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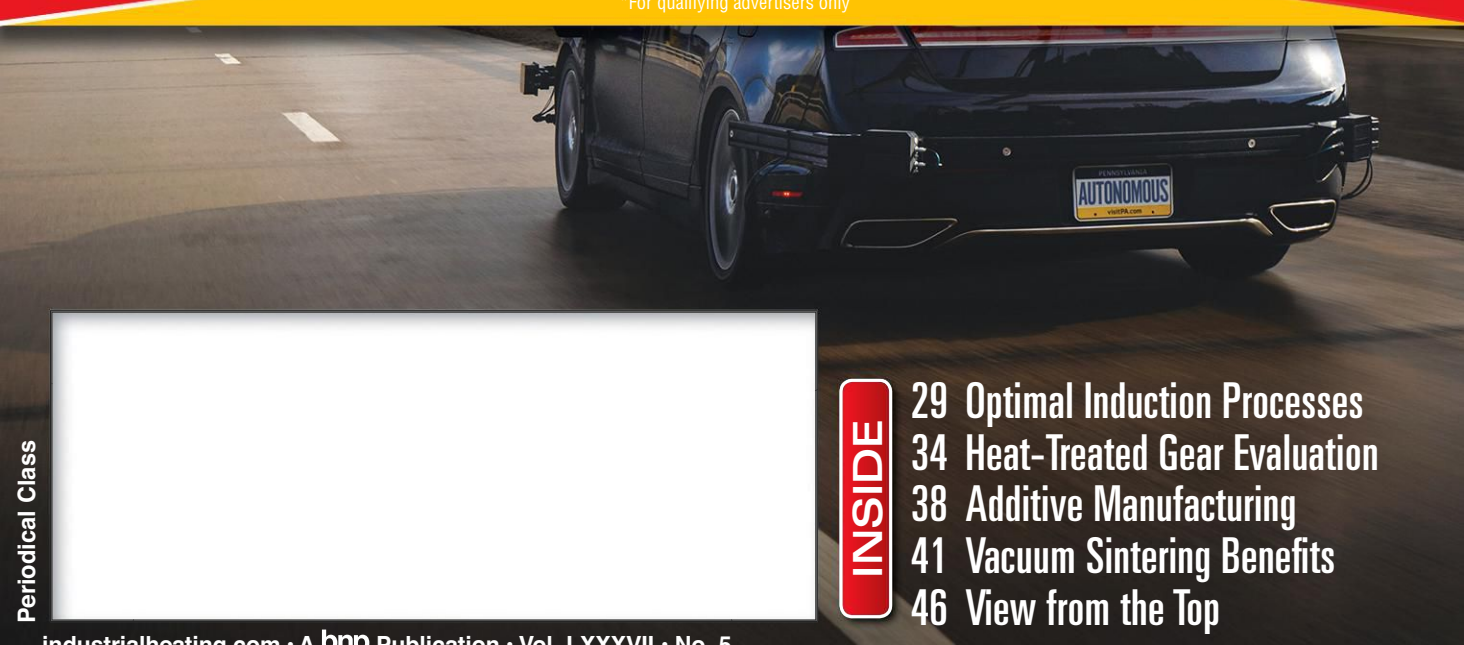

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Autonomous Vehicle Technology

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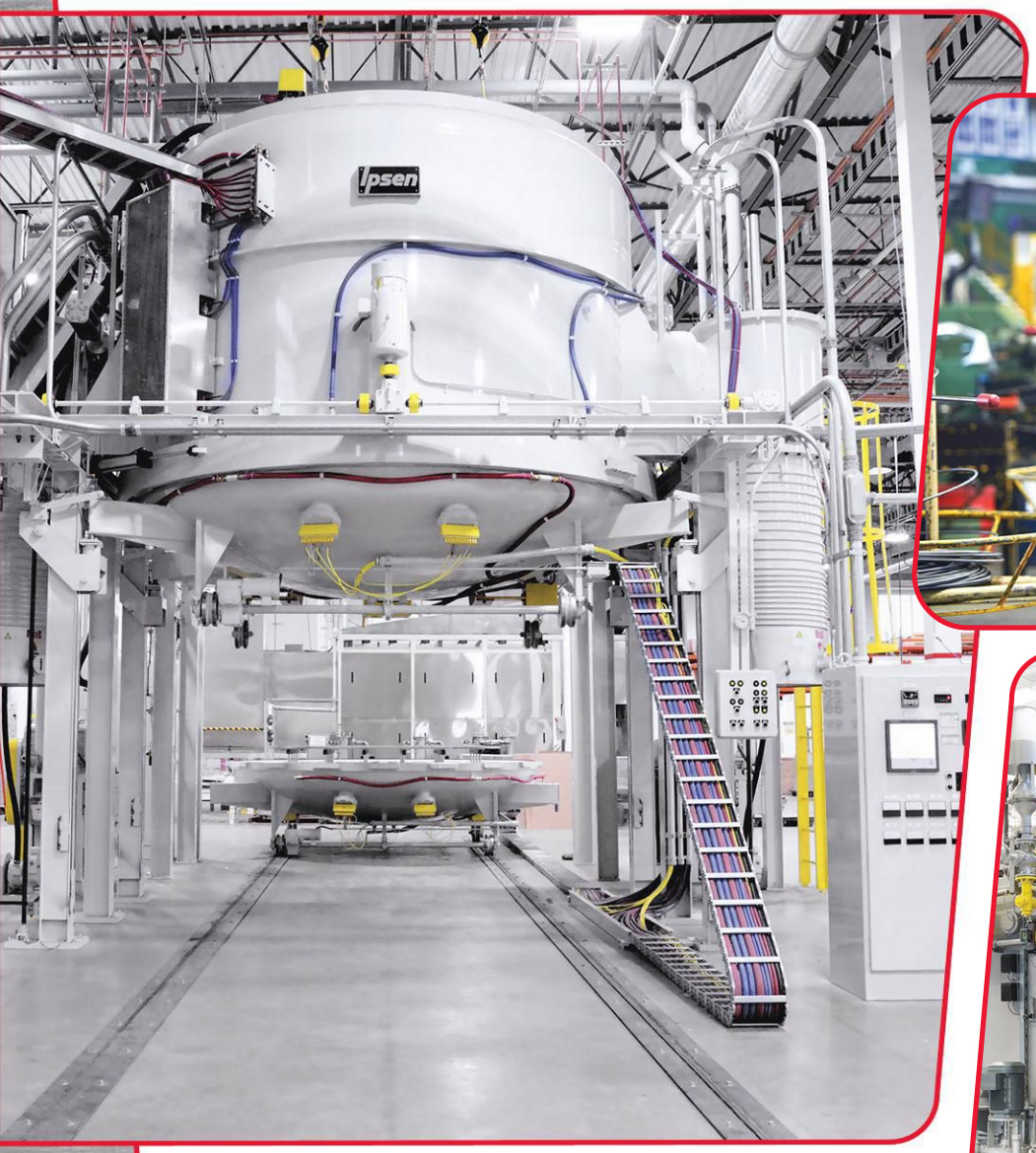

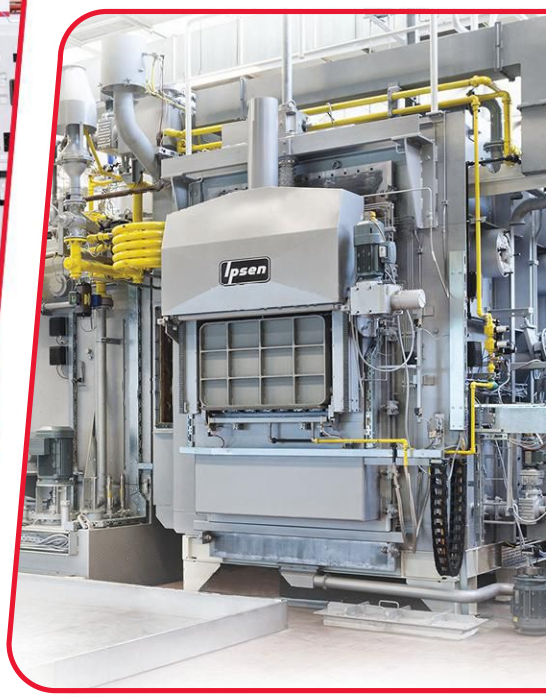

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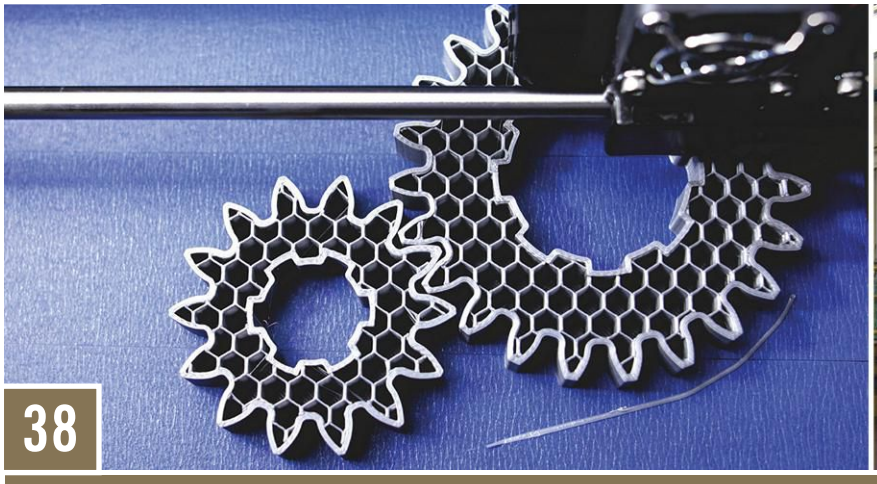

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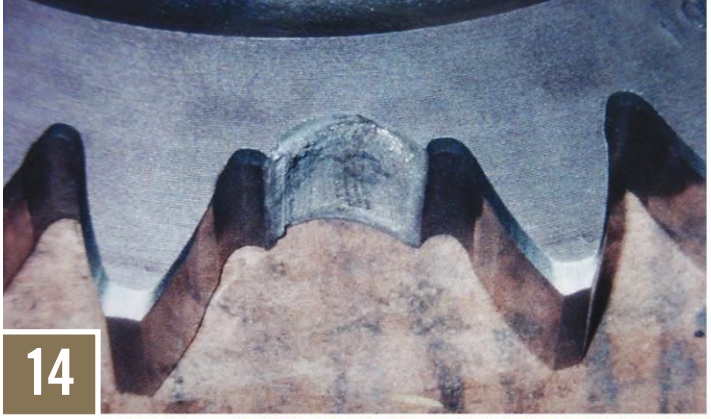

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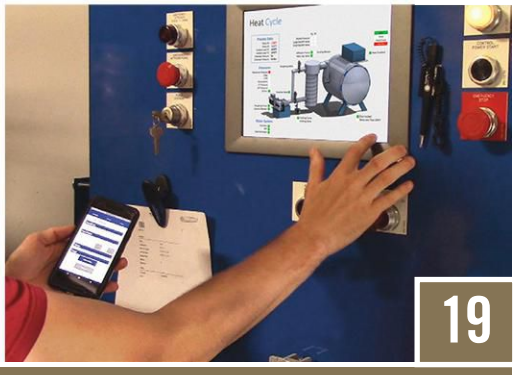

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An autonomous vehicle takes on the challenging infrastructure of Pittsburgh, Pa.

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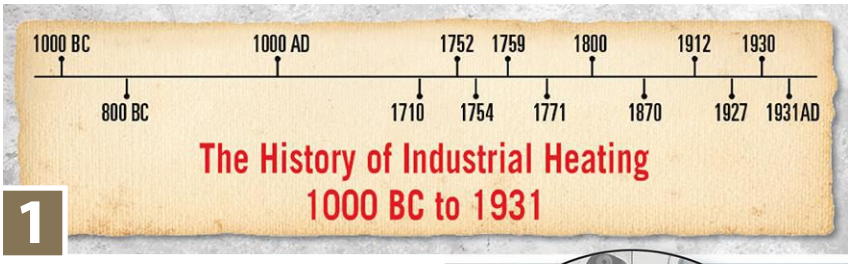

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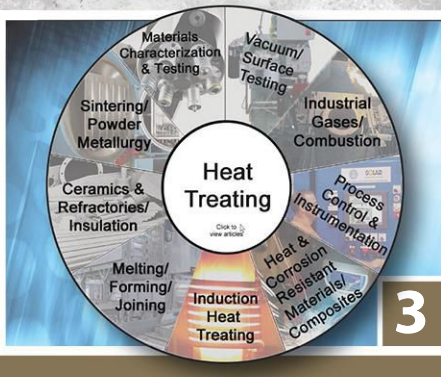

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Automotive Actions

REED MILLER
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Several topics seem to describe the state of the automotive industry at the moment: technology (AI), autonomous, electric and additive manufacturing. Let's look at what's happening in each of these areas.

Technology

In order to achieve advancements such as autonomous vehicles, wireless technology needs to improve. The fifth generation (5G) of wireless technology will allow us to take great advantage of artificial intelligence (AI), virtual reality (VR) and the Internet of Things (IoT). Internet speeds will be 100 times faster than 4G, which will be necessary to usher in autonomous vehicles.

Along these lines, Hyundai Motors recently announced that it would be spending $40 billion in the next five years to develop new models and technologies for electrified and autonomous vehicles in addition to transportation services. The latter is in response to demand shifts due to ride-hailing services.

Technology is also being used by Toyota and other manufacturers to make practical improvements such as maximizing efficiency. Toyota's "Dynamic Force Engines" incorporate advanced technologies (e.g., laser-clad valve seats). Initially released in the 2018 Camry, nine new high-tech engines will roll out by 2021.

Autonomous

We have discussed this technology several times because it is not going away. Self-driving cars use hundreds of sensors to give the car the ability to take over for humans. This creates great volumes of data that require the faster 5G network speeds.

I attended a recent webinar on autonomous-vehicle (AV) technology, and here are a few things that were discussed.

- Station-to-station people movers are likely the first adoption of AV.
- A survey indicated that people are more likely to trust a technology company (versus automotive) with AVs.
- So many things need to be addressed, including factors as simple as temperature. AV sensors need to be able to live in very hot and very cold environments.
- High performance with low power is a must.
- Unless the costs of systems go down, personal vehicles are unlikely to adopt the highest levels of AV technology.
- Algorithms need to be developed through learning. In addition to actual miles driven (10 million), simulations are helping to accelerate the learning process. It was said that 7 billion miles were in simulation.
- As a start, we may want to restrict AVs to certain areas, special lanes, etc.

Electric

Clearly, there is a lot of movement in the electric vehicle (EV) category. A number of these vehicles are manufactured by smaller and startup companies while others are a part of the lineup for the likes of Toyota. Checking out two comprehensive lists showed a total of 46-65 EV models with the higher number including large trucks. With brands like Sono Motors, Tazzari, Thunder Power, Weima and Lucid, many are not household names.

A concern addressed in The Economist is whether the world can produce enough cobalt for all of these EVs. The primary source is the unstable Democratic Republic of Congo. First Cobalt is working toward developing a source of battery-grade cobalt in North America at its Iron Creek Project in Idaho. If we can't find enough in the ground to meet the need, the floor of the Pacific Ocean is known to be lined with nodules rich in cobalt.

Additive Manufacturing

Much is happening here, but one example is Bugatti Automobiles S.A.S. They are using AM to optimize design, thereby saving weight and enhancing performance. AM parts include a titanium brake caliper, active spoiler bracket, motor bracket with integrated water cooling, front-axle differential housing and cylinder-head cam covers.

It is an interesting if not unsettling time to be in the automotive business. Keep an eye on our twice-monthly magEzine newsletter for up-to-date reporting on this dynamic industry.

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BARRY ASHBY
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A paper titled "How Perception of Fossil Fuel Futures Have Evolved," which was published in late February, is unpopular with climate-change advocates across the country. The author, Ronald Voisin, is a retired engineer and has a hobby of studying climate change. The topic as reported is truly an "inadvertent, serendipitous, scientific discovery," according to Thomas Lifson, who reviewed Voisin's article for American Thinker.

Apparently, the world has fossil-fuel supplies for maybe 500 years, and it is more than fracking that will make it all possible. New satellite data – in what was nearly an accident – revealed heretofore unknown, vast, new oilfields globally. North America is where most of these deposits are located. This all came about when volcanologists arranged for new gravimeter sensors on satellites. With improvements of them over the years, scientists have found progressively improved, high-resolution imagery confirming these fossil-fuel deposits. This kind of report was one to make it "Google disappear" for quite a while, if you get my drift – another marker about the declining state of honesty and believability of the media.

In the 1920s, it was widely thought that petroleum reserves might last 10 years. Then with each passing decade for the next century, the expectation varied from 10 to 20 years. In 2008, new space sensors indicated the world has much larger and distributed oil and gas supplies, something that makes this information "possibly the greatest geopolitical significance of any human discovery ever." And with every passing year there is more widely based and definitive understanding of these global deposits.

The U.S. Energy Information Administration (EIA) reports that the U.S. is now, and in 2020, a net energy exporter due to large production of petroleum, gas and natural gas plant liquids (NGPL), at affordable prices, while total U.S. energy consumption remains relatively flat. All this is true while global energy needs rise more slowly than in the past but still should expand by 30% between today and 2040. The largest contribution to demand growth, about 30%, is from India, whose share of global use will rise to 11% by 2040.

It is expected that global use of coal-fired electric demand, which has grown nearly 900 GW over the last 20 years, will add only 400 GW over the next two decades. Oil demand is forecast to grow over the next 20 years but at a steadily decreasing rate, while use of natural gas should rise worldwide by 45% in the next two decades. The outlook for nuclear power generation continues to wane, with China becoming the largest producer of nuclear electric power by 2030. And for the "greenies," global progression of renewables consumption is expected to grow from 9% today to about 16% over the next 20 years.

What all this means is that America seems to be on a road to a stable energy supply at affordable prices for the foreseeable future. And the future seems bright and stable for the most intense-use sector of the U.S. manufacturing economy. This short summary is encouraging. What has been left unsaid so far is how this energy supply and use, domestic and foreign, could or may be manipulated to the detriment of our country.

Most readers are busy-busy with their business activities and often pay too little attention to the truths and realities of ongoing society. It is my view today, being an observer for many decades, that our country is headed in the wrong direction in allowing and countenancing the political class to get serious traction with screwball ideas about how our country is led and operates. Further, the government must be held accountable to the people – that means the ones with some sense in their heads and an understanding of how the nation operates … not as a platter of nutcase views that are impractical and expensive while spending "other people's money."

I am reminded of an oft-repeated story from Reinhold Niebuhr about Nazi Germany in the mid-1930s. The public was busy doing its thing and ignored the building wave of atrocities and bad government actions. "First they came for the union leaders; I said nothing. Then they came for the Jews, and I said nothing. Then they came for me."

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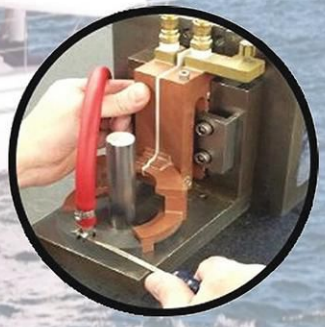

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How Gears Fail – A Pictorial Guide for the Heat Treater

DANIEL H. HERRING
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Heat treatment plays an important and – most would agree – critical role in gear manufacturing. As such, there is a need on the part of the heat treater to better understand the different types of gear failures. Material, design, heat treatment and service application provide examples that will serve as an excellent platform to discuss the different types of gear failures, what causes them and how they might be avoided. Let's learn more.

