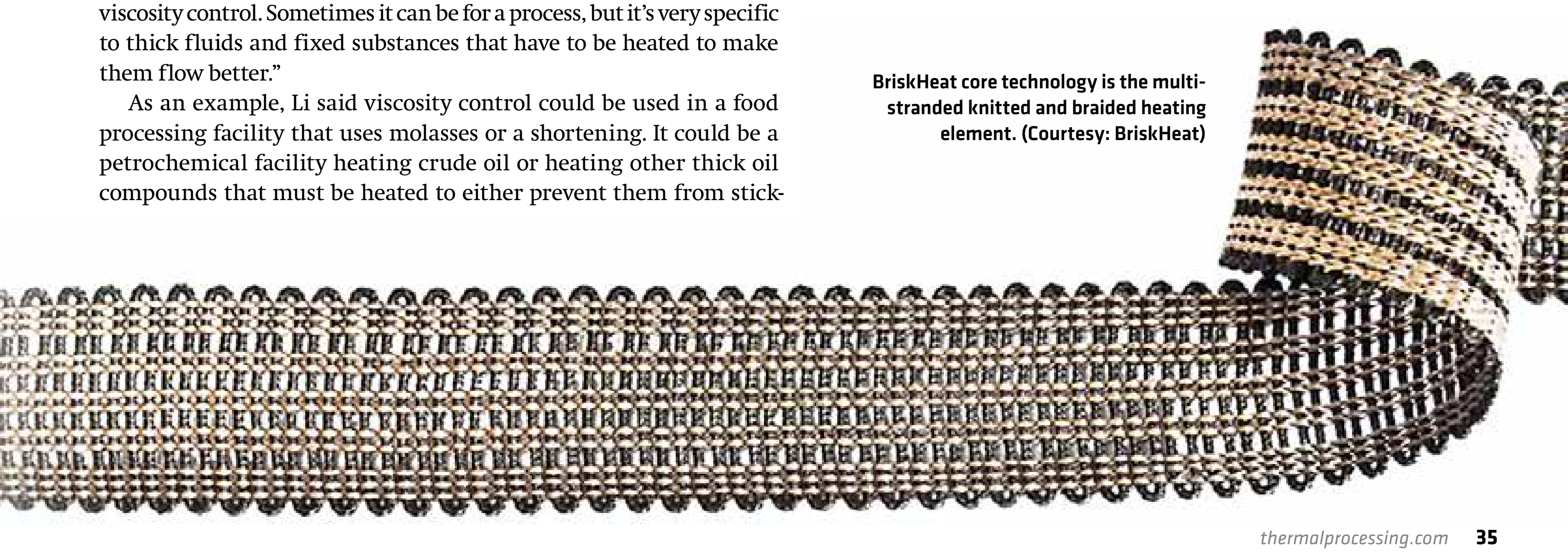
"Composite curing would be an example of that." Li said. "It's a process used to fix airplane wings or to fix holes in boats. It's very specific to the actual need of that application, which is a combination of melting the composite material that bonds while you're also trying to prevent air from getting inside that repair."

During the '70s, BriskHeat developed a controller that not only controls the heat, but the vacuum as well. The process creates a vacuum underneath the repairs to remove air bubbles.

JOBS FROM THE SIMPLE TO THE COMPLEX

With those four divisions, Li points out there are two specific aspects when BriskHeat is working with a customer with regards to the process of different types of heat.

"One is surface heat where you're trying to heat the outside of a vessel or heat the outside of a container," he said. "It could be as simple as drum heating where companies need to empty the contents of the drum and to other vessels or into a productive machine. If it's a thicker



BriskHeat core technology is the multi-stranded knitted and braided heating element. (Courtesy: BriskHeat)

BriskHeat Vietnam Co., Ltd. production floor. (Courtesy: BriskHeat)

fluid or if it's cold outside, the fluid won't empty from the drum as well. That's just one of many examples."

The second aspect might be much more complex, according to Li.

"If you're talking about a chain reaction where you need a certain temperature for that reaction to take place, that can be solved with surface heat, but the other is where you're actually immersing heat," he said.

In 2018, BriskHeat became part of the NIBE Group and their more than 140 companies. For example, Backer North America products include products such as cartridge heaters, band heaters, immersion heaters, and tubular heaters. The variety of metal type heaters that is used for immersion involves a higher heat — 500 degrees or more. This allowed BriskHeat to expand into new markets and expand our product offerings, according to Li.