Types of Gear Failures

Failure modes for power-transmission gears include wear, scoring, profile pitting, tooth breakage and spalling. In broad terms, these can be classified into two general categories: fatigue failures and wear-related failures. Fatigue failures are most often associated with bending (root fillet cracks), subcase (subsurface) fatigue, contact (impact, stress rupture) and thermally induced issues. By contrast, wear failures are often associated with macropitting (pitch-line surface degradation) and abrasive or adhesive wear.

Root fillet cracks and fractured teeth failure are generally the result of cyclic bending stresses exceeding the fatigue strength of the material at the root fillet surface (Fig. 1). Improper case depth, non-martensitic transformation products (NMTP) present in the root microstructure and overload are often the cause of surface cracking, followed inevitably by crack propagation to failure.

Fatigue cracking (i.e., subcase spalling or case/core separation) starts near the case-core interface where the stress exceeds the strength on the applied-stress and critical-strength curves. The contact load induces a fluctuating applied-stress gradient opposed by the critical-strength gradient developed in the material by heat treatment. Case crushing (Fig. 2) is a related phenomenon, and both are due to improper heat treatment, a high stress concentration or both. Case depths that are either too shallow or too deep (not leaving an adequate core to support the case) are common heat-treating-related causes.

Surface or subsurface pitting (Fig. 3) occurs at the intersection of the applied (shear) stress and allowable strength at or extremely close to the surface. When sliding is present and the coefficient of friction is significant (due to poor lubrication, improper lubricant selection or lubricant breakdown), the stress is maximum at the surface.

Other types of gear failures can be traced to poor heat treatment. Examples are shallow case depth or soft spots (Fig. 4) from improper cleaning, incorrect case-hardening process parameters or improper tempering. Poor quenching methods and improper austenitizing temperature can also lead to inadequate hardness, with gears prematurely failing due to soft teeth (Fig. 5).

Material issues such as hardenability, grain size and inclusions (Fig. 6) can result in various gear failures. This underscores the criticality of steel cleanliness as well as controlling the size, shape and type of inclusions present. Alloy segregation and banding are other issues that one can encounter in a given material, which is one of the reasons why normalizing is considered a prudent step in the heat treatment of gears.

Preventing Gear Failures

It is important to recognize that fatigue strength is influenced by factors such as hardness distribution (case depth and case and core hardness), microstructure (grain size, retained-

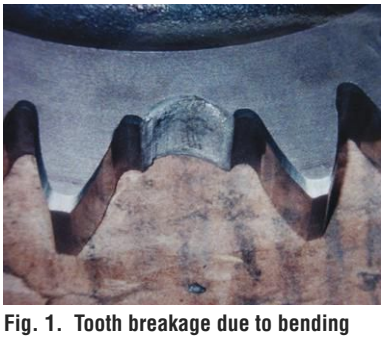

Fig. 1. Tooth breakage due to bending fatigue

Fig. 2. Gear teeth torn away from the gear surface

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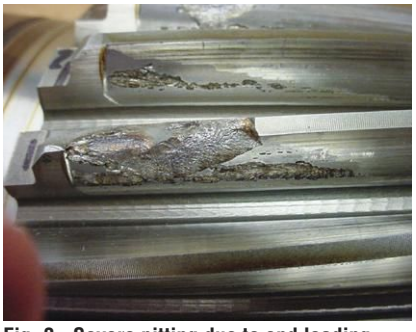

Fig. 3. Severe pitting due to end loading

Fig. 4. Soft spots in the carburized case (observed after shot peening)

Fig. 5. Inadequate hardness leading to gear failure

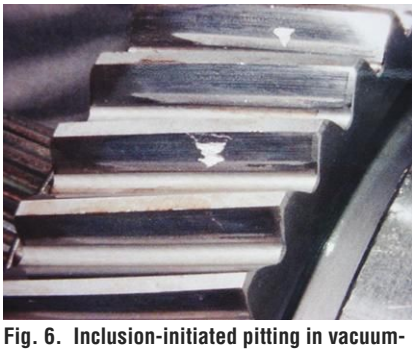

Fig. 6. Inclusion-initiated pitting in vacuum-degassed steel

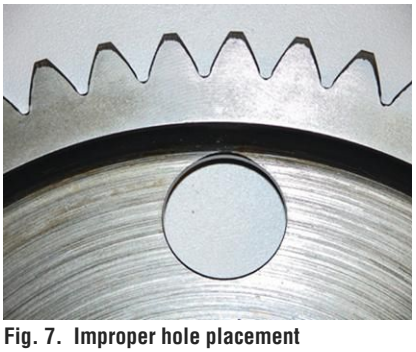

Fig. 7. Improper hole placement

austenite percentage, non-martensitic phases, carbide morphology and intergranular toughness) and also by design (Fig. 7) and manufacture (residual compressive stress state, surface finish and geometry). The objective of heat treatment is to have high hardness and adequate subsurface strength on the active flank and good surface hardness and high residual compressive stress in the root area.

Selecting case depth (i.e., the strength gradient) is influenced heavily by core hardness and tempering temperature. From an alloying standpoint, molybdenum and manganese strongly influence core hardness, while chromium has a moderate influence and nickel has only a weak influence. It should also be noted that the case hardness is much more sensitive than the core hardness to the tempering temperature employed, which is why tempering temperatures must be selected based on final case hardness.

Low case hardness can also be due to carburizing with too lean a carbon potential, formation of undesirable microstructural constituents, partial decarburization of the surface, a "slack" quench or use of the wrong tempering temperature. Variations in process parameters result in undesirable microstructures.

Excessive retained austenite (Fig. 8a) and excessive carbide formation (Fig. 8b) can both lead to premature failure of the gears in service. Possible reasons for massive amounts of retained austenite include too high a carbon potential or

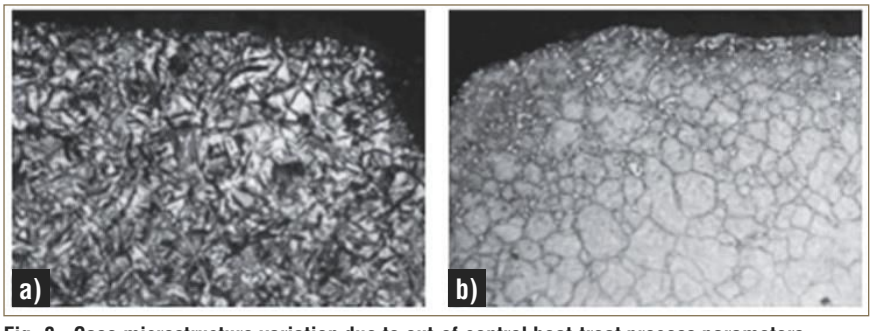

Fig. 8. Case microstructure variation due to out-of-control heat-treat process parameters

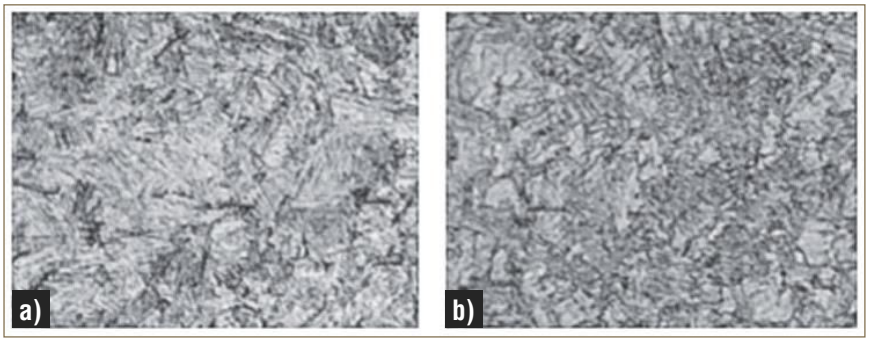

Fig. 9. Core microstructure variation due to quenching: (a) fully martensitic microstructure with a core hardness of 44 HRC, (b) martensitic microstructure with transformation products (bainite and ferrite) present with a core hardness of 26 HRC

direct quenching from carburizing temperature. Possible causes of carbides and carbide necklacing is, again, too high a carbon potential, insufficient diffusion time, too short a soak time and too low a hardening temperature.

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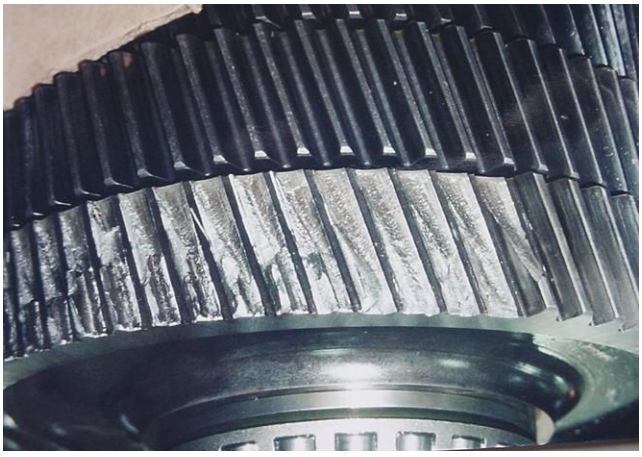

Fig. 10. Case/core separation

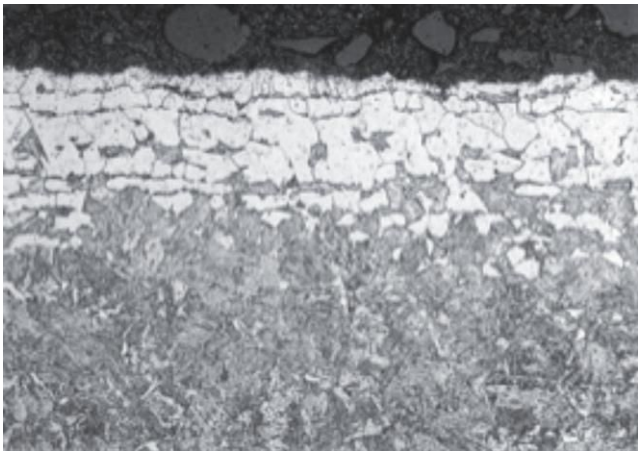

Fig. 11. Complete surface decarburization

Certain gear failures can also be traced to issues with case leakage, which is failure of selective carburization masking methods (e.g., copper plating, stop-off paints) to protect the surface from damage. In some instances, surface contamination or improper drying will cause surface blistering. Overly aggressive blasting after plating can also damage the mask. When nital etched, unwanted carburization often appears as an irregular dark-gray indication (in an area that should have been light gray).

Variations in quenching, even within the same quench medium, can cause improper core microstructure and hardness. An 8822RH transmission gear was quenched at two different gas pressures (20 bar, 12 bar) and resulted in differences in hardness and microstructure (Fig. 9).

Gear geometry and carburizing too deep for the given tooth profile can result in a crack within the case, which starts in the subsurface. This phenomenon is commonly referred to as case/core separation (Fig. 10). By reducing high carbon concentrations at the surface (e.g., masking the top lands and end faces) and employing a case depth on the low end of the specification, the problem can often be avoided.

The condition of a particular heat-treat furnace can also play a major role in premature gear failure. Air intrusion into the furnace – whether through poor practices or leaks – can affect case hardness and residual-stress patterns by creating partial or, in some extreme instances, complete (total) surface decarburization (Fig. 11). Having an atmosphere carbon potential less than the surface carbon content in the part or a loss of protective atmosphere (such as when a power failure occurs) are common reasons for this condition to exist.

Finally, the choice of carburizing method (atmosphere, vacuum) can result in differences in surface condition, intergranular oxidation (IGO) and surface de-alloying due to oxidation.

Summary

Gears fail for a variety of reasons, but those induced by heat treatment are avoidable through good practices and tight control of process and equipment variability.

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How the Next Generation is Changing Culture: There May Be a Better Way

STEVEN CHRISTOPHER
Super Systems, Inc.
West Coast Sales Engineer
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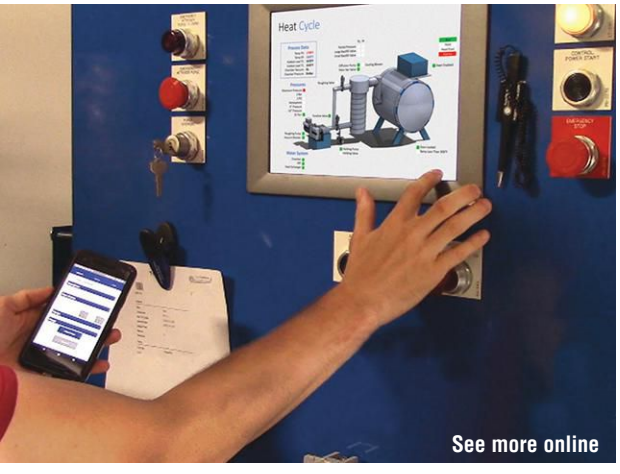
Having graduated from Purdue University with an ME degree, I have been working in manufacturing for 15 years – 10 of those dedicated to heat treat. I immediately loved this industry, striking a balance working both on equipment and from a desk. I have worked for a commercial heat treater and a supplier, viewing the industry from both perspectives. I have visited both simple family-owned and high-tech facilities. When inquiring why either did things a certain way, I was met with the same answer: "Not sure. That is just how we have always done it."

Customers and accreditations are constantly evolving and improving how we operate. At the same time there seems to be a national changing of the guard. Nearly every facility I visit has an owner or employee planning their retirement and navigating that transition to the next generation; exciting me as the next generation becomes involved in company decisions.

These individuals seem to not be satisfied with "that is just how we have always done it," and they are willing to invest their own time to revolutionize the industry. During this Information Age, the future lies with understanding the difference between data and information – and more importantly doing something about it! Many companies record an extraordinary amount of data but fail to convert this into easily accessible information. The answer lies within both equipment and software used to capture, display and report data.



See more online

Facilities historically maintained separate charting, quality and often enterprise resource planning systems. Each functioned independently, with users alternating between multiple systems. I recently collaborated with several companies working to marry these systems. Others want information to be available 24/7. We provided team leaders with wireless tablets to view production activity and built notifications to text them of process deviation. I am excited thinking these efforts have (hopefully) barely scratched the surface of this technology.

Understanding realistic utilization is a goal for most management. One customer had a very reliable system calculating their equipment efficiency, which displayed time in or out of production per shift, week or month. While many may be envious of such a system, one of their young engineers saw room for improvement. He believed these numbers were helpful, but he needed to evaluate beyond binary terms to truly improve his efficiency.

His goal was to understand not just utilization but the cause for being out of production. For a year, he tried "postmortem" to answer this question. Every evening, he would evaluate charts and talk with operators, documenting what happened between loads. He expected there was an easier way and asked for help.

Over the next year, we developed a solution to simplify this approach and improve accuracy while minimizing extra work for the operators. Before starting a cycle, operators would quickly select from a list what had occurred since the previous cycle (maintenance, TUS, waiting on parts, etc.).

At the end of the first month, he ran a report and saw the largest contributor to downtime was a lack of baskets and fixturing. His ability to think "outside of the box" and our partnership allowed him to transform data into information. After receiving new fixturing, he immediately increased throughput on the production floor. Over the next few months, reporting allowed for improvements to pyrometry and maintenance, which streamlined planned downtime and increased productivity.

I am lucky to be part of an industry that has so many experienced, knowledgeable members willing to share what they have learned with my generation. I am also excited to be part of a generation ushering in ideas changing the way we heat treat parts.

Studying Automotive-Steel Microstructures

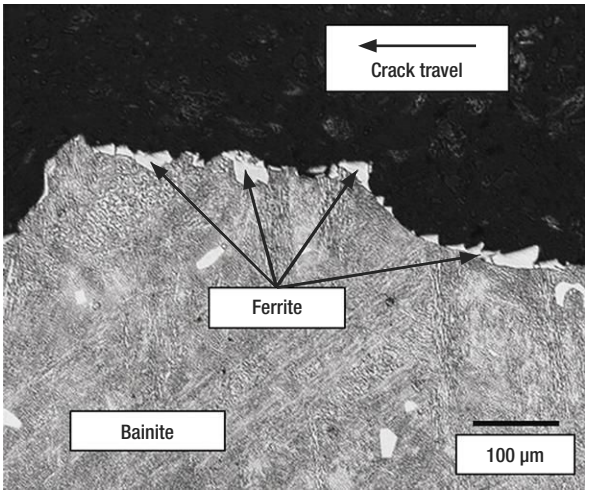
DR. BRYAN WEBLER
Assistant Professor of Materials Science and Engineering
Carnegie Mellon University

Despite its history and ubiquitous presence as an infrastructure material, steels remain a complex material system with many persisting research questions. One of the reasons for this is steel's enormous variability in properties depending on composition and processing.

I am part of a research group, the Center for Iron and Steelmaking Research (CISR), at Carnegie Mellon that is devoted to these research questions. One of my PhD students has just about finished a project investigating the classic metallurgical problem of "microstructure–processing–properties–performance" relationships in steels but with the twist that we care about performance during processing of the steel, not just performance in service.

The steels of interest in this project are new grades that have potential for automotive vehicle structures. Steel remains the material of choice for vehicle structures because of its low cost and wide variability in properties, particularly strength and ductility. This variability gives vehicle designers flexibility in structural design.

There is competition from other materials, particularly aluminum, and the steel industry has responded with new steels and new processing schemes to produce material with even wider ranges of strength and ductility. These new steels for vehicles are higher in the alloying elements manganese and silicon than many other steels. These elements, combined with carefully controlled heat treatments, result in the desirable properties. There are challenges in making these steels in current steel plants because the equipment and the practices have not typically been used to make steels of these high-alloy contents.



There are essentially five steps to making steel: (1) obtain metal from iron ore or scrap, (2) melt and refine, (3) cast into solid form, (4) shape into desired product and (5) heat treat or galvanize. Our focus has been on step 3.

Steels for automotive applications are cast into approximately 9-inch-thick slabs. The slabs are cooled and sometimes shipped long distances for the shaping and treating steps. Typically, as-cast slabs are not of concern because additional processing steps will completely change their microstructures and properties. That's not the case for these steels – the as-cast state is of critical importance. This is because these steels are brittle in the as-cast state and easily fracture.

We have been performing experiments and simulations to describe these microstructures and test if certain microstructures cause fracture. Because of the alloying elements, these steels have much more complicated microstructures than are typically observed in the as-cast state.

We have found that slower cooling (typically beneficial in preventing cracking) results in formation of thin films of ferritic iron. Cracks propagate through these ferrite films, and the steels easily fracture. This is illustrated in the figure, which is an optical microscope image of a broken steel sample that shows how the crack moved through the microstructure.

The crack traveled right-to-left along the bright, white ferrite films (the gray part of the microstructure is bainite). With faster cooling, there is insufficient time for the ferrite films to form, and fracture is more difficult. Our fundamental results linking steel composition, microstructural development and mechanical properties can be used by steel plants to design cooling strategies that keep slabs from cracking.

The difficulties in designing and controlling processes to efficiently produce steel with the right properties at scale are not limited to new grades. However, doing something new always creates many challenges. The complexity of steel and the pace of alloy development are likely to increase. Research at CISR helps ensure industrial-scale production can keep up.

Paulo

MTI
Metal Treating Institute
904-249-0448
www.HeatTreat.net

When you think of U.S.-based thermal-processing providers, one of the names that immediately comes to mind is Paulo.

Founded in 1943, Paulo is one of the largest providers of thermal-processing and metal-finishing solutions in North America. Headquartered in St. Louis, Mo., the company operates six divisions servicing the Midwest, Great Lakes and Southeast regions of the U.S. and northern Mexico.

Paulo, which today has 450 employees, started out as a two-person operation. Ben and Pauline Rassieur started Paulo Products Company over 75 years ago, offering heat-treating services using homemade salt baths and second-hand tempering furnaces out of a rented space in St. Louis. The company built its first plant in 1948 at 5711 W. Park Ave., a site that still stands in 2019.

This MTI member grew steadily over the decades. In the 1960s, Paulo was contracted to braze and assemble 6.5 million fuel-pump housings per year for 10 years, touching every fuel-pump housing for every Ford and Chrysler model for a decade. The company also won jobs to treat track pins from salvaged World War II tanks and M14 rifle magazines and braze 106-mm artillery shell casings. It was around this time that Paulo became one of the first heat treaters to install a computer to aid in processing orders.

In 1972, Paulo built a 3,200-square-foot facility in Kansas City. Two years later, the company purchased Mid-South Metal Treating Co. of Memphis, Tenn. A two-story office building was constructed adjacent to the St. Louis plant in 1977 and remains corporate headquarters to this day. Throughout the 1980s, Paulo acquired Olin Metal Products of Murfreesboro, Tenn., and three plants from U.S. Steel Supply in Alabama, Ohio and Tennessee.

Paulo officially went international in 2018 when it opened a 50,000-square-foot heat-treatment plant in Monterrey, Mexico. The company also broke ground on a 30,000-square-foot expansion of its Cleveland plant, which added five vacuum furnaces.

Today, Paulo provides a wide range of thermal-processing services to the automotive, aerospace, mining, agriculture and heavy equipment industries. These services include, but are not limited to: annealing, austempering, case hardening, ferritic nitrocarburizing (FNC), gas nitriding, induction heat treating, precipitation hardening and vacuum brazing/heat treating.

Paulo does focus on a couple of key areas, namely vacuum and continuous belt. The company operates roughly 50 vacuum furnaces across its plants with a core competency of heat treating and brazing superalloy aerospace parts and tool steels. The company also operates several continuous belt furnaces, processing small stamped or fine-blanked components for the automotive industry.

In an effort to stay ahead of the competition, Paulo has invested in building its own software since the early 1990s. PICS (production information and customer service) allows the company to track orders from receipt to shipping; download recipes to equipment to error-proof and ensure repeatability; and automatically quarantine orders in the case of a processing or testing anomaly. Paulo also employs a large metallurgical staff dedicated to problem solving and designing processes to meet specifications.

As for the future, Paulo's newest investment – a hot isostatic press – will be installed in Cleveland in the third quarter of 2019. And, as it always has, Paulo will continue to invest in its people, equipment and technology to support customers, both current and new.

Remembering Where We Came From

IHEA
Industrial Heating Equipment Assoc.
859-356-1575
www.ihea.org

In this fast-paced world, it gets harder and harder to remember the past. It seems like the only thing that matters is this quarter. But without occasionally taking the time to stop and reflect on the past and where we came from, we tend to lose perspective.

It was Jan. 19, 1929, when a group of furnace manufacturer's met in Pittsburgh, Pa., to form an organization. Initially called the Industrial Furnace Manufacturer's Association (IFMA), there were seven founding members: Chapman Stein Company, Costello Engineering Co., George J. Hagan Company, Holcroft & Company, Rust Engineering Company, Surface Combustion Co. and William Swindell & Bros.

F.W. Manker of Surface Combustion was the association's first president. Total receipts of the association in 1929 were $800! Expenses for 1929 were $75.75! It was a really tough time to start anything, yet these companies had the vision to work together and form an association that would serve the industrial heating marketplace in the U.S.

In 1933, a meeting was held to study and discuss a proposed code under the National Recovery Act of 1933. In 1934, there was a hearing on the proposed code, which was approved by the industry. The purpose of the code was to promote cooperative action among businesses to achieve fair competition and provide for national planning and a second section establishing a national public works program, which was ultimately signed by President Roosevelt on June 16, 1933.


IHEA's Board of Directors and officers in 1959

At that point, 52 companies were reporting sales data to the IFMA Code Authority. Between 1933 and 1936, however, membership and activities hit a low ebb when Stewart Clarkson donated his time to rejuvenate IFMA.

In the ensuing years, IFMA served as a mediator for potential patent suits among members, and the Army Ordnance specifications for furnaces were reviewed by IFMA committee members. When World War II came along, IFMA represented the industry in Washington, D.C. Membership doubled during that time. The IFMA also compiled a list of labor contract clauses that could be used by member companies.

By the late 1940s, the association was promoting articles to appear in the trade press, getting 105 articles published between 1947 and 1948. This was also the time frame that the association permitted associate memberships.

It was November 1954 that an official name change was made to the Industrial Heating Equipment Association (IHEA). In the years since, IHEA has served the industry by providing a wide variety of educational opportunities, being an unbiased representative to NFPA codes and influencing governmental agencies on behalf of the membership. 2019 also marks the 50th IHEA Annual Combustion Seminar.

Times have certainly changed in the 90 years since IHEA was founded. Communication is now instantaneous, responses are expected almost as quickly, mobile devices are now nearly an appendage for most people and many individuals find it difficult to disconnect. Ninety years of history, meetings, minutes, photos, committees and people have gone into making IHEA the resource for the thermal-processing industry that it is today.

As IHEA celebrates these milestone anniversaries, we hope that we aren't too busy to stop and reflect on where we came from and allow that to guide us to where we want to go as an industry. We hope everyone will celebrate with us as we turn 90 and work with us to further the mission of the industry started by our founding members on that long-ago January day.

EQUIPMENT NEWS

Batch Integral-Quench Furnaces

Surface Combustion supplied two new Allcase batch integral-quench furnaces to Cambridge Heat Treating of Cambridge, Ontario. Cambridge also purchased two used Allcase furnaces. All four units were installed in the same line along with a previously purchased 30- x 30- x 48-inch Allcase with top cool. All the furnaces are serviced by Surface's charge car, Uni-DRAW batch tempering furnaces, washers and an RX endothermic-atmosphere gas generator. The 36- x 48- x 36-inch batch heat-treat line greatly expands Cambridge's capacity for carbonitriding, carburizing, neutral hardening, ferritic nitrocarburizing (FNC) and normalizing.

www.surfacecombustion.com

Nitrocarburizing System

Nitrex Metal received an order for a turnkey nitrocarburizing system from Alu Menziken Extrusion AG, a Swiss manufacturer of aluminum profiles and complex extrusion-press products. The system, which incorporates Nitreg-C technology for treating aluminum extrusion dies, was installed at the company's new state-of-the-art manufacturing facility in northwestern Romania. The pit furnace has overall chamber dimensions of 31.5 inches in diameter x 59 inches high (800 x 1500 mm) with capacity optimized to nitrocarburize a 3,300-pound (1,500-kg) load. The process technology adapts to the application requirements to deliver improved performance of extrusion dies.

www.nitrex.com

CAB Furnace

SECO/WARWICK delivered and commissioned what it says is the first-ever vacuum-purging semi-continuous controlled-atmosphere brazing (CAB) furnace for a North American automotive aftermarket manufacturer. It is the company's first furnace of any type and also its largest capital equipment investment. The furnace, equipped with vacuum purging in the loading and unloading chamber, allows for reduction of nitrogen consumption and cost. It also provides exceptional control of brazing atmosphere quality, which applies particularly to heat exchangers with joints brazed in a closed space. Vacuum purging allows for the removal of oxygen from these spaces before brazing, which cannot be achieved by traditional purging.

www.secowarwick.com

Hydraulic Open-Die Forging Press

SMS group received a contract from Chinese steel and forging company Daye Special Steel Co. Ltd. for the engineering and delivery of a high-speed hydraulic open-die forging press. The press operates with a forging force of up to 50 MN and an upsetting force of 60 MN. The high forging frequency of the press enables sophisticated materials requiring a narrow temperature range to be forged and reduces machining times. Daye Special Steel plans to use the press, which will be installed in its Huangshi plant, to forge a variety of products of high-temperature alloys and special steel. Commissioning is scheduled for May 2020.

www.sms-group.com

Dual-Chamber Box Furnace

L&L Special Furnace Co. Inc. shipped a dual-chamber heat-treating furnace to a southeastern U.S. manufacturer of various items used in the production of heavy equipment and transportation devices. The box furnace will be used to heat treat the tooling used to manufacture these items. Its top chamber, which has an effective work zone of 16 inches wide x 16 inches high x 32 inches deep, is used to harden tool steels. Its bottom chamber, which has an effective work zone of 14 inches wide x 14 inches high x 32 inches deep, is used for tempering, stress relief and preheating. The top chamber has a uniformity of ±20° above 1200°F, and the bottom chamber has a uniformity of ±10°F from 300°F to 1250°F.

www.llfurnace.com

UBQ Furnaces

AFC-Holcroft received multiple orders throughout 2018 for UBQ (universal batch quench) furnaces and companion equipment from Modern Heat Treat, a commercial heat-treating operation in Richland Hills, Texas. The equipment was installed alongside similar equipment already in operation at the facility. Modern Heat Treat benefitted from the modular, flexible UBQ design with the ability to add new equipment incrementally, creating full production cells that utilize existing controls.

www.afc-holcroft.com

BUSINESS NEWS

IHEA Announces Fall Seminars, Business Conference

The Industrial Heating Equipment Association (IHEA) announced that the 2019 Fall Seminars and Fall Business Conference will be held in Cleveland, Ohio, Sept. 24-26. The technical seminar series will be held on Tuesday and Wednesday, followed by the Fall Business Conference on Thursday at the Intercontinental Cleveland. The Combustion Seminar and the Safety Standards and Codes Seminar will take place

concurrently over both days. There will also be two separate one-day seminars on infrared heating and induction technology. Attendees of all four seminars will enjoy access to IHEA's tabletop exhibition and reception on the afternoon of Tuesday, Sept. 24.

The Combustion Seminar is presented by industry professionals from heat-processing companies who will deliver relevant information on combustion technologies. The Safety Standards and Codes Seminar covers critical safety information for those involved with a wide range of industrial thermal-processing applications as well as the 2019 updates to the NFPA 86 standard. IHEA's Infrared and Induction Divisions have created two agendas that thoroughly review the basics, useful applications, equipment and benefits of each technology in order to improve plant operations.

IHEA's Fall Business Conference follows the seminars, beginning Wednesday evening, Sept. 25. The conference brings IHEA member company representatives together for committee meetings and educational presentations to discuss challenges and issues of concern to members.

Nucor Picks Kentucky for $1.35 Billion Steel Plate Mill

Nucor Corp. will build its new state-of-the-art steel plate mill in Brandenburg, Ky., located along the Ohio River southwest of Louisville. The company will invest approximately $1.35 billion to build the mill, which will be capable of producing 1.2 million tons per year of steel plate products. The project, which was originally announced in January, will create more than 400 full-time jobs at an average annual salary of $72,000. The plate mill, which is expected to be fully operational in 2022, will give Nucor the ability to produce 97% of the products demanded in the domestic plate market, including specialty higher-margin products. The facility will produce cut-to-length, coiled, heat-treated and discrete plate ranging from 60 to 160 inches wide and in gauges from 3/16 of an inch to 14 inches.

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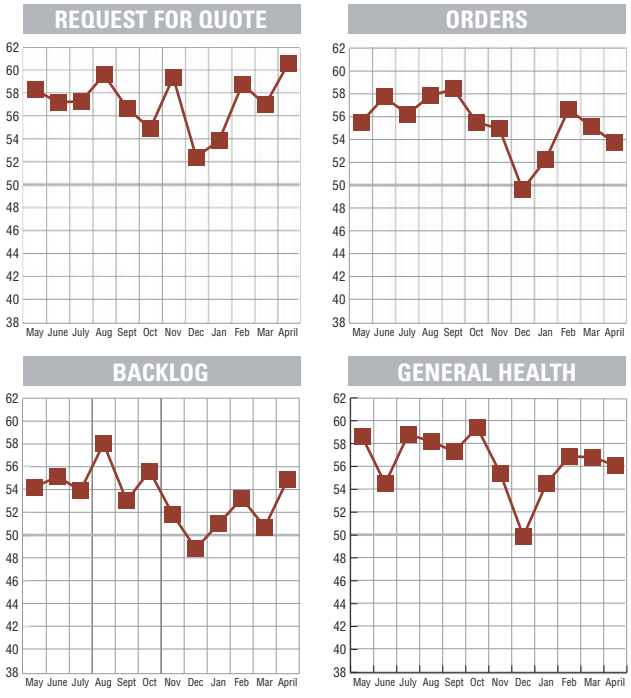
ECONOMIC INDICATORS



Values above 50 indicate growth or increase. Values below 50 indicate contraction or decrease.
To participate in this survey, please contact Bill Mayer at bill@industrialheating.com

Tenaris to Acquire IPSCO Tubulars

Tenaris S.A. entered into a definitive agreement to acquire from PAO TMK, a Russian manufacturer of steel pipe, 100% of the shares of its wholly owned U.S. subsidiary IPSCO Tubulars Inc. for $1.2 billion. IPSCO Tubulars is a U.S. domestic producer of seamless and welded OCTG and line pipe products with an annual production capacity of 450,000 metric tons of steel bars, 400,000 metric tons of seamless pipe and 1,000,000 metric tons of welded pipe. The acquisition will add a first U.S. steel bar production facility at Koppel, Pa.; complement Tenaris' seamless production in Bay City, Texas, with a second facility in Ambridge, Pa.; and bring additional heat-treatment, welding and finishing facilities to better serve customers.

INDUSTRY EVENTS

June 23-26 **Powdermet 2019;** Phoenix, Ariz. www.mpif.org

June 23-26 **Conference on Additive Manufacturing with Powder Metallurgy;** Phoenix, Ariz. www.ampm2019.org

June 25-29 **Thermprocess 2019;** Düsseldorf, Germany www.thermprocess-online.com

Sept. 24-25 **IHEA Safety Standards & Codes Seminar/Combustion Seminar;** Cleveland, Ohio www.ihea.org

Sept. 24-27 **PMTi 2019 – Powder Metallurgy and Additive Manufacturing of Titanium;** Salt Lake City, Utah www.pmti2019.org

Oct. 8-9 **MEITECH 2019 (Heating Technology Expo);** Queretaro, Mexico www.meitechexpo.com

Oct. 15-17 **Heat Treat 19 – 30th Heat Treating Society Conference & Exposition;** Detroit, Mich. www.asminternational.org

Oct. 17-18 **Thermal Technology 2019;** Osaka, Japan www.thermaltechnology-expo.com

Oct. 22-24 **The Quality Show;** Rosemont, Ill. www.qualityshow.com

Determining the Optimal Induction Process for Your Application

David Lynch – Induction Tooling, Inc.; North Royalton, Ohio

Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction through heat generated in the object by eddy currents.

An induction process consists of an induction power supply that passes a high-frequency alternating current (AC) through an inductor. The rapidly alternating magnetic field penetrates the object, generating electric currents inside the conductor called eddy currents. The eddy currents flowing through the resistance of the material heat it by Joule heating.

The frequency of current used depends on the object size, material type, coupling between the work coil and the object to be heated, and the penetration depth. Determining the process parameters of an induction hardening process can be very complex and challenging. I will attempt to break this process into steps to better understand what is required to identify the optimal induction process for any given application.

Is the part a good candidate?

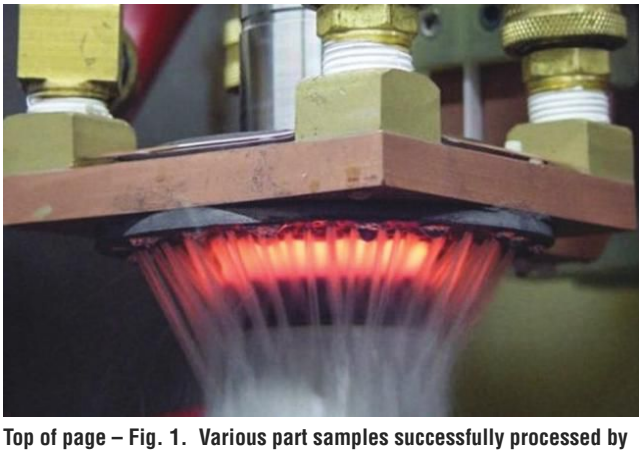
Material composition and pre-treatment must be conducive of heat treatment to the required heat-treat specification. The heat-treat specification must be accommodating to the induction heating process. The part geometry needs to provide adequate clearance to present an inductor coil and generate the required induction field to achieve specification.

These parameters must be considered to determine the feasibility of any given application. Figure 1 shows various part samples successfully processed by induction heating. These samples have been cut and etched to reveal the hardened areas.

Heating Method

There are two primary methods of heating parts by induction: scanning and single shot. Scan hardening is commonly used to heat treat long, uniform parts. The part is rotated and passed through the center of the inductor with the power turned on at a controlled rate of travel.

At the inductor, a controlled band of heating is generated into the surface of the part (Fig. 2). As the part continues to travel, it moves into a liquid shower quench. The energy required to



Top of page – Fig. 1. Various part samples successfully processed by induction heating
Fig. 2. A controlled band of heating is generated into the surface of the part at the inductor.

scan harden can be significantly less than single-shot hardening because you are only heating a small portion of the part at any given time.

Single-shot hardening heats and quenches the required hardness pattern all at once and is often the only method available for parts with complex geometries (Fig. 3).

Power Requirements

There are simple calculations that can be used to estimate the power requirements for a given process. First, it is necessary to calculate the square inches of the surface area to be heat treated. For single-shot hardening, this would include the total square inches of all surfaces to be heat treated. Single-shot hardening typically requires approximately 15 kilowatts (kw) per square inch of surface area for a successful heat treat (e.g., 10 square inches x 15 kw = 150 kw required).

For scan hardening, it would be the surface area of the heating band, which is the largest circumference of the part multiplied by the face width of the inductor coil. Scan hardening typically requires approximately 10 kw per square inch of the heating band surface area (e.g., 2.00-inch-diameter shaft x 0.5-inch inductor face width = 3.14 square inches x 10 kw = 31.4 kw required).

The reason less power is required for scan hardening is because the power is turned on and the part dwells in place for a short period of time before scanning begins. This dwell is necessary to allow time for the heat to build up and penetrate into the part to achieve case-depth requirements at the start position. This dwell also allows thermal conduction to move up the part and acts as a preheat. As the part starts to move from dwell through the inductor, it already has some heat in the surface ahead and requires less energy to achieve the target temperature.

Frequency Requirements

Common frequencies available for selective hardening vary from as low as 1 kHz to as

Fig. 3. Single-shot hardening

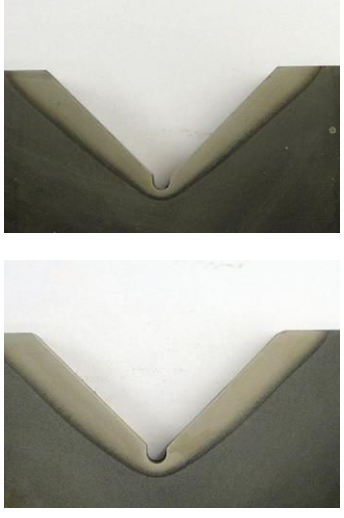


Fig. 5. Two cross sections of a cross roller bearing that have been acid etched to show the heat-treat pattern

Figure 4 shows examples of three induction hardened transmission shafts. The splined shaft (top) has relatively uniform geometry and was successfully scan hardened. The output shaft (middle) was single-shot hardened due to the large step from the smallest to largest diameters while requiring hardness depth in the fillet area between.