THE KNITTED AND BRAIDED ELEMENT

Much of BriskHeat's innovation can be traced back to the company's beginnings, when the founder, Earnest Briscoe, a retired Army Air Corps General at the time, created knitted and braided elements flexible enough to wrap around the curvature of airplane wings. The product was later used for pipes, tubing, and any type of apparatus where surrounding it with heat would be difficult.

"To do that, he created a multi-stranded nickel-chromium resistance wire that took a lot of fine tuning because the resistance wire is a super thin gauge thinner than a hair," Li said. "To get the dimensions, he was looking for ruggedness, heat transfer, and better capability of a lot of different watt densities, so he found a way to use twine machines to multi-strand the resistance wire."

The next trick was to make sure the element was heating uniformly, according to Li.

"Surface heat is extremely tied to how uniform the heater is because, if there's a cold spot, it goes counter to what you're trying to achieve," he said. "He found a way to take this resistance wire, which was now almost like a thread, put it into spools on a weaving machine — sort of like a carpet-weaving machine — and actually weave knitted and braided tapes of different thicknesses."

Heating tape wrapped around valve. (Courtesy: BriskHeat)

'ALMOST AN ART'

Due to the complexity needed to knit these fine wires into braided heating elements, Li stressed that BriskHeat's products form a unique challenge for potential competitors.

"It's almost an art," he said. "It takes a long time for new operators to learn how to do that, so they don't break the resistance wire. Of course, if you break the resistance wire, you'll lose your heat circuit. And so, because of that, no one's really ever been able to duplicate that."

And that uniqueness becomes an advantage to BriskHeat's customers, who Li said his company treats like partners.

"We believe in the customer experience of trying to create unique relationships that carry through the entire customer journey of working with us," he said.

THE CUSTOMER'S JOURNEY

BriskHeat begins this journey with a customer by asking a lot of questions, according to Li, whether the initial contact is through a phone call or online.

"We try to make sure we understand the application; in some cases, it's simple," he said. "We have heating cable; we have heating tapes, silicone rubber heaters, and cloth heating jackets, plus the new lines we've picked up from other NIBE Companies. The methods that we can use to heat something are extremely varied. In fact, compared to most of our competitors, we have the most varied in the industry. What we try to do is match the most economical choice that we know will meet the need of the customer. And that comes with questions and then usually the next step is we have a checklist to help them decide the things that are important to them. We'll either go through that with them on the phone or show them where they can find it online. By knowing their needs through questions we've asked them and with the checklist, we can recommend something that'll fit their need and their budget."

"We see heating needs going the route of a lot of other devices that people use, which means user interfaces becoming friendlier in terms of different things people can do with them."

Condensation prevention featuring cloth heating jackets and the LYNX™ temperature control system. (Courtesy: BriskHeat)

ADDING TO ITS PRODUCT LINE

With the knitted and braided element still BriskHeat's key core technology, the company has branched out significantly since it began in 1949.

During the 1970s, BriskHeat expanded during what Li calls the company's decade of BriskHeat innovation. BriskHeat introduced an encapsulated silicone product and its first ACR, a type of temperature control used for composite curing, particularly in aviation.

In the '80s, BriskHeat looked to the semiconductor industry as a key opportunity because of the need for heat.

"That led us to a whole new era of growth to the point where I joined the company, which was in 1998," Li said. "And at that time, almost 70 percent of our business was semiconductor, so, that's how productive that decision was. But on the other hand, it was sort of limited growth because semiconductor was a very cyclical market. So, in the late '90s, we started to reinvest in a lot of the core technologies for non-semiconductor heat. And that created the growth that we still experience today."

FROM HEATING TO HEATING SYSTEMS

In the early 2000s, BriskHeat turned some of its focus on the user interface of heating systems or controls, according to Li.

"At that time, we came out with the Centipede control system, which was one of the first systems where you had a series of heaters, maybe 20 heaters, covering an exhaust line, for example, and each heater had its own little PID controller," he said. "So, 2004 was a big year because that was developed. And that took us to a whole new level of semi-conductor innovation and led us into becoming who we are now: the key supplier to some of the top semi-conductor OEMs in the world. That was all due to our Centipede technology."

GLOBAL GROWTH

Over the last 10 to 15 years, BriskHeat has branched out across the world, particularly in the Asian market. In 2010, the company developed a factory in Vietnam to be closer to the world's largest semiconductor companies, according to Li.

With all its advances in the heat-treat field over the decades, Li said BriskHeat still has an eye on the future and how and where the company's innovative technology can be next implemented.

"We see heating needs going the route of a lot of other devices that people use, whether it be their car or whether it be for different equipment they use, which means user interfaces becoming friendlier in terms of different things people can do with them. In heat, that means the control side," he said.