Attempting to scan harden the output shaft would be extremely difficult or may prove to be impossible. Scan hardening the output shaft would be marginal at best with probable overheat in the corner of the largest diameter.

The input shaft (lower) was actually processed both ways successfully. This originally started as a scan-hardening process. The product moved to a different machine with a larger power supply, and single-shot hardening was implemented to increase throughput. It was much faster to process these parts single shot rather than scanning, but it required more power.

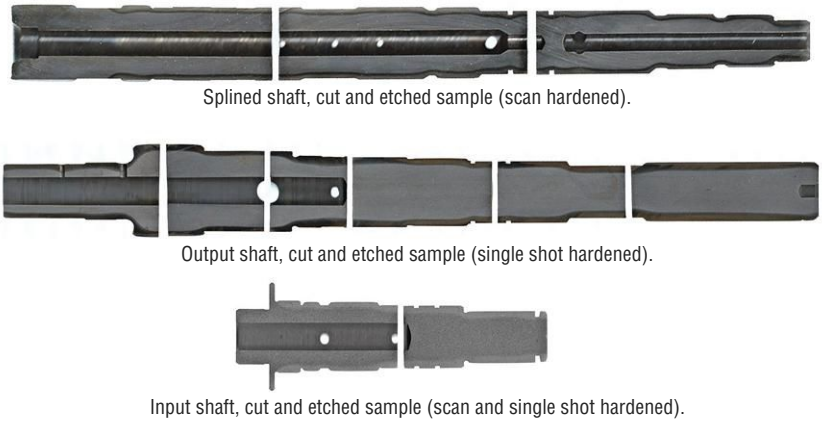


Fig. 4. Examples of three induction hardened transmission shafts

Fig. 6. Various sizes of scanning inductors designed to scan harden the outer diameter of round shafts

high as 450 kHz. Most of the induction equipment available today falls into one of three different categories.

- Low frequency (1-8 kHz) is typically used for deep hardness specifications of 0.100-0.400 inch (2.5-10.0 mm) case depth.
- Medium frequency (8-100 kHz) is typically used for medium hardness specifications of 0.050-0.100 inch (1.3-2.5 mm) case depth.
- High frequency (100-450 kHz) is typically used for shallow hardness specifications of 0.015-0.050 inch (0.4-1.3 mm) case depth.

Sometimes the equipment available is not ideal for a given application. Figure 5 illustrates a case study run in our induction laboratory that shows two cross sections of a cross roller bearing that have been acid etched to show the heat-treat pattern.

These parts were both heated with the same power at the same scan rate using the same quenching method. The variable that changed was the frequency. The sample on the top was run at 15 kHz, and the sample on the bottom was run at 8 kHz. You can see a significant difference in the case depth at the valley of the groove. Although the difference in the frequency range may not seem substantial, you can see what a difference frequency can make to any given process.

Tooling Requirements

The proper inductor design and size are essential to achieving good repeatable results in any given process. Figure 6 shows various sizes of scanning inductors designed to scan harden the outer diameter of round shafts. The quench shower is machined into the inductor to provide optimal quenching. The sizes vary based on the size of the parts to be processed.

These inductors offer flexibility to run different parts of similar size. However, this does come with limitations. As the gap between the outside of the part and the inside of the inductor increases, the induction field generated by the inductor may not couple to the part efficiently and may suffer side effects. These

side effects may include fuzzy or not fully transformed structure.

Spotty hardness can also occur due to the field not wanting to remain coupled with the part. The field may jump and lead to bands of hardness. Figure 7 is an example of a single-shot inductor with machined integral quench to heat treat two independent race areas simultaneously on an automotive wheel-bearing outer-race hub. Single-shot inductors are typically dedicated to one unique part geometry. It is very important to keep the inductors clean and free of debris and buildup because contamination is the leading cause of premature inductor failure.

Quench Requirements

Once a part is heated to a desired temperature, it needs to be cooled rapidly to achieve proper hardness transformation and structure. This cooling process is typically achieved by liquid quenching with a water-polymer solution. If the quenching is not sufficient, hardness and structure in the part may not reach specification. If the quenching is too aggressive, cracking may occur.

There are variables that may contribute to the quenching effect that must be considered. The physical mass of the part behind the area of the part being heated can help remove some, if not all, of the heat in a given application. If this mass is great enough, it may offer enough heat removal to fully transform the structure without the use of additional liquid quench.

Polymer concentration can also be adjusted to retard or make the quench more aggressive. The position of the quench shower in scan-hardening applications can be positioned farther away from the heating zone to delay the quenching action. In single-shot applications, a dwell can be added between the power off and quench on to delay the quenching action as well.

Fig. 7. Single-shot inductor with machined integral quench

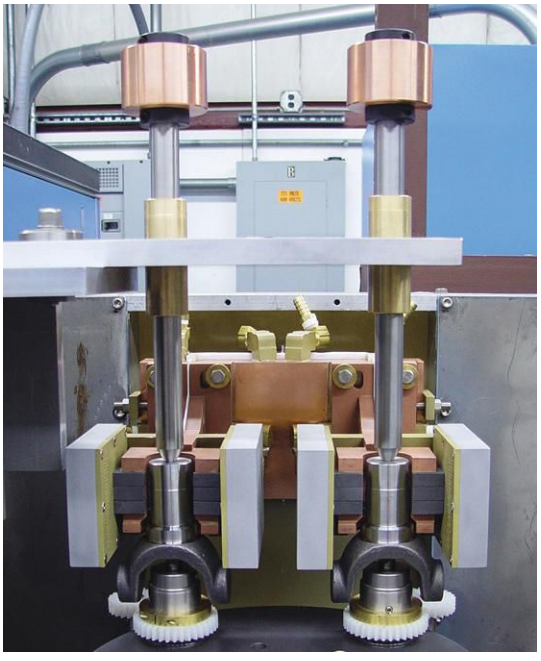


Fig. 8. Multiple parts run together in high-volume applications

Fig. 9. A typical development program yields a fully characterized inductor, process parameters, validated ISO 17025-compliant metallurgical report and additional prototype pieces for testing.

Cycle Time

Cycle time from part to part can vary greatly depending on process, material handling and other factors. Automation can improve cycle times, but it is often common practice to run multiple parts at once in high-volume applications (Fig. 8) if enough power is available.

Process Confirmation

Once testing parameters for a given process have been established, part samples need to be processed and then submitted for metallurgical evaluation. There are commercial labs offering these development and metallurgical services. A typical development program yields a fully characterized inductor, process parameters, validated ISO 17025-compliant metallurgical report and additional prototype pieces for testing (Fig. 9).

Conclusion

With any complex process, it requires some knowledge and some experimentation to achieve success. To quote Wernher von Braun (1912-1977), rocket engineer and designer: "One test is worth one thousand expert opinions." I hope this article has provided knowledge to those looking to implement induction heat treating to their process or improve their existing process.

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Metallurgical Quality Evaluation for Heat-Treated Gears

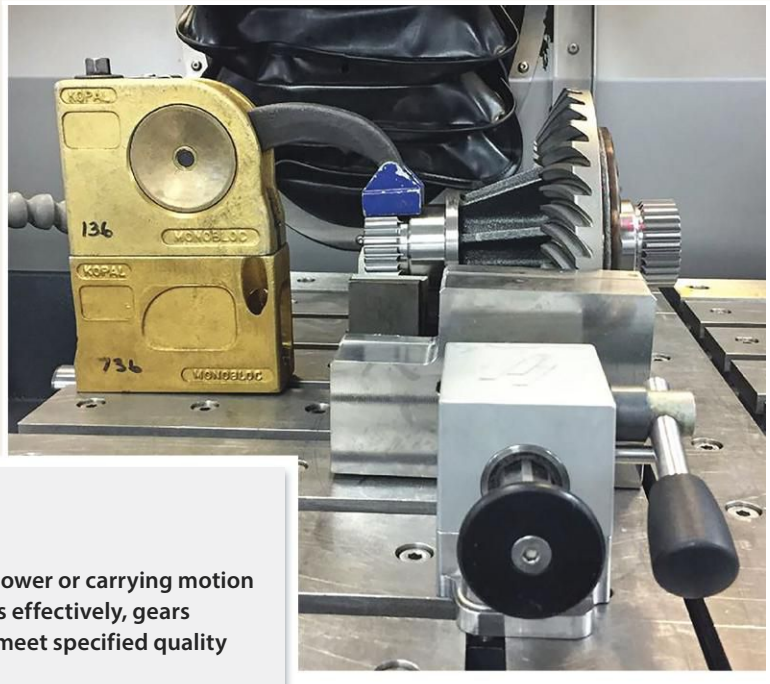

Fig. 1. Clamping for sectioning and intricate gear

Kelsey Torboli and Henry Udomon – Struers, Inc.; Westlake, Ohio

Gears perform the critical functions of transmitting power or carrying motion in mechanical assemblies. To perform these functions effectively, gears need to have certain properties that enable them to meet specified quality requirements.

Gear manufacturers and design engineers often designate "gear quality" based on the so-called AGMA gear-quality number. While this number provides an indication of the geometric accuracy of the gear teeth, it does not provide information on the metallurgical soundness of the gear. Therefore, the ANSI/AGMA 200 A88 Gear Classification and Inspection Handbook also provide specifications for the type of material and the heat-treatment process to be used in gear manufacture. The heat-treated gear in this study was evaluated based on its microstructure and its hardness values from the hardened surface to the softer core.

Material and Heat-Treatment Process Selection

A good starting point in gear manufacture is the selection of an appropriate gear material: nonferrous materials or plastics for motion-carrying gears and steels or cast irons for power-transmitting gears. This is followed by the careful selection of a suitable heat treatment and process conditions that will impart the right microstructure that will, in turn, enable the gear to achieve certain properties that assure its satisfactory performance.

Heat treatment is a critical component of gear manufacturing, accounting for about 30% of the manufacturing costs. Different heat-treatment processes are used in gear manufacturing depending on intended end use. For example, while annealing and normalizing are used to soften the gear, others such as carburizing, nitriding, carbonitriding, etc. are used to harden the gear.

Any of these processes can be tailored to achieve desired end results by modifying process parameters such as furnace temperatures and atmospheres, cycle times, quench media, tempering cycles, etc. In general, heat treatment of power-transmission gears seeks to impart hard, wear-resistant surfaces while maintaining a relatively tough and ductile interior.

Thus, metallurgical properties such as martensitic structure and physical properties such as surface hardness, case depth and core hardness can vary greatly depending on the type of heat-treatment process used and how well the process parameters are controlled. The gear examined in this study was a helical gear that had been surface-hardened by carburizing.

Evaluation of Metallurgical Quality

To verify that the gears have been appropriately heat treated, many companies perform metallography. Metallography includes sample preparation and evaluation of the true structure. The true structure gives an accurate understanding of the material's microstructure and thus mechanical properties and suitability for the intended application.

Sample Preparation

In almost every type of examination, a small sample must be sectioned from the larger part. Due to the gear's complex geometry, multiple clamping tools were utilized to make the series of cuts (Fig. 1). The gear was isolated from the assembly and then cut into pie-shaped sections. The 30-degree wedges were sectioned further to fit inside a 2-inch-diameter mount (Fig. 2).

The mounting resin used was chosen for its wear resistance. Ideally, the removal rate for the sample material and mounting resin should be equivalent

to ensure a perfectly flat sample with maximum edge retention. After mounting, the hardened gears underwent plane grinding, fine grinding and polishing. Between each preparation step, the samples were thoroughly cleaned using an ultrasonic cleaner to remove abrasives, lubricant and particles of sample material that could cause cross-contamination of the preparation cloths.

Repeatable sample preparation is necessary for reliable hardness test data. By performing a coarse grinding step only, the sample may show artificially high hardness readings. Lower hardness loads exaggerate this problem, so sample preparation is critical for microhardness testing.

Microstructure

The prepared mounts were etched with 5% nital to expose the microstructure. A microscope with bright-field illumination was used to capture images of the etched surface. The hardened case of the sample showed a martensitic microstructure, while the core showed a ferrite/pearlite microstructure (Fig. 3).

During a heat treater's quenching cycle, steel is heated sufficiently to form an austenitic microstructure and quenched to prevent a normalized microstructure from forming. The austenite transforms into martensite due to the rapid cooling process. This quenched microstructure is a non-equilibrium

Fig. 2. Sectioned helical gears

structure and, as such, yields the highest hardness possible for the grade of steel being used.

A side effect of this very hard microstructure is a very low ductility, meaning that there is a high potential for fracture if used in the wrong way. Ideally, the steel being used can be

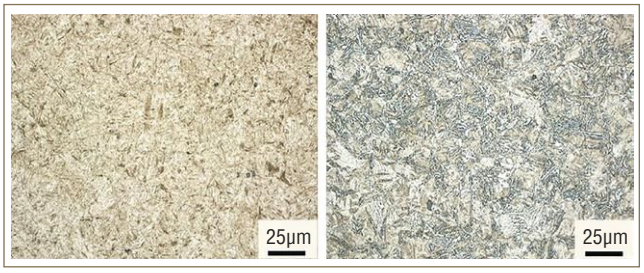

Fig. 3. Microstructure of surface and core of hardened gear

processed in such a way that only the surface of the material cools fast enough to form this martensitic structure and the core cools slowly enough to allow a more normalized structure to form. This optimal situation will achieve a hard surface with its associated appealing wear properties while keeping the ductility and toughness of the core to add strength to the component.

In an atmosphere carburizing process, the sample is heated in a carbon-rich environment to a point at which the austenitic structure will allow additional carbon to diffuse into the surface due to the higher carbon solubility of the austenite. A quench at this point will prevent the carbon from diffusing back out and lock it in place, forming a non-equilibrium structure.

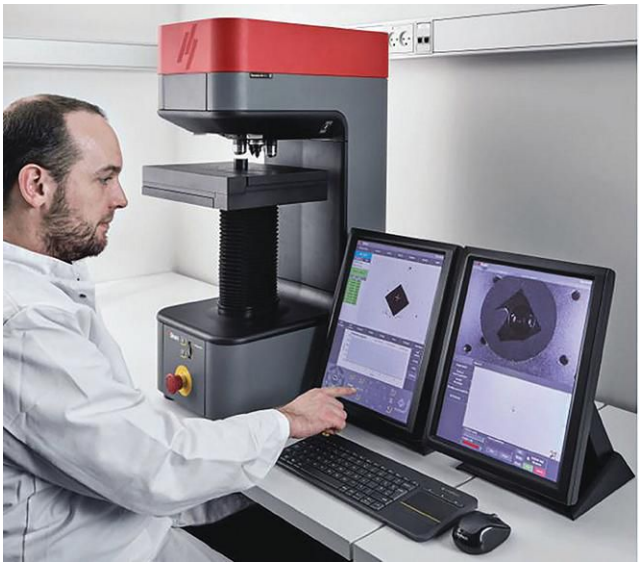

Fig. 4. Automated hardness testing of gear

The high-carbon case and its subsequent high hardness value improves wear resistance. The lower-carbon microstructure and corresponding low hardness values in the core allow the material to retain its ductility and toughness.

These are ideal features for a gear tooth.

Hardness Testing

Hardness testing was chosen to evaluate the material properties and verify that the heat treatment yielded the correct case depth. Because the gear-teeth samples were mounted, 500 gram-force Vickers testing was utilized. The mount was fixtured in a specimen holder to ensure perpendicularity between the indenter and surface and to avoid flexing under the indenter's load application.

An automated Vickers hardness tester was used to set up multiple traverses perpendicular to the surface (Fig. 4). ASTM E92 gives recommendations for dwell time, indent spacing and test forces. Multiple rows of indents were run on the tip, midpitch and root of each gear tooth with a 10-second dwell time per indent. The tip row showed the deepest effective case depth, while the midpitch and root traverses had equivalent effective case-depth values (Fig. 5).

The case-depth results are critical to understanding the gear's pitting fatigue life. The case depth must be appropriately deep to handle the load applied to the gear tooth. Too shallow a case will lead to pitting, while too deep a case may cause the tip to break away from the tooth. The optimal case depth is related to the size of the tooth. Larger gear teeth require deeper cases to handle the load application.

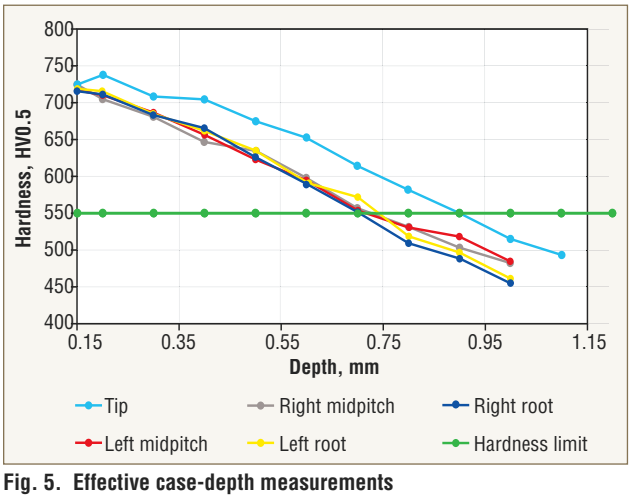

Fig. 5. Effective case-depth measurements

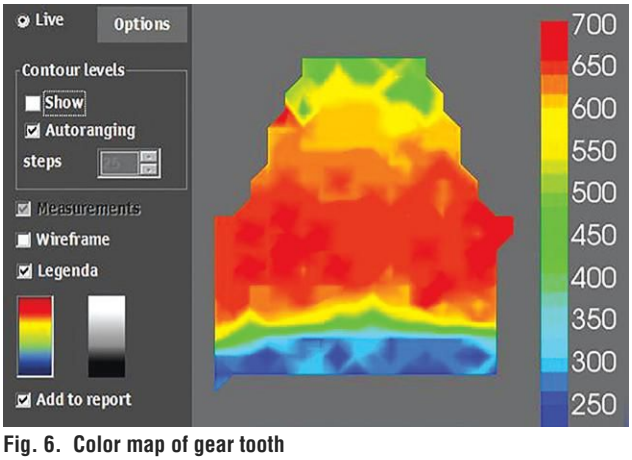

Fig. 6. Color map of gear tooth

In addition to the case-depth traverses, hardness maps were created from the gear-teeth samples. An array of indents was dropped across the gear tooth, and the resulting hardness values were displayed as a color map (Fig. 6).

The hardness map may include over 500 indents and take too much time for routine use by high-volume heat treaters. However, hardness maps have proven useful when developing new heat-treatment processes or when performing other R&D tasks. High hardness values were shown as red and orange colors, and low hardness values were shown as blue and green colors. The hardness map is a useful way to visualize the changes in hardness across the sample from the martensitic case to the ferrite/pearlite core.

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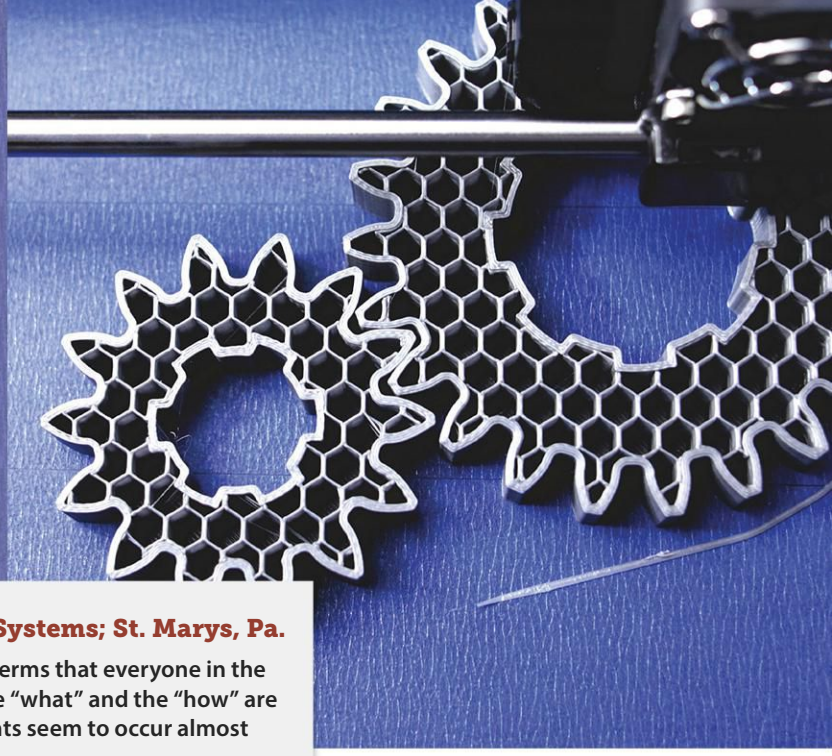
References available online

Sintering and Additive Manufacturing



Mark Saline – Gasbarre Thermal Processing Systems; St. Marys, Pa.

Metal additive manufacturing or metal 3D printing are terms that everyone in the metal-processing industry is seeking to understand. The "what" and the "how" are becoming clearer every day. However, new advancements seem to occur almost daily with no real end in sight.

The question that has yet to be answered for many is, "How will this affect my business and when?" Additive manufacturing has been labeled a global disruptive technology for a multitude of different industries, deeming the question valid. Yet the answer is unclear.

Many companies are throwing their hat in the ring by either developing their own printing equipment or purchasing equipment to try to stay ahead of the curve. The two main technologies utilized in metal 3D printing are high-temperature laser-jet and binder-jet printing. The two technologies produce highly complex components by the deposition of ceramics or metals. The benefits are shortened prototype development time and shortened build times of final components.

The use of metal or ceramic powders in the production of components is not uncommon. An entire powder-metal industry is focused on producing components from metal or ceramic powders by pressing and sintering (PM), powder injection molding (PIM/MIM) and now additive manufacturing (AM). The products from these manufacturing methods supply many business sectors, including automotive, lawn and garden, hand tools and medical devices as well as many others.

Automotive Lightweighting

The Metal Powder Industries Federation (MPIF) reports that the average PM content in North American passenger vehicles in 2017 was approximately 45 pounds (20.4 kg). The number has been driven up from 43 pounds (19.5 kg) over the last 10 years by a move from sedans to a demand for large SUVs and trucks. The expectation is that this number will shrink over the coming years due to lightweighting initiatives, smaller engines and electric vehicles.

Additive manufacturing surely will play a part in lightweighting initiatives now and in the future. Although no current data supports information on the use of AM in passenger vehicles, there are a variety of outlets reporting on prototype components being tested. Product development for noncritical components seems to be leading the way.

Binder Processes

The three metal-powder processes – PM, PIM/MIM and AM (specifically 3D binder-jet printing) – have the similarities of producing "green" components that subsequently require the removal of a binder or lubricant followed by sintering. PIM/MIM and 3D binder-jet printing are most closely aligned and can utilize anywhere between 2-50% binder. In many cases, the product requires a two-stage debind, where the debind process consists of a chemical/solvent debind followed by a thermal debind and then sintering.

Some binder-jet materials and printers are utilizing only a single-stage binder that eliminates the chemical/solvent debind process. The binder is typically organic in nature, allowing thermal debind to occur at the early stages of the sintering process, typically at temperatures of 200-600°C (392-1112°F). At these temperatures, the binder is off-gased in the form of a carbonaceous vapor. If an oxidizing environment is provided, the carbon will combine with oxygen and remain in gaseous form as it evacuates the furnace.

Sintering

Wikipedia defines sintering as "the process of compacting and forming a solid mass of material by heat or pressure without melting it to the point of liquefaction." No melting of the metal powders occurs in the process. However, the bonding of the metal particles occurs through a process called solid-state diffusion. The diffusion process occurs at temperatures below the material's melting point.

The final properties of these products are highly dependent on the sintering process because it sets the microstructure and

the final density of the component. Significant shrinkage must occur during sintering to achieve the required 95-99% relative densities. The sintering processes for higher-volume components will generally occur in electric, high-temperature pusher-style furnaces or vacuum furnaces that can achieve the sintering temperature range of 1200-1600°C (2192-2912°F), depending on the material to be sintered.

Sintering Furnaces and Atmospheres

Lower-volume prototype components may be sintered in a tube furnace or a manual pusher furnace. Extended time at elevated temperatures produces pore shrinkage between the powder particles, pore rounding and growth among the adjoining particles providing the 14-20% shrink rates (Fig. 1). At this point, the final microstructure is set unless additional thermal treatments are applied.

Furnace and atmosphere selection are based on the materials being sintered. High-temperature pusher furnaces satisfy the requirements for a large portion of the materials processed, such as carbon steels and stainless steels. Atmosphere control in the furnace is critical to the sintering process. Furnace atmospheres typically range from hydrogen-nitrogen, pure hydrogen, argon and vacuum.

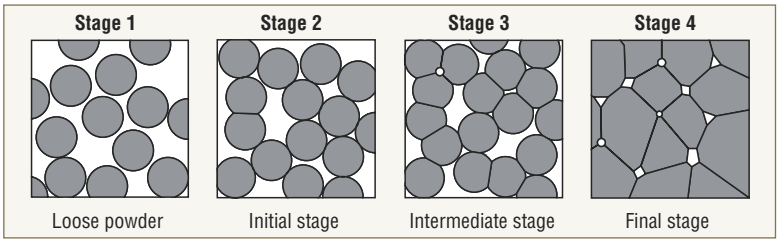


Fig. 1. The three stages of solid-state sintering. Left to right is initial, intermediate and final stages *(courtesy EPMA).*

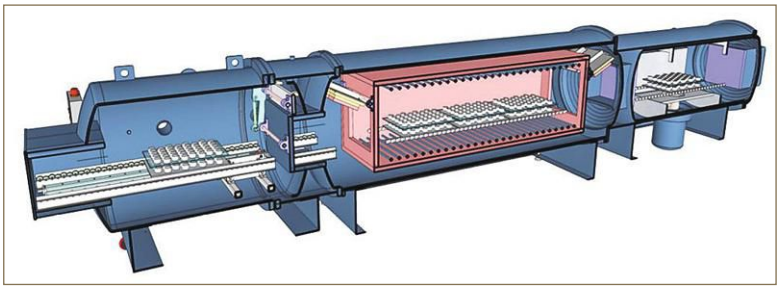


Fig. 2. The continuous vacuum furnace has multiple chambers.

In a pusher-style furnace, a positive-pressure, dry, reducing atmosphere is required because metal-powder particles typically have a thin layer of oxide that must be removed to allow particle bonding to occur. Hydrogen in the atmosphere breaks down the oxide and is evacuated from the furnace as water vapor. Atmosphere dew points should be -40°C and below depending on the materials being sintered.

Sintering in a vacuum furnace provides the purest of atmospheres. Oxides and impurities are evaporated and removed from the furnace, which provides enhanced sintering and a cleaner microstructure. Subatmospheric partial pressures can improve the efficiency of sintering reactions.

Materials requiring the cleanest of atmospheres and higher sintering temperatures (e.g., tool steels, stainless steels, highly reactive materials and exotic alloys) lend themselves to vacuum sintering. Vacuum furnace designs allow for both small- and large-batch processing. Continuous vacuum furnaces allow for continuous processing of higher-volume products.

The continuous vacuum furnace has multiple chambers that the product steps through. The beauty of this furnace is that the heat chamber is always under vacuum and at temperature (Fig. 2). Thermal debinding can be completed prior to vacuum sintering or directly in the vacuum furnace by the use of binder traps to ensure the vacuum pumps remain isolated from the binder.

Summary

A variety of debinding and sintering options are available for 3D-printed components. 3D-printing equipment, materials and binders continue to evolve. Future developments in microstructural control may provide the ability to tailor specific microstructures to multiple areas of a single component.

Printing speeds and component production rates will continue to increase. However, the science behind the sintering process (i.e., time, temperature and atmosphere) remains unchanged. Material requirements will continue to drive the selection of the type of sintering equipment and atmosphere. Sintering will continue to be a process for the development of the final microstructures, densities and strengths of materials.

Additive manufacturing offers the ability of increased part complexity, customized material properties and shorter lead times. The technology is and will continue to be disruptive. It will eventually settle in as another tool in the metal-processing toolbox.

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The Benefits of Vacuum Sintering (part 2)

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Many factors come into play during the vacuum sintering process, from the size and materials used in the furnace hot zone to whether debinding and sintering processes are combined in a single unit. But there's one thing that all sintering operations have to consider: how to efficiently remove binding agents from materials.

Fig. 3. Vacuum sintering furnace with all-metal hot zone

This article will run through the fundamentals of removing binders during sintering operations without risking contamination. It is an important thing to get right, and there are numerous ways to approach it. Let's start by thinking about one key aspect – whether to burn or capture binders as they are released by the heat of the furnace.

Capturing or burning? Which makes sense for your sintering furnace?

When binding agents are generated during sintering, they can be disposed of in two ways: capturing or burning. Both have their strengths and weaknesses, and one method could be particularly useful in certain situations.

The first thing to bring into consideration is pressure. Sintering can take place at less than atmospheric (partial) pressure, or it can be carried out in slight overpressure conditions. The pressure level in a furnace largely dictates the kind of binder removal method.

If a sintering furnace uses partial pressure, any gases created during the process need to be pumped away from the material being sintered. In these situations, pumped binder vapor should be prevented from entering the pump, and this can only be achieved using a condenser.

A burner might still be present after the pump, but its purpose is not to dispose of the binder but of flammable gases used in the process. Things are very different if sintering is carried out under overpressure conditions. If this is the case, users have a choice of binder removal methods.

On one hand, condensation and capture could be appropriate. Condensation can be carried out with varying gas flow rates and percentages of binder, so it's a flexible option. But it comes with a catch. The condensates still need to be captured and disposed of, which adds costs on top of the sintering process.

Where labor and disposal costs are an issue, burning binding agents could be the right way to go. However, this also has its potential problems. On a mechanical level, it is vital to set up the burner efficiently so that binders don't condense before they reach the burner.

Sometimes there can be an imbalance between the gas flow rate and the burner's capacity to process gas, so this needs to be monitored carefully. And when materials with too high a binder percentage are processed, it can lead to residue buildup inside the burner's pipes, raising the risk of failure. And on top of that, there's the cost of running a burner, which must be added to the general furnace costs.

In some cases, furnace users opt to use the built-in burners on their vacuum furnaces to remove binder gases instead of investing in additional removal mechanisms. However, the flames found on vacuum sintering furnace outlets are generally intended for a specific purpose: preventing hydrogen accumulation in the environment to eliminate explosion hazard. They aren't designed to filter emissions to remove toxic gases or to efficiently remove debinding agents from the kiln.

That's why it makes sense to install a specialist combustion chamber to handle binder gases as they are released. These chambers can be precisely calibrated to different gas flow rates and binder percentages along with the right incineration period needed to oxygenate the binder.

Fig. 1. Vacuum sintering furnace (T 50-50-75) with water-cooled binder trap

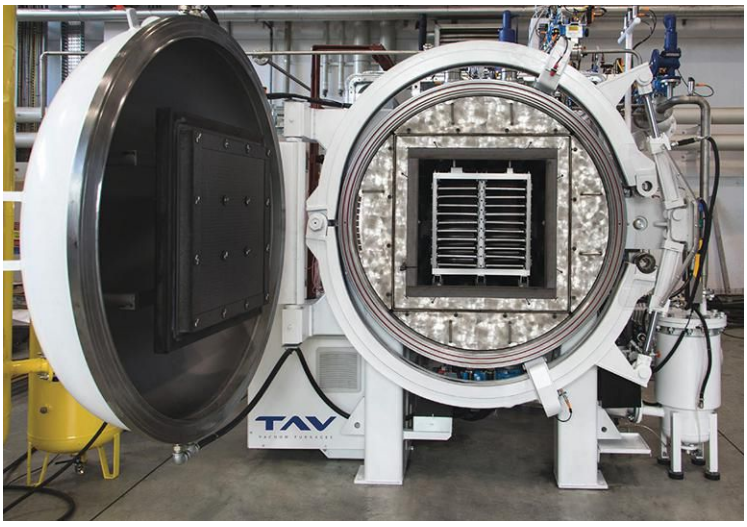

Fig. 2. Vacuum sintering furnace (THS 30-30-45) with MIM box and water-cooled binder trap

How to Pick the Right Condenser for Your Vacuum Furnace

If you have made the decision to install a condenser to handle your binder removal needs, it's essential to make the right choice. The most important issue here is whether you go for liquid or solid condensing units.

The choice you make will be determined by the chemical makeup of the binders that you use. These materials have varying liquefaction points and solidification temperatures, so they will create either liquid or solid residues when removed

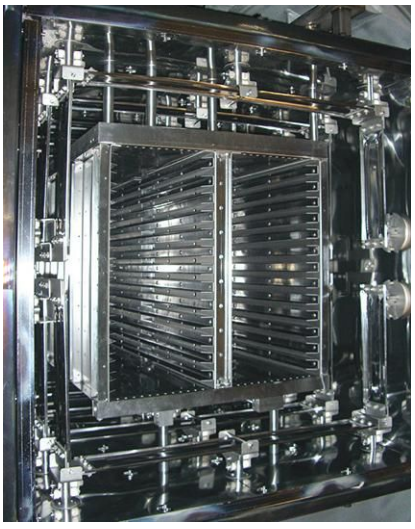

Fig. 4. Molybdenum MIM box hot zone

from the furnace. Each type of residue demands a specific type of condenser.

Solid residues are the most complex. Here, the challenge is to prevent condensation before the binders reach the capture chamber (hence avoiding pipe blockages or valve failures). Because of this, the piping and components in the condenser need to be properly heated, keeping binders at a constant temperature before they reach the condensing unit.

These condensers tend to have wide conduits to capture solid residues. This can limit the efficiency of their heat exchange. Because the binders they use condense easily, however, solid residue condensers don't tend to need a large surface area or require low-temperature operation. But they do require cleaning, and this is a key element of a solid residue system.

Solid residues can be heated, liquefied and removed automatically, or they can be manually removed. Ideally, the first system would be used because it can be faster and demands less labor.

If the sintering process creates liquid residues, the condenser is likely to be far simpler. A large, cooled surface area is needed to convert as much binder as possible in the shortest possible time. They tend to be directed downward, leading to a removable collecting vessel, and might include filters to remove dust particles as well. Automation is much easier to implement with liquid condensates, which usually makes this kind of condenser much more efficient.

Choose the Optimum Binder Vapor-Removal System

When you have chosen the right type of condenser, one more task remains before your vacuum sintering furnace is ready to operate. We previously mentioned that the sintering process generates vapor from the binders, along with solid or liquid

residues. We know what happens to those residues. But what can be done with the binder vapor?

The gases pumped from the chamber go through the condenser before reaching the vacuum pumps. Ideally, all the vapor should be condensed before reaching the pumps, but this is not necessarily the case.

Even if your condenser is working at 100% efficiency, there may still be some binder dissociation residues to deal with. It is possible to capture these residues before they enter the pump in a wet-capture system, which resembles the emissions scrubbing used in power plants. But this is an expensive solution and poses problems related to the retro-diffusion of residues back into the vacuum chamber.

This means that some binder vapor might actually reach the vacuum pump, and it is crucial that the pump is suitably chosen to cope with this issue in order to increase its lifetime. This can be achieved by either trying to prevent vapor condensation inside the pump or removing the condensation residuals from the pump.

How can you prevent condensation from occurring? There are basically two ways. The first method involves modulating pressure. By adding a gas ballast valve to the pump, users can ensure that the exhaust valve opens before the condensation starts, protecting the pump from contamination. Of course, if the gas being pumped can be ignited, the gas ballast should be fed with inert gas to prevent explosion hazard inside the pump.

The other method involves temperature. Pumps with higher working temperature are less likely to promote vapor condensation and are therefore more suitable for this kind of process. It is interesting that such pumps are usually cheaper and less sophisticated than higher-quality pumps, in which a lower temperature is attained in order to reduce oil backstreaming into the vacuum chamber.

A completely different scenario is when vapor is allowed to condense and is then removed. In this case, dry pumps should be used. Once again, not all the dry pumps are suitable. The best choice is a pump that includes a "cleaning kit," which periodically isolates the pump from the process and literally washes it.

Final Considerations for Configuring a Sintering Operation

Choosing the right condenser and binder gas-removal system is an essential part of

setting up a properly functioning sintering furnace, but they need to be put in a wider perspective in order to understand which type of furnace to install.

For example, you may have concerns about the reactivity of certain substances like titanium with oxygen and feel that a very high-vacuum furnace is the way to go. It's possible to reach a vacuum level of $1x10^{-6}$ mbar, and it's true that high vacuums can drastically reduce the risk of reactivity with binder gases. But this level of vacuum isn't really crucial.

The cost and complexity of maintaining high vacuum levels is not necessary. Instead, the pump systems outlined here and the use of short cleaning sequences featuring inert gases can handle oxidization issues in the vast majority of cases.

The same applies to high pressure. Sintering generally doesn't require very high pressure levels to be successful (aside from cases where overpressure is needed to get gases moving into or out of the chamber).

However, this doesn't apply in all cases. Most importantly, some materials require the use of a hot isostatic pressing (HIP) process directly after sintering. HIP demands high pressures ranging from 30-150 bar and dramatically reduces the porosity of the materials being handled by increasing their density.

Ensure that you Make the Right Vacuum Sintering Investment

Both HIP and high-vacuum processing raise the costs of the sintering furnace and are not required in all cases. So it is important to be clear about your own precise requirements and to avoid overspending on the vacuum sintering furnace.

But it is equally important to invest wisely in key elements of the furnace. From the right hot-zone insulation to sourcing an easily cleaned and efficient rotary pump, many different factors need to be balanced. By making the right investment in these systems, users can reduce costs and workloads, raise efficiency and – most importantly – ensure that their products are manufactured successfully.

For more information: Contact Andrea Alborghetti, Deputy General Manager, TAV VACUUM FURNACES SPA, Via dell'industria 11- 24043 Caravaggio (BG) - ITALY; tel: +39 0363 355711; e-mail: info@tav-vacuumfurnaces.com; web: www.tav-vacuumfurnaces.com. Our North America representative: FURNACARE Inc., a TAV GROUP company, 100 Corporate Dr Ste A, Spartanburg, SC 29303; e-mail: info@furna.care; web: www.furna.care.