But even with all its impressive achievements through the years, Li emphasized that it all boils down to one major focus: the customer.

"When you talk about whether it's achievements or whether it's our specific niche in the industry, our philosophies, and even when you talk about 10, 20 years, it's all about that customer relationship and managing their needs with what we can supply and making sure that we're keeping those customers delighted," he said.

MORE INFO www.briskheat.com

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JOHN NIGGLE /// BUSINESS DEVELOPMENT MANAGER /// PELICAN WIRE

"Pelican Wire specializes in fine gauge alloy wire used for temperature measurement applications such as thermocouple and RTD wire."

What's a typical week like for you at Pelican Wire?

Pelican is a custom wire manufacturer, and for that reason, it is a little difficult to describe a typical week succinctly. To begin with, every day of the week we make something we never made before. The variety of processes and capabilities Pelican has is necessary because we are a solutions-based company. On the production floor, there are multiple extrusion lines running bunchers, cablers, tapers, braiders, and other specialized equipment as well. We can get some pretty interesting requests from our customers. If there is a pattern that we follow, it is regularly scheduled intra-departmental and inter-departmental meetings.

These meetings can be focused on design and development of wires for new and unique opportunities, for example. There are collaborative discussions between the sales and operations team daily to ensure priorities are coordinated. Continuous improvement discussions take place weekly as well. While it looks like there is a lot of talking taking place, in the end we believe good communication ensures we are living our company values and in turn bringing value to our customers.

What types of products in your inventory are ideal for the heat-treating industry?

We focus on high-temperature resistant insulations such as FEP and PFA, as well as E Glass and S Glass, high-temp textiles, and tapes. We have quite a bit of finished wire in stock because, in the temperature measurement industry, which heat treating is a part of, speed of business can be critical. Because we are a custom wire manufacturer, we have a broad selection of alloys, gauges, insulations, and capabilities available to make unique thermocouple and RTD wire constructions.

Another core competency for Pelican is custom resistance heating applications using, again, fine gauge alloy wire. We strand wires to customer-specified resistances and dimensions and insulate the wires as required for the application. These insulations can be high temp like mentioned previously or can be a variety of other thermoplastic compounds. Our resistance wires range from fractions of an ohm to 10,000 ohms per foot. We can incorporate strength members such as glass or aramid fibers if needed and can braid or spiral-wind glass or textile insulations on the wire, also.

What makes Pelican's products unique in the heat-treat field?

About 10 percent of our employees are engineers — either design engineers who work closely with the sales team or manufacturing engineers who spend much of their time on the manufacturing floor. And we have a great mix on the engineering team of long time, wire-industry professionals and a few more recent graduates. So, with the combination of experience and seasoned judgment on one hand and a fresh set of eyes on the other, Pelican is up to the challenges that customers bring us. We have been in business for more than 50 years and have developed systems and processes directed toward accuracy, repeatability, and customer satisfaction. While all this may sound somewhat standard, the customer-focused attitude and attention to detail that the employee-owners of Pelican Wire possess really make us unique. Pelican has been an ESOP since 2008, and the pride of ownership is evident. Regular town hall events keep the employee-owners aware of what and how the company is doing. Discussions about who our customers are, how they use our wire, what they expect, and what Pelican needs to do for them are routinely held.

How do you approach a potential customer when they have a need that doesn't exist within your standard inventory?

Pelican is, at its core, a custom wire manufacturer. As such, other than a substantial amount of finished common thermocouple and RTD wire, we do not have a large amount of finished inventory. We do have a significant and varied inventory of alloys, gauge sizes, insulating compounds, shielding and overbraid material, tape, strength members, and other components used in wire and cable construction. We also have the resources and willingness to develop customer specific solutions for temperature-measurement and resistance-heating needs.

In fact, Pelican is not limited to those areas. We make a number of unique sensing wires, precisely wound variable pitch heating wires, and other wires and cables. We routinely make our own equipment, tooling, and fixtures in house to achieve the desired results. We also have a detailed and formal on-boarding procedure for evaluating and developing new opportunities to ensure the desired outcome for the customer and Pelican. This on-boarding procedure is inter-departmental and promotes collaboration between the customer and all the teams at Pelican to increase the likelihood of success.

Where do you see Pelican Wire's place in the future of heat treating?

Pelican Wire recognizes the importance of supporting the industry with new ideas and capabilities. This has long been a philosophy of Pelican. Through recent acquisitions, we have added to our portfolio and have positioned the company to be even more suited to assist with custom-wire requirements from prototype to production.

MORE INFO pelicanwire.com


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