Download the eBook at https://bit.ly/2VWA6z4 and understand how powdered metal, metal injection molding (MIM), additive manufacturing and other similar technologies can greatly benefit from the superior quality and versatility of vacuum sintering.

2019 VIEW FROM THE TOP

This special section is dedicated to the advertising companies in this issue. Learn more about what they do, and find out what makes them successful. Stay in touch with the thermal-processing industry, and read VIEW FROM THE TOP.

Across International

For more than 25 years, Across International has continued to be a leading laboratory equipment manufacturer and supplier for various industries across the world.

Headquartered and founded in New Jersey, our company is constantly innovating, improving and expanding upon popular scientific equipment categories. A few of our many products include vacuum ovens, forced air ovens, induction heaters, rotary evaporators, chillers, vacuum pumps and jacketed glass reactors. We proudly continue to provide excellent equipment to both heat-treating and R&D facilities throughout the world.

Projects big and small are welcome. In addition to offering outstanding lab equipment, we also provide sample testing for most product lines, including induction heaters. Our expert sales team can help match the right equipment for the job.

Prompt, courteous customer service and support are always our top priority. In order to meet the ever-growing needs of our customers, we established a second location in Sparks, Nev., and a third location (our first international) in Victoria, Australia. No matter where in the world our customers are located, we guarantee excellent customer service and rapid response rates to all inquiries.

ACROSS INTERNATIONAL
Material Processing Equipment

Across International
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Air Products

Air Products is a world-leading industrial gases company in operation for over 75 years. In addition to high-purity industrial gases, the company provides gas handling equipment and technology, gas atmospheres, and unmatched industry experience and technical know-how to help heat treaters and metal processors improve product quality and consistency, reduce operating costs, increase production and optimize gas use.

"Our application engineers work with customers around the world to fully understand their particular needs and then recommend industrial gas-based technologies and process improvement solutions that can help them operate more efficiently," said Francesco Maione, vice president, Northern Region-Americas.

Air Products helps customers optimize their heat-treating processes by providing controlled atmosphere solutions, enabling equipment, as well as process optimization and troubleshooting. It also operates a state-of-the-art lab in Allentown, Pa., where new application development and customer support activities are performed. The heat-treating lab includes furnaces capable of testing a wide variety of atmospheres, metallurgical and atmosphere analysis equipment, thermodynamic equilibrium and diffusional calculation capability, and computational fluid dynamics (CFD) modeling.

By leveraging these capabilities, Air Products' engineers can simulate customer operations prior to actual field testing. In addition, by combining process modeling with real-time data monitoring and analysis, the company can provide its customers better visualization and control of their heat-treating processes.

Francesco Maione, vice president, Northern Region-Americas

"As Industry 4.0 evolves, we also continue to expand our Air Products Process Intelligence offerings, enabled by the Industrial Internet of Things, which help our customers improve process optimization and control in their operations," Maione said.

AIR PRODUCTS

Air Products
7201 Hamilton Blvd.
Allentown, PA 18195
800-654-4567; www.airproducts.com/mp

Ajax TOCCO Magnethermic®

Ajax TOCCO Magnethermic® is a worldwide leader in induction heating and melting technologies. We offer an extensive range of products through a global network of sales and service centers, providing efficient and reliable equipment with exceptional service.

In 2019, Ajax TOCCO continues to invest in technology development and personnel to provide superior products and services. These include:

- 3D-coil technology – redefining the limits and possibilities of process development and coil longevity
- Silicon-carbide-based induction power systems for tube welding offering higher efficiency with fewer devices
- Advancements in pipe and tube heat-treatment systems
- Large foundry coreless melting solutions up to 85 tons
- Coreless pre-melt and coatings furnaces for strip galvanizing
- Transverse flux heating of ferrous and nonferrous strip

Ajax TOCCO's diversity in products and global resources enable our customers to benefit by transferring technology from the different industries we serve. Our ability to simulate coils with 3D FEA and fabricate the coil in a customized 3D printer expedites development time, ensuring our customers always receive a precise model of the original equipment.

Our advanced Power Systems pair perfectly with these applications, efficiently heating products in levels ranging from 2 kW to 16,000 kW (frequencies from 15 Hz to 500 kHz). Many of the technologies developed for large systems are implemented into our standard power units, ensuring long-term reliability for our customers.

John Caruso, global sales director

Our products are supported by a world-class organization of individuals dedicated to providing excellence in all areas of business from service to engineering and sales support. We look forward to continuing to serve our global customers.

Ajax TOCCO Magnethermic

1745 Overland Ave. N.E., Warren, Ohio 44483
330-372-8511; www.AjaxTocco.com

ALD Thermal Treatment Inc.

Innovative Vacuum Technology

Since ALD Thermal Treatment Inc. opened in 2005 in Port Huron, Mich., it has provided a testimonial to the distortion minimization merits of vacuum carburizing (LPC) + high-pressure gas quenching (HPGQ) by means of its unique automatic equipment, which offers a premier source for heat-treatment services to the precision manufactured component segment.

Port Huron and its sister facilities in Mexico and Germany revolutionized the processing of gear components by providing superb metallurgical and dimensional characteristics. ALD continues expanding its processing benefits to fuel injection systems, bearings and other critical applications, such as aerospace components.

This year, ALD Thermal Treatment will start the operation of one additional automated line for engine components with cryogenic processing in a large scale. The company will also add equipment for nitriding and ferritic nitrocarburizing (FNC) processes. As a complement, our laboratory is now able to perform spectrometry analysis in addition to our dimensional and hardness inspection capabilities.

ALD is continuously looking for new business opportunities and is evaluating new facilities to support customers in growing markets. Recent expansions in processes and capabilities reflect our commitment to a solid future in the heat-treatment market.

Enrique Lopez, sales and marketing director-North America

ALD recently received, for the third year in a row, "Supplier of the Year" recognition from GM for both of our plants in the U.S. To be an award winner means having something no one else has, and it certainly provides motivation to continue striving to earn other customers' confidence.

The Solution

ALD Thermal Treatment Inc.
2656 24th St., Port Huron, MI 48060
Phone: 810-357-0685
www.aldtt.net

Buehler

Innovates for Customer Success

Buehler is committed to providing high-quality service to customers in the industrial heating arena. Julien Noel, Buehler general manager and ITW vice president, explains, "Our recent innovations, such as the Mosaic diamond grinding discs (DGD) and the AutoMet programmable grinder-polisher, are focused on delivering superior results while saving you time. Buehler developed the high-strength abrasive surface of the new Mosaic DGD to effectively grind steel, sintered carbides, alloyed metals, coatings and other hard materials. The Mosaic DGD provides users with an enhanced material removal rate, consistency in results, labor savings and an extended lifetime that saves on repeat purchases."

Buehler focuses on heat-treating, automotive, aerospace and other industrial markets where quality is imperative and fast, reliable results are required in production. Noel said, "We conduct global product research in collaboration with our customers and the Buehler team of materials scientists who provide input, testing and validation. Buehler's accomplishments are the result of delivering solutions to the market for production reliability, supporting the growth of our customers and improving their bottom line."

Buehler maintains an extensive network of service, distributor and sales engineer teams that are available to meet with customers at their location or at the worldwide Buehler Solutions Centers. To find out more on improving methods, see the recent Technical Papers by Buehler's material scientists in the "Industries" section of Buehler's site.

Julien Noel, general manager

Buehler maintains its legacy of industry partnership with affiliations such as ASM International, American Society for Testing and Materials and International Metallographic Society. In 2019, Buehler is celebrating 75 years of partnership with ASM International.

BUEHLER

Buehler
41 Waukegan Road, Lake Bluff, IL 60044
marketing@buehler.com; www.buehler.com

Busch Vacuum Pumps and Systems

As the number-one company for individual vacuum system production, Busch Vacuum Pumps and Systems has been providing leading-edge, custom solutions to our customers for over 50 years. Our vacuum and pressure technology can be found in all areas of life and industry worldwide – from food packaging to the coating of microchips.

We are a family business through and through. Our customers have always been the focus since the company was founded in 1963. Today, with over 3,500 employees, 60 subsidiaries in more than 40 countries and sales agents in over 30 countries, we can provide sound advice and technical support directly at our customers' locations.

Whether the need is pumping capacity for pump-down, high vacuum for holding or anything in between, our wide product offering and application understanding ensures the right technical solution.

Our Project Management Team will ensure the job is executed on time, communicating major milestones along the way. Busch manufacturing sites use the most modern manufacturing techniques, machinery and equipment. The strict quality management procedures we implement allow us to meet the specific requirements of all industries we supply. We constantly evaluate our operation in order to maintain the highest standards, and we continue to develop innovative technologies that will define the future of vacuum system applications.

Ben Cameron, systems manager

The Busch solution doesn't end there. We have established the industry's most advanced service network for vacuum systems, and our team of Service Specialists will ensure your system is operating reliably for years to come.

BUSCH
Vacuum Pumps and Systems

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CAN-ENG Furnaces International Ltd.

CAN-ENG Furnaces International Ltd. is a global leader in the design and manufacture of industrial heat-treating equipment for ferrous and nonferrous metals and focuses on the development of high-volume batch and continuous industrial furnace systems. As one of North America's largest designers and manufacturers of heat-treating equipment, CAN-ENG services the globe from our North American head office located in Niagara Falls, Ontario.

The scope of CAN-ENG business units covers a wide range of heat-treatment furnaces, thermal-processing equipment and auxiliary products. Our innovative furnace systems provide the latest advancements in energy-saving technology, material handling and automation, incorporating new technology to replace conventional designs and improve production flow and facility efficiencies.

CAN-ENG designs and builds equipment for the aerospace industry; the automotive industry; the fastener industry; commercial heat treaters; the foundry and forging industries with equipment to reheat and heat treat ingots, forgings, billets, blooms, plates, bars, coiled bar and wire; the oil and gas industry with equipment to heat treat oil country tubular products including seamless tubing, mechanical tubing, transmission liner and casings; and steel plants with equipment for continuous plate production.

Michael K. Klauck, president

CAN-ENG's Technology Development Center is dedicated to process development research and product testing. Whether you are looking for confirmation of material properties using a new process, equipment utilization or trying to optimize your current processes or properties, CAN-ENG has the tools available to support your current and future development needs.

CAN-ENG Furnaces International Ltd.
6800 Montrose Rd., Niagara Falls, Ontario Canada; L2E 6V5
905-356-1327; furnaces@can-eng.com; www.can-eng.com

Control Concepts Inc.

Control Concepts is very bullish on the industrial heating marketplace for 2018 and 2019. We've been a market-leading designer and manufacturer of SCR power controllers since 1980. In fact, that's all we do 24/7/365.

Providing ultra-reliable power controllers designed to meet the needs of high-temperature thermal-processing customers, as well as short lead times, has been the hallmark of our organization since its inception. As our team develops new, state-of-the-art controllers, we consider not only the latest power control needs but also total installed cost.

Understanding the industries we serve has enabled us to design and bring products to market that exceed those needs. For example, when safety grew in importance and became an absolute necessity, we developed a touch-safe power controller with a 100,000A Short Circuit Current Rating (SCCR). Then when customers requested digital connectivity, we developed and introduced FUSION series controllers, which provide the ability to communicate over all standard bus networks. When it was necessary to reduce the cost of digital communications, we introduced a bus module that makes multiple-zone digital control more cost-effective. Additionally, realizing that plant floor space is highly valued, we developed MicroFUSION power controllers, which reduced the physical size of the power controllers by as much as 35%. Finally, understanding utility power penalties, we designed and developed a unique SCR firing mode that improves power factor and lowers plant power bills.

Cory Watkins, CEO

Control Concepts vows to continue being a leader in the thermal-processing industry by providing the most profitable long-term power control solutions for our customers. Watch for news from us in the near future. We are well on the way to introducing the next generation of power control for the industrial heating market.

CONTROL CONCEPTS
SCR Power Controllers

Control Concepts Inc.
18760 Lake Drive East
Chanhassen, MN 55317
www.ccipower.com

Diablo Furnaces

Diablo Furnaces is an OEM company providing custom furnace engineering services at affordable prices. Custom designed means taking the purchasers' challenges and determining the best equipment solution. This has ranged from using manufacturing space in the air to automating aspects of repetitive motions and improving process flow to mating a new furnace to an existing furnace line.

Using our degreed, in-house engineering group, purchasers are always surprised by the ingenious ideas. With a veteran team of experienced personnel and many new faces learning the trade, we are growing dynamically and building relationships within every market.

Our collaborative effort, from each person, allows us to achieve a common goal in the most effective and efficient way. With this solid approach, we have made inroads into many markets, such as aerospace, marine, oil and drilling and many others, affording us a healthy backlog.

Preparing for the future, we continue to reinvest in our manufacturing tools and equipment, along with employee training. Some investments that we are proud of is our new service vehicle wrapped in Diablo signage that travels throughout the country. From our new plasma table, Hydmech-saw and pipe fitting tools, we are very proud to manufacture a turnkey product that's American made.

Sue Harrod, chief operating officer

Call or e-mail us anytime. We are here to serve you.

Diablo Furnaces
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Dry Coolers Inc.

Dry Coolers Inc. is a major supplier of industrial cooling systems and professional engineering services. Located in the heart of the automotive industry, Dry Coolers has experience working with large and small companies to design and manufacture energy-efficient industrial process cooling solutions, including air-cooled heat exchangers, pumping stations, chillers and cooling towers.

Our specialty is providing reliable cooling for high-temperature processes such as vacuum furnaces, induction equipment and quenches. We have been a leader and innovator for over 30 years in the heat-treating market and are active members in MTI and IHEA.

Using degreed, in-house engineering talent and the latest CAD design programs, Dry Coolers provides state-of-the-art assistance to make installation go smoothly. Our involvement in a project can be as simple as that of a supplier of individual system components or as complex as the complete design and installation of plant-wide cooling systems.

Dry Coolers can supply Internet-enabled, PLC-driven systems for automated operation. Each project is provided with professional documentation in the form of operation and maintenance manuals, engineering and installation drawings. Drawings are provided with 3-D views as well as conventional 2-D layouts for clarity of illustration. Control panels are designed and assembled in-house and certified UL 501a.

Dry Coolers is authorized to apply the American Society of Mechanical Engineer (ASME) certification mark to its products. Dry Coolers can now offer the ASME Section VIII, Division 1 certification mark to its Solanus quench oil coolers, Thermoflow plate-and-frame heat exchangers, CyClean centrifugal separators and other products.

Brian Russell, president

Dry Coolers also owns and operates DCI Thermal Equipment (Foshan) in China to service the East Asian market. We focus on product quality and customer satisfaction, and we are ISO 9001:2015 registered. Call us today with your cooling needs. We are ready to assist you.

Dry Coolers Inc.
575 S. Glaspie St., Oxford, MI 48371
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sales@drycoolers.com; www.drycoolers.com

ECM USA Inc.

ECM Technologies is ever-expanding with innovative technology in vacuum furnaces and semiconductor manufacturing. Not only are we a prominent manufacturer in low-pressure vacuum carburizing (LPC) furnaces, but we have now acquired a rapid thermal processing and annealing (RTP/RTA) furnace line, JIPELEC, and expanded our R&D facilities in the U.S. and Europe.

In 2018, our ECM USA Synergy Center R&D team successfully reached 100 test loads in carburizing, carbonitriding, brazing and specialty heat treating in our ICBP® Nano (our newest in-line LPC system capable of 20-bar gas quenching with either nitrogen or helium). Haven't heard of our Synergy Center? Schedule a visit to test your parts for complete distortion and metallurgical analysis with our team of experts.

Our new line of rapid thermal processing or annealing furnaces, JIPELEC, is a well-known brand in the semiconductor industry. Acquired from our sister company, SEMCO, ECM USA is proud to represent this new laboratory R&D furnace line in the U.S.

These additions are simply enhancements to our already successful base line of LPC systems (including the established ICBP® Flex, Nano, Duo and Jumbo) using more than 1,100 heating cells on more than 230 systems while serving the industry for over 25 years. Whether you need to replace an existing atmospheric furnace, upgrade your equipment or if you want to bring your outsourced heat treating in house, we have the solution for you!

Dennis Beauchesne, general manager

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Epcon Industrial Systems

With over 4,000 completed systems worldwide, Epcon is a global leader in developing innovative air-pollution control technology and process-heating equipment. Founded in 1977, Epcon has grown from a one-man operation into a large-scale organization, complete with in-house engineering, design, a 250,000-square-foot on-site manufacturing facility and a global service team. From concept to completion, our dedicated professionals work together to design an efficient, customized product for each customer's unique process requirements while maintaining complete control over the project's quality and schedule.

Epcon's significant market share is based on successful patented designs and expertise as an industrial supplier, focus on our customers' ROI and "next-generation manufacturing," ensuring maximum value creation.

Sustainability is also a major focus at Epcon. A large proportion of process-heating equipment designed and built by Epcon does not require operating fuel, instead running off clean hot air recovered directly from the air-pollution control system that eliminates the process VOCs. This energy recycling is not only good for the environment but also for the operator's bottom line.

With all the challenges manufacturers are faced with today, from labor shortages to tariff and trade instability, our solutions can help mitigate these unexpected cost increases and outside influences by providing long-term quality equipment that optimizes the processes. Daily operating costs are engineered to a bare minimum.

With over 40 years in the Industry, when you do business with Epcon® Industrial Systems, you deal with a company you can trust.

Tasha Jamaluddin, managing director

Epcon Industrial Systems, LP
17777 I-45 South, Conroe, TX 77385
936-202-1004; www.epconlp.com

G-M Enterprises

California-based G-M Enterprises is a leading supplier of state-of-the-art vacuum furnaces to the aerospace, nuclear, metal injection molding and high-temperature sintering industries, as well as to commercial heat-treating companies. G-M Enterprises also provides equipment for VPA (vaporized aluminide coating) of aircraft engine blades and vanes to withstand extreme atmospheric/space conditions.

G-M Enterprises has pioneered vacuum furnaces for high-pressure quench up to 20 bar with unique external cooling blower and heat-exchanger construction to meet critical cooling requirements and produce the highest metallurgical results and properties. G-M holds many U.S. and European patents for its innovative and unique designs.

Suresh Jhawar, CEO

Superior user-friendly design features, user-friendly computer control software, fast and dependable aftermarket quality service and a reputation of making furnaces that really work make G-M Enterprises the most qualified company in the marketplace to supply equipment and services to meet your heat-processing needs.

G-M Enterprises
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Induction Tooling Inc.

Now ISO 9001:2015 certified and in our 43rd year, Induction Tooling Inc. is the world's premiere source for selective hardening inductors. Through the years we have grown and continuously improved our business model. With customers in the automotive, heavy equipment, agriculture, aerospace and medical industries, we are able to supply production inductors that are PPAP ready.

Our design team works closely with our customers to ensure that the end product produces a specification heat treatment to their parts. To accomplish this, we build inductors that are induction-laboratory tested using our customers' parts. Our induction laboratory is capable of replicating the exact frequency, power and time that our customer might expect or has achieved in production. Characterization of the inductor is the process of homing in the closet midrange of the specification-hardened depth. To do this we must adjust the heating effect of the inductor geometry, including manipulation of the flux field, using products commonly called intensifiers. Once the midrange specification-hardened depth is achieved, the part is cut into pieces, mounted in Bakelite and examined by our metallurgical staff, which is headed by Sandra Midea, P.E.

Since our metallurgical laboratory is ISO 17025-certified as a commercial testing facility, we are able to examine our customers' parts when processed on their equipment often the same day before submitting a professional metallurgical report.

William Stuehr, president/CEO

The process of building quality selective hardening inductors requires precise flow from design to production. The details are addressed in between. It is imperative to have a full-service facility under one roof. Our design team, production personnel and laboratory staff work diligently to accomplish this.

Induction Tooling Inc.
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North Royalton, Ohio 44133
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Fax: 440-237-7009
www.inductiontooling.com

Ipsen

The heat-treating industry demands maximum furnace uptime and generating the highest return on investment. With the Fourth Industrial Revolution beginning, heat-treating solutions providers are laser-focused on analyzing data metrics, predicting when maintenance should occur and planning around scheduled downtime. Sensors supply the raw data, while active algorithms provide key metrics that enable operators to be aware of changing furnace conditions well in advance of unplanned downtime.

How does the algorithm learn from these trends? The answer: predictive maintenance platforms like Ipsen's PdMetrics® software. Predictive metrics, unlike preventive, helps users operate smarter by learning from patterns in the furnace environment. The easy-to-navigate software then delivers recommendations on operational adjustments and how the user should plan for any required corrective maintenance, when necessary.

The algorithm is more than just data – it's smart analytics. And just like the famous human-like robot Sophia, predictive maintenance learns from the past and adjusts algorithms from those trends. It even provides the end user an anticipated failure timeline, which is predicated on previous device trends. The diagnostic helper provides procedures to address immediate concerns, and the maintenance routine feature logs and reminds users of key dates in routine maintenance.

Jim Grann, technical director

PdMetrics measures more than 40 key parameters like temperature, leak-up rate, heat loss and running time. These features allow users of all backgrounds to rely on a proven system, which can also be accessed remotely. As the user gets smarter using PdMetrics, so does Ipsen, because it learns with the user. Stay ahead of the curve and use predictive maintenance software.

Ipsen
984 Ipsen Road, Cherry Valley, IL 61016
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www.Ipsenusa.com

McLaughlin Furnace Group

McLaughlin Furnace Group is defined by its core values of using advanced technology to bring the most efficient, maintenance-friendly and customer-driven designs to the forefront of the heat-treat industry.

Following record years for both McLaughlin Services and Vesco-McLaughlin, McLaughlin Furnace Group has set the bar high for 2019 with the release and production of its first Tru-Carb IQ furnaces. These furnaces will utilize state-of-the-art technology, proving to be one of the most process- and energy-efficient furnaces on the market to date.

To start the year, McLaughlin Furnace Group has been manufacturing an influx of Tru-Mix™ endo generators. Replacing older, energy-inefficient generators with new, high turn-down generators has proven an effective solution for customers nationwide. Overall, McLaughlin Furnace Group is excited to see where rapidly changing technology can take the heat-treat industry in 2019.

New inventory management, service, quoting and CRM software have also proven advantageous for McLaughlin Furnace Group. Being able to provide accelerated and top-notch service to customers has continually increased with new software implementations.

Ryan McLaughlin, production manager (left); Ben Tackett, project manager

McLaughlin Furnace Group
333 Progress Way
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260-897-HEAT
www.mclaughlinsvc.com

Pfeiffer Vacuum

Pfeiffer Vacuum is one of the world's leading providers of vacuum solutions for industrial applications. The product portfolio comprises a wide range of vacuum pumps, gauges, gas analyzers and leak detectors. Pfeiffer Vacuum has over 125 years of experience in building pumping stations.

What sets us apart?

Pfeiffer Vacuum's innovative magnetic coupling available on our Roots pumps eliminates the shaft seal to provide more reliable operation. Since the shaft seal is eliminated, there are no unexpected process interruptions due to oil leaks. This technology offers a safer environment – no oil on the floor. It also reduces downtime since there is no radial shaft seal to maintain.

Vacuum Pumping Stations

Pfeiffer Vacuum CombiLine™ pumping stations offer solutions in low, medium and high vacuum with a pressure range of up to $5\text{-}10^{-4}$ mbar. CombiLine pumping stations are a combination of individual vacuum pumps and components that are mounted on the same frame with interconnecting piping.

Standard and Gas-Cooled Roots Vacuum Pumps

Pfeiffer Vacuum OKTA G series Roots pumps with pumping speeds from 210-12,000 m^3/h offer solutions in the low and medium vacuum range. The air-cooled pumps provide high differential pressures with lower power consumption.

Mobile Helium/Hydrogen Leak Detectors

The ASM 310 helium/hydrogen leak detector is the lightest (just 46 pounds), smallest footprint (133 in^2), and fully configured helium mass spectrometer leak detector available.

A sintering furnace that utilizes Pfeiffer Vacuum rotary vane pumps, Roots blowers and leak detection equipment.

PFEIFFER VACUUM

Pfeiffer Vacuum
24 Trafalgar Square, Nashua, NH 03063
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Plibrico Company, LLC

Companies today operating critical heat environments are running at near capacity to meet surging demand. This trend is forecasted to continue into the foreseeable future.

Here at the Plibrico Company, we have seen firsthand how ramped-up production is taking its toll on the refractories installed to protect heat equipment against mechanical stress, abrasion and corrosion brought on by high temperatures.

Plibrico, a name synonymous with highly durable refractory solutions, has been focused on solutions that help the heat industry reduce downtime and extend refractory life.

- Precast refractory shapes that get damaged furnaces up and running in hours. Ready to install, Plibrico Redi-Shapes™ are tailor-made to exact specifications and are available in any size or intricate configuration.
- Unique repair solutions that combat the physical effects from charging, as well as corundum and alkali attacks, turning downtime from weeks to days. Plibrico has knowledgeable experts with genuine experience that know both construction and refractories.
- Strong refractories with corrosion-, abrasion- and wear-resistant properties that last longer in harsh environments. Born from our unique blend of application know-how and material science, Plibrico's high-performance technology provides dependable and economical solutions for extreme conditions.

The team has demonstrated time and again how its customer-driven core value, combined with swift response and flexibility, enables customers to get their critical heating systems back online and operational quickly.

Brad Taylor, president and CEO

The Plibrico Company has built a business over more than a century based on trust, knowledge and experience – qualities that create close, lasting relationships to deliver superior heat control solutions.

Plibrico

Plibrico Company, LLC
1935 Techny Road – Unit 16
Northbrook, IL 60062
312-337-9000
contact@plibrico.com; www.plibrico.com

Praxair Inc.

Praxair Inc., a wholly owned subsidiary of Linde plc, is a leading industrial gas company in North and South America and one of the largest worldwide. We have more than 100 years in the gas industry producing, selling and distributing atmospheric, process and specialty gases and high-performance surface coatings.

Praxair products, services and technologies bring efficiency and environmental benefits to a wide variety of industries, including chemicals, food and beverage, electronics, energy, healthcare, manufacturing, primary metals and heat-treating markets like aerospace, automotive and metal fabrication.

Our emphasis on heat-treating applications has allowed us to help our customers produce the most durable metals for today's demands. We offer a diverse portfolio that can help improve the quality and appearance of your metals, help you make highly reproducible parts, and give you more control over your process.

At Praxair, we are proud to be able to supply a variety of gases in quantities to meet your needs. These include nitrogen, hydrogen, oxygen, argon and helium – in a high purity, resulting in a consistent atmosphere. In addition, Praxair offers a reliable supply via our nationwide network of air separation plants, our national logistics system and our tracker automated delivery system.

Steve Mueller, associate director, business development

Thank you for taking the time to learn more about us. We look forward to helping you achieve your goals and provide you with complete customer satisfaction every step of the way!

PRAXAIR
Making our planet more productive

Praxair Inc.
10 Riverview Drive
Danbury, CT 06810
1-800-PRAXAIR
www.praxair.com/heattreating

Solar Manufacturing

The Brightest Solutions Through Ingenuity

Since 2002, Solar Manufacturing has been a valued partner to heat treaters across a wide variety of industries, bringing our ingenuity in vacuum heat-treat technology to each customer. As one of the nation's premier developers of innovative vacuum furnaces, Solar Manufacturing strives to deliver energy-efficient hot zone designs, feature-rich SolarVac® automation and controls, and high-performance gas quenching systems. Our trail-blazing engineering offers heat treaters the most technically advanced furnaces designed for a wide range of vacuum processes. We are continually researching ways to improve furnace performance.

We see a bright future for manufacturing around the world, especially in North America. We are witnessing outstanding growth in the aerospace industry along with unprecedented expansion of medical devices requiring thermal processing, as well as the exciting innovations of additive manufacturing. With a vision to remain at the forefront of vacuum furnace technology, we are positioning ourselves to meet the demands of our future customers, building a manufacturing facility specifically designed for the production of vacuum furnaces of all sizes, especially large-capacity furnaces. With completion of our new building expected in spring of 2019, we are preparing to transition mid-year to the new space, keeping production rolling without disruption.

While this latest building is important for efficient production, our experienced and dedicated staff is the key to providing outstanding value to our customers. Many of our engineers, production mechanics and service technicians each have over two decades of experience in the business. Together, every day, we develop new solutions to vacuum thermal-processing applications and advance the art and science of vacuum furnace technology.

Trevor Jones, CEO

SOLAR MANUFACTURING

Solar Manufacturing
1983 Clearview Road, Souderton, PA 18964
267-384-5040; info@solarmfg.com; www.solarmfg.com

Surface® Combustion

Surface® Combustion has earned a trusted reputation over 100 years of providing rugged, reliable heat-treating solutions equipped with the latest technology and backed by strong technical support. From our standard atmosphere and vacuum furnace designs to custom-engineered thermal-process solutions to quick and responsive aftermarket support, Surface stands ready to serve you.

For almost 70 years, the Allcase® batch integral-quench furnace has been the versatile workhorse of the industry. Whether used for automotive, off-road, aerospace, mining, oilfield, wind power, tool and die or commercial heat-treating applications, it is well known for producing quality, repeatable results. Surface provides a full host of companion equipment, best-in-class controls and automation solutions to enhance the Allcase line.

In the same vein, our RX® endothermic atmosphere gas generator is unequaled. Surface pioneered the development of RX endothermic gas to be used as the atmosphere for modern gas carburizing, and customers consider our generators to be an on-site utility that run with minimal, infrequent adjustment.

Surface maintains customer relationships for decades. Our Rebuild/Retrofit business unit offers effective capacity, productivity and process upgrades. The Aftermarket Parts business unit can ship most replacement parts immediately from our multimillion-dollar inventory. Our field service engineers and technicians repair furnaces, solve equipment problems, perform preventive maintenance and train personnel on proper equipment operation.

B.J. Bernard, president

When you require a thermal-processing partner that can draw from a broad portfolio of proven designs, including pioneering atmosphere and vacuum products as well as custom-engineered equipment, let us show you the Value of Surface™.

Surface Combustion

Surface Combustion
1700 Indian Wood Circle
Maumee, OH 43537
Phone: 419-891-7150; Fax: 419-891-7151
www.surfacecombustion.com

T-M Vacuum Products

A pioneer in the high-vacuum heat-treating industry, T-M has been manufacturing high-vacuum furnaces and ovens for over 50 years in our 53,000-square-foot New Jersey facility. T-M has been run by three generations of the Stuffer family.

Our furnaces and ovens are used by different industries, including the world's top medical and aerospace manufacturing companies, the U.S. military and the U.S.'s top nuclear and accelerator laboratories. Our equipment is shipped worldwide. We span the globe from Siberia to New Zealand and full circle from the U.S. to Asia.

We have built furnaces and ovens to achieve 1 x 10^{-11} torr vacuum and achieve ±1 degree uniformity. Our newest product launch was a laboratory-size furnace that flips. You can use it horizontally or vertically if you need more height, and it can be manufactured to run up to 2000°C.

We are proud to use the highest quality American-made components, such as power supplies, SCRs and cryo pumps, and we only manufacture all-stainless steel chambers. We offer equipment with workspaces from 1 ft^3 to as large as 64 ft^3 and process temperatures from as low as 80°C to over 2000°C.

Rennie Stuffer-Wessner, CEO

Our company goal is to always strive to make the next best thing and to accomplish what no one has done before. Whatever you need, we can design and build it. We are never afraid to take on a challenge.

T-M Vacuum Products, Inc.

T-M Vacuum Products
630 S. Warrington St.
Cinnaminson, NJ 08077
856-829-2000
info@tmvacuum.com
www.tmvacuum.com

TAV VACUUM FURNACES

TAV VACUUM FURNACES, established in 1984 near Milan (Italy) in the city of Caravaggio, designs and manufactures standard and customized advanced vacuum furnaces in a wide range of geometries and dimensions that are used in the heat treatment of steels, alloys and advanced ceramic materials.

We support these processes mainly in the following fields: production of heat exchangers, aviation/aerospace, automotive, IGT (industrial gas turbine), heat treatment of additive-manufactured parts, commercial heat treatment, component sintering industry (medical, precision mechanics, optics) and R&D laboratories.

The R&D department is constantly working to ensure a product in line with customer needs. These products meet the strictest criteria and procedures to ensure compliance with the most stringent international industry specifications.

In 2015, in order to develop and enhance our commercial relationship with the North American market, we established our American company group Furnacare Inc. in Spartanburg, S.C. Furnacare continues to grow our engineering, technical and commercial staff. We work to communicate to the market the high quality of TAV vacuum furnaces coupled with our ability to reduce customer cost and maximize efficiencies through delivering proven, premium-quality manufactured solutions that are durable, customized and technologically advanced to carry our customers forward.

Our aim is to facilitate the work of your engineers, operators and maintenance team to have your furnaces always operative in the production process with top performance.

Guido Locatelli, deputy general manager of TAV

Our core service competencies include hot zone refurbishment and replacement, repairs, spare parts, upgrades, TUS, SAT, calibrations, leak detection, preventive-maintenance programs, new vacuum furnace installations and new vacuum furnace sales.

TAV VACUUM FURNACES SPA
info@tav-vacuumfurnaces.com
www.tav-vacuumfurnaces.com

Furnacare Inc.
info@furna.care; www.furna.care

Thermocouple Technology

Thermocouple Technology (TTEC) is composed of an experienced group of professionals dedicated to providing precision temperature measurement and control devices for industry. Founded in 1985 by veteran temperature sensing specialists, TTEC has provided temperature sensing products/solutions to nearly every industry.

TTEC's enthusiasm for understanding the physical changes that occur in extreme industrial environments has resulted in advanced product developments, customized to the demands of each unique environment. By leveraging engineering and design resources, key process temperatures are measured in the most accurate, efficient and reliable manner. TTEC's commitment to service through superior engineering, product quality and customer satisfaction has fueled substantial growth while improving the satisfaction of the many loyal customers that have relied on their products for decades.

The 34-year-old company is continuously implementing new technologies and procedures to increase product offerings and enhance quality. TTEC has committed significant capital toward stocking critical high-temperature raw materials. This ensures that time-sensitive orders are filled in days, not weeks. The recent expansion of the calibration lab and newly streamlined manufacturing programs ensure efficient production of precision assemblies. Additionally, investments in machinery and skilled personnel have resulted in improved efficiency and capabilities. Expect new and enhanced product solutions in the months and years to come.

Michael McKinney, president

When presented with a temperature-related challenge, feel confident that you can reach out to TTEC's friendly sales and engineering team for a customized solution.

TTEC THERMOCOUPLE TECHNOLOGY

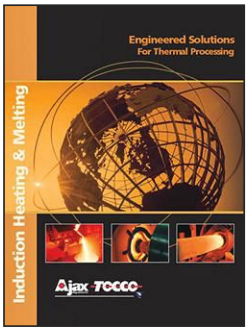
Thermocouple Technology LLC
350 New St., Quakertown, PA 18951
800-784-3783
sales@tteconline.com
www.tteconline.com

LITERATURE & WEBSITE SHOWCASE

Induction Heaters

Across International

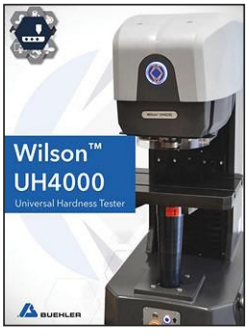
Founded and based in New Jersey, Across International supplies laboratory equipment in the areas of heat treatment and material processing for universities, research facilities and labs. We have more than 20 years of industrial manufacturing experience with induction heaters, drying ovens, ball mills, lab furnaces and pellet presses.
www.acrossinternational.com



Induction Heating Systems

Ajax TOCCO Magnethermic Corporation

Ajax TOCCO Magnethermic Corporation is a world leader in the induction heating, melting and forging industries. Our proven applications include brazing, annealing, hardening, tempering, seam annealing, shrink fitting, curing, forging and melting.
www.ajaxtocco.com



Universal Hardness Tester

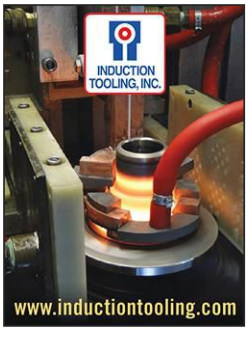
Buehler

The Wilson UH4000 Series is designed for rugged environments and is ideal for hardness testing and analysis of castings, forgings, flat or cylindrical workpieces, steels and heat-treated materials. It comes in two key configurations: UH4250 hardness scale 0.5-250 kgf and UH4750 hardness scale 3-750 kgf. The UH4000 brochure contains all the product specifications and features.
https://bit.ly/2KPTzAc

SCR Power Controllers

Control Concepts, Inc.

Control Concepts, Inc. is known for reliable products, expert customer support and next-day shipping. Visit our website to find the ideal controller for your application, or contact us about modifications and custom OEM controllers. We also carry metering and signal conditioning cards and high-speed, branch-rated fuses and fuse blocks.
www.ccipower.com



Induction Products

Induction Tooling Inc.

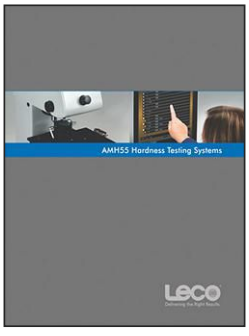
Since opening our doors in 1976, Induction Tooling Inc. has evolved into the premier manufacturer of selective hardening inductors, bus bars, quenches and modular quick disconnect induction products. We supply the commercial and captive heat-treat, automotive, aerospace, mining, wind energy, agricultural and medical industries. We specialize in bearings, gears and drive-line components. www.inductiontooling.com

LITERATURE & WEBSITE SHOWCASE

Magnetic Products

Jackson Transformer Company

Jackson Transformer Company is a leading designer and manufacturer of transformers, reactors, chokes and other magnetic products. We have been developing, designing and manufacturing water-cooled and air-cooled magnetic products since 1955. We provide repair and reconditioning services on transformers used in induction heating equipment, regardless of OEM. www.jacksontransformer.com



Automatic Hardness Testing

LECO

The AMH55 introduced LECO's innovative Cornerstone® brand software for increased usability, simplified reporting and streamlined analysis times. Supporting accurate and efficient microindentation and Macro/Vickers hardness testing, the AMH55 is a valuable resource for users needing precise and productive hardness testing while tailoring the data and results to their needs. www.leco.com

Hardness Testing

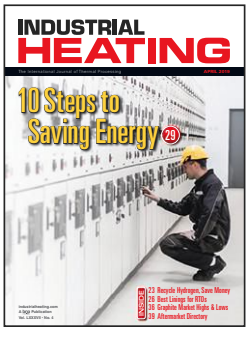
Sun-Tec Corp.

Sun-Tec Corp. specializes in Rockwell-type, Brinell, Vickers and Knoop, Leeb, tensile/compression, ductility testing and sample preparation equipment. We also supply hardness standards, indenters and anvils. Clark Instrument, Detroit Testing Machine and Service Physical Testers are divisions of Sun-Tec, which is a 17025-accredited company. www.sunteccorp.com

Temperature Measurement

Thermocouple Technology

Thermocouple Technology (TTEC) manufactures a full line of industrial temperature measurement products, including thermocouples, RTDs, thermowells, transmitters, thermocouple wire, indicators, controllers and accessories. TTEC's experienced engineers specialize in custom-built temperature sensors for applications exceeding 4000°F. www.tteconline.com



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Industrial Heating

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Thermal Processing Products

Diamond Grinding Discs for Sample Preparation

Buehler

The Mosaic line of diamond grinding discs (DGD) are designed for superb material removal in the grinding process of sample preparation. Especially suited for demanding laboratories working with heavy-duty metals or durable materials, they are available with a magnetic backing and come in 8-, 10- or 12-inch discs in 120-, 220-, 320-, 400- and 1,000-grit sizes. The high-strength abrasive surface of the DGD effectively grinds steel, sintered carbides, alloyed metals, thermal spray coatings and other hard materials. Mosaic provides users with an enhanced material removal rate, consistency in results, labor savings and an extended lifetime that saves on repeat purchases. www.buehler.com

Infrared Pyrometer Software

Ametek Land

Enhanced infrared pyrometer software packages, SPOTViewer and SPOTPro, are designed to give users a better understanding of the performance of their processes and help realize industry 4.0 connectivity. Specifically developed to work seamlessly with the latest generation of single point pyrometers, SPOTViewer is a software facility that enables a user to connect, configure and analyze temperature measurement data from any SPOT pyrometer and temperature profile graphs with a SPOT Actuator. It configures, displays and logs data from a single location. Designed with an intuitive user-friendly interface, it presents data in a graphical view, making sophisticated analysis of trends and patterns simple. www.ametek-land.com

Roots Vacuum Pump

Pfeiffer Vacuum

HiLobe series Roots pumps can be used for industrial vacuum applications such as electron-beam welding, vacuum furnaces or freeze drying. The compact pumps are of particular interest for fast evacuations (load-lock chambers or leak detection systems) and are also suitable for use in coating applications. Offering a wide nominal pumping speed range of 520-2,100 m^3/h, the pumps can be precisely tailored to customer-specific requirements utilizing individual speed control. A new drive concept permits HiLobe to achieve approximately 20% shorter pump-down times than conventional Roots pumps. Rapid evacuation reduces costs and increases the efficiency of the production system.

www.pfeiffer-vacuum.com

Cabinet Oven

Grieve

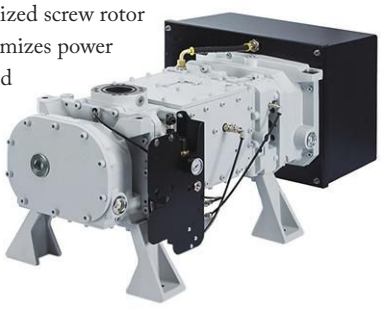
No. 934 is an 850°F (454°C) cabinet oven that can be used for heat-treating processes. Workspace dimensions of measure 38 inches wide x 20 inches deep x 26 inches high, and 10 kW are installed in Incoloy-sheathed tubular heating elements. A 600-CFM, 0.5-HP recirculating blower provides horizontal airflow to the workload. The oven has 6-inch insulated walls, an aluminized steel exterior and Type 430 stainless steel interior. Controls include a digital indicating temperature controller, 10-inch-diameter circular chart recorder and SCR power controller.

www.grievecorp.com

Screw-Type Vacuum Pump

Leybold

The DRYVAC DV 200 and DV 300 complement the existing product range of DRYVAC 450, 650 and 1200 and offer the same user benefits for applications requiring smaller sizes. This series of dry compressing screw-type vacuum pumps is engineered for the new era of smart manufacturing. All DRYVAC models offer benchmark energy efficiency, durability and future-ready network integration. Due to an optimized screw rotor design, the DV200/300 minimizes power consumption, saving costs and reducing carbon footprint. Designed for harshest industrial conditions, the pumps also feature minimal maintenance and easy cleaning of water cooling channels. They are equipped with an automatic shaft-seal purge control for optimal protection of shaft seals and bearings.

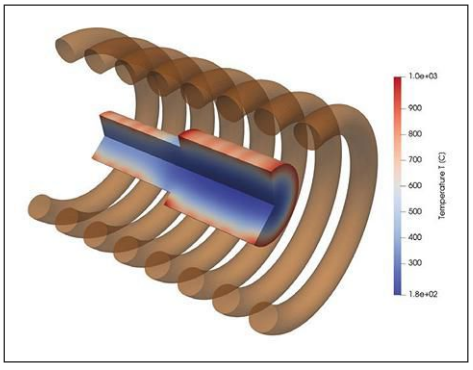


www.leybold.com

Simulation Software for Induction Heating

Cenos LLC

The Cenos platform enables computer-aided engineering for smaller companies focused on induction heating and hardening technologies. While traditional simulation software is tailored for large companies with excessive functionality and high price, this desktop software's user-friendly interface enables engineers with no previous simulation experience to design an induction coil in less than an hour. Users can enter parameters like geometry, frequency, electric current and materials and get simulation results, which are visualized in 2D and 3D renderings, graphs and tables for energy economics. Open-source tool ParaView is connected to the platform for the best post-processing experience. The technology ensures full control of data flow and implementation of smart automation algorithms.



www.cenos-platform.com

Hybrid Laser Process Gas Analyzer

Emerson

The Rosemount CT4400 is a purpose-built quantum cascade laser (QCL) and tunable diode laser (TDL) analyzer designed to help plants reduce ownership costs and report emissions accurately in environmental monitoring applications measuring standard components such as nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2). Optimized for cold and dry applications running at ambient pressure, the continuous gas analyzer offers the benefits of QCL/TDL technology, including high sensitivity, accuracy, improved stability and low-drift performance in a configuration that allows fast, easy integration into existing plant infrastructure.

www.emerson.com

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Phone: 734-331-3939 • Fax: 734-331-3915
E-mail: john@heattreatequip.com

Batch

C0052 Surface Combustion Temper Furnace (30"W x 48"L x 30"H, 1200°F, gas-fired)
C0068 Despatch Aluminum Aging Box Furnace (60"W x 72"D x 66"H, 395°F, electric)
U3624 Lindberg Nitrogen Temper Furnace (24"W x 36"D x 18"H, 1350°F, gas-fired)
U3656 Despatch Batch Temper Furnace (56"W x 72"D x 55"H, 1400°F, electric)
V1010 Dow Batch Temper Furnace (30"W x 48"L x 20"H, 1250°F, gas-fired)
V1024 PIFCO Batch Temper Furnace, Skid Hearth (36"W x 48"L x 30"H, 1200°F, electric)
V1095 Surface Combustion Temper Furnace (30"W x 48"D x 30"H, 1250°F, gas-fired)
V1106 Dow Batch Normalizer Furnace (45"W x 84"D x 32"H, 1800°F, gas-fired)

Batch High-Temp Furnaces

U3556 Pacific Industrial Batch High-Temp Furnace (24"W x 36"L x 18"H, 2800°F, electric)
U3637 Pacific Scientific Batch Temper Furnace (30"W x 48"D x 24"H, 1600°F, gas-fired)
U3643 Surface Combustion Temper Furnace (30"W x 48"D x 42"H, 1400°F, electric, 81kw)
V1013 Thermolyne High-Temp Batch Furnace (10"W x 14"L x 9"H, 2000°F, electric)
V1067 Seco Warwick High-Temp Batch Furnace (24"W x 36"D x 24"H, 2000°F, electric)
V1068 Surface Combustion Oil Quench Furnace (30"W x 30"D x 48"H, 1950°F, gas-fired)
V1130 Onspec Slot Forge Furnace (72"W x 96"D x 48"H, 2400°F, gas-fired)

Car Bottom Furnaces

U3653 Thermal Dynamix Car Bottom Furnace (5'W x 10'D x 5'H, 1650°F, gas-fired)
V1144 Selas Car Bottom Furnace (72"W x 120"D x 84"H, 1800°F, gas)

Drop Bottom Furnaces

C0069 Enviro-Pak Drop Bottom Furnace (48"W x 48"D x 48"H, 1200°F, electric)
U3543 Despatch AL Quench Drop Bottom Furnace (48"W x 72"L x 48"H, 1200°F, electric)

Internal Quench Furnaces

C0064 Lucifer IQ Furnace (18"W x 24"D x 18"H, 1900°F, electric)
U3569 Surface Combustion IQ Furnace (24"W x 36"D x 18"H, 1750°F, gas-fired)
V1046 Surface Combustion IQ Furnace (87"W x 87"L x 36"H, 1850°F, gas-fired)
V1082 Holcroft IQ Furnace with Top Cool (36"W x 48"D x 30"H, 1850°F, gas-fired)
V1111 Surface Combustion IQ Furnace (30"W x 48"D x 30"H, 1850°F, gas-fired)

Mesh Belt Brazing Furnaces

C0102JL Becker MB Brazing Furnace w/Exo & Dryer (30"W x 24'5"heated L x 10"H, 2050°F, electric)
U3529 CI Hayes Mesh Belt Brazing Furnace (18"W x 6"H x 8' heating, 2100°F, electric)
U3592 JL Becker Mesh Belt Brazing Furnace (12"W x 6"H, 2100°F, electric)
V1035 Seco Warwick Mesh Belt Brazing Furnace (18"W x 12"H x 8'heated, 2100°F, electric)

Mesh Belt Tempering Furnaces

C0044 CGS Moore Mesh Belt Curing Oven (22"W x 20'L x 10"H, 500°F, gas-fired)
C0073 Heat Machine Mesh Belt Tempering Furnace (24"W x 10'L x 4"H, 1000°F, gas-fired)
C0075 Industrial Heating Mesh Belt Tempering Furnace (24"W x 22'L x 10"H, 950°F, gas-fired)
C0080 Surface Combustion Mesh Belt Temper Furnace (18"W x 11"H, 13' long, 1000°F, gas-fired)
C0081 Park Thermal Mesh Belt Temper Furnace (17.5"W x 7"H, 15'8" long, 900°F, gas-fired)
C0083 Eltropuls Plasma Furnace System (56"Dia x 80"D, 1022°F, electric)
C0090 Hengli Mesh Belt Sealing Furnace - Atmosphere (6"W x 3.5"H, 2100°F, electric)
U3638 American Gas Furnace MB Temper Furnace (31"W x 5"H, 17' heated length, 1200°F, gas-fired)

Pusher Furnaces

U3648 Ipsen P-12 Pusher Furnace (30"W x 30"L x 30"H, 1650°F,gas-fired)

Roller Hearth & Rotary Furnaces

U3550 PIFCO Powered Roller Hearth Temper Furnace (21"W x 120"L x 18"H, 1000°F, electric)
V1009 Ipsen Continuous Temper Roller Hearth Furnace (24"W x 120"L x 18"H, 1350°F, electric)
V1091 Finn & Dreffein Rotary Hearth Furnace (13'3"ID x 5'3"ID x 4'W x 2'8"H, 2275°F, electric)

Steam Tempering Furnace

U3616 Degussa Durferrit Steam Tempering Furnace (24"Dia x 48"D, 1200°F, electric)

Tip Up Furnaces

C0043 Industrial Furnace Tip-Up Furnace (8'W x 22'4"D x 6'H, 1800°F, gas-fired)

Vacuum Furnaces

C0013 CI Hayes Oil Quench Vacuum Furnace (24"W x 36"D x 18"H, 2400°F, electric)
C0027 Pacific Scientific Vacuum Temper Furnace (24"W x 36"D x 24"H, 1450°F, electric)
C0111 Lindberg Vacuum Furnace (15"W x 24"L x 12"H, 2400°F, electric)
C0137 Surface Combustion 2-Bar Vacuum Furnace (48"W x 60"D x 48"H, 2400°F, elect)
U3612 AVS Vacuum Annealing Furnace 2-Bar (18"W x 24"D x 12"H, 2400°F, electric)
U3659 Ipsen 6-Bar Vacuum Furnace (36"W x 48"D x 36"H, 2400°F, elect)
V1004 CI Hayes Vacuum Furnace, Oil Quench (18"W x 30"L x 12"H, 2400°F, electric)
V1131 Abar Vacuum Furnace (24"W x 60"D x 24"H, 2250°F, electric)
V1135 Abar Vacuum Furn Vert Bottom Load 2 Bar (72"Dia x72"Deep, 2400°F, electric)
V1136 Surface Combustion Vacuum Furnace, 2-Bar (26"W x 36"L x 22"H, 2400°F, electric)
V1138 Ipsen Vacuum Furnace, 5-Bar (24"W x 36"L x 14"H, 2400°F, electric)
V1143 Surface Combustion Vacuum 2-Bar Furnace (48"W x 60"D x 48"H, 2400°F, elect)

Endothermic Gas Generators

U3594 AFC-Holcroft Gas Generator (3,000 CFH Endo, gas)
U3635 Lindberg Hydryzing Gas Generator (6000 CFH Endo, gas)
U3647 Lindberg Gas Generator (3000 CFH Endo, 2050°F, gas)
V1075 Lindberg Gas Generator (3,000 CFH Endo, gas)

Exothermic Gas Generators

U3652 Surface Combustion Gas Generator (10,000 CFH Exo, gas)
V1036 Seco Warwick Gas Generator (3,000 CFH Exo, gas)

Material Handling - Conveyors

U3565 Conveyor - Roller (48"W x 20'L)

Ovens - Cabinet

U3625 Lindberg Atmosphere Oven (38"W x 38"D x 38"H, 850°F, electric)
U3629 Cabinet Oven (30"W x 30"D x 36"H, 750°F, electric)
U3642 Blue-M Oven/Ref, 20"W x 18"D x 20"H, (-4°F/400°F)

Ovens - Walk-In

C0039 Gehnrich Walk-In Oven (72"W x 96"L x 72"H, 400°F, electric)
U3654 Precision Quincy Walk-In Oven (60"W x 72"D x 72"H, 700°F, gas-fired)
U3655 Wisconsin Oven Walk-In Oven (61"W x 144"D x 97"H, 650°F, elect)

Freezers

V1129 Webber Freezer (-120°F, electric)

Blowers

U018 Twin City Blower (20 HP, RBA-SW, Class 22)

Charge Cars

U3621 Dow Charge Car, DEDP (66"W x 60"D x 54"H)
V1085 Holcroft Charge Car (DE/DP, 36"W x 48"D)

Scissors Lifts & Holding Tables

V1086 Holcroft Scissors Lift & (2) Holding Tables

Heat Exchanger Systems

U030 Graham Systems Heat Exchanger - Plate
V1104 SBS Heat Exchanger - Air Cooled

Holding & Cooling Stations

V1113 Surface Combustion Forced Cool Station (30"W x 48"D x 30"H)
Many other holding stations - ask for details

Water Cooling Systems

U3404 JL Becker Cooling Tower with Tank: Tower: (51"W x 36"D x 64"H, Tank: 72"W x 84"D x 66"H)
U3595 JL Becker 2-Tank Water Cooling System, 2 Dayton 1HP Motors
U3646 HydroThrift, Duplex Pump Base, Water Cooling System
V1038 Bell & Gossett Shell & Tube Heat Exchanger with Tank

Washers

C0134 Surface Combustion Washer (60"W 60"D 40"H, 180°F, gas-fired)
V1084 Holcroft Spray/Dunk Washer (36"W x 48"D x 30"H, 190°F, gas-fired)
V1101 Surface Combustion Spray Washer (36"W x 48"D x 30"H, 180°F, electric, 58kw)

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SURFACE COMBUSTION
SURFACE COMBUSTION Single Ended Charge Car, 30" wide x 48" long, 480 volt, 3 phase, 60 hz complete with controls.

BAKER
Baker Gas Fired Oven with Cooling, 7'W x 7'H x 8'L (Heating chamber), 7'W x 7'H x 8' L (Cooling chamber), vertical rising door between chambers, 600°F, 750,000 BTUH, powered carts, stainless steel interior and controls.

SELAS
Selas Gas Fired Car Bottom Furnace, 6'W x 7'H x 10'L, 1,800°F, 3,000,000 BTUH, 6 North American Tempest Burners, 460V/3Ph/60Hz, variable speed drive, combustion blower complete with free-standing panel and controls.

SHERWOOD
Sherwood Gas Fired Mesh Belt Furnace, 5'W x 10'H x 30'L (Heated), 500°F, 500,000 BTUH c/w controls.

VACUUM INDUSTRIES (CENTORR)
Vacuum Industries (Centorr) VII Metallurgical Vacuum System, 6"W x 5"H x 15"L, 2,400°F, 460V/3 PHASE/60 CY/55 AMPS/38 KVA c/w controls, pumps etc

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Gas Fired Car Bottom Furnace, 10' wide x 25' long x 8' high, 1,650°F, 18,000,000 BTUH, 16 North American Burners, 3 zones of control, 440V, 3 Phase, 60 Cycle complete with controls.

INDUSTRIAL HEATING EQUIPMENT
Industrial Heating Equipment Gas Fired Mesh Belt Furnace, 24"W x 10"H x 22'L, 500,000 BTUH, 950°F c/w controls.

PARK THERMAL
Park Thermal Gas Fired Mesh Belt Furnace, 17-1/2"W x 7"H x 15' 8"L, 375,000 BTUH, 900°F c/w controls.

SURFACE COMBUSTION
Electric Batch/Oil Quench Furnace, 30" W x 30" H x 48"L, Max. Temp. 1,950°F, System 1 Rear Handler, 3500 Gal. Quench Tank, 2 Agitators & Controls.

AFC - HOLCROFT
(2) INTEGRAL QUENCH FURNACES, 36"W x 30"H x 48"L, 1,800°F Max, Recuperated with Top Cool, Rear Handler, Oil Heaters (54kW), Re-Circ. Fan, Control System.

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INTEGRAL QUENCH FURNACE, 10,000 lb. payload, 87" W x 87" L x 36" H, 1,850°F, 4,600,000 BTUH, 12,500 Gallons, 6 Agitators, Eclipse Burners, 3 Rear Handlers & Controls with PLC.

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36"W x 60"H x 48"L, Electric, 600°F, Blue M
50"W x 54"H x 30"L, Electric, 350°F, Grieve
48"W x 72"H x 48"L, Electric, 500°F, Despatch
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Surface Hardening Procedures for Steels

THURSDAY, MAY 16 @ 2PM EDT

This webinar describes and illustrates surface hardening procedures for a wide variety of steels with multiple examples to show how these procedures alter the microstructure and surface hardness. Tempering must be performed on surface hardened steels, but generally the temperatures used are rather low causing little loss of hardness.

In this Webinar You Will be Shown Examples of:

- **Surface hardening procedures**
- **How such structures can be revealed using different etchants**
- **Hardness data for most processes as a function of the depth below the surface**
- **Failures due to improper surface hardening procedures that caused service failures**

Speaker: George Vander Voort
President, Vander Voort Consulting L.L.C.

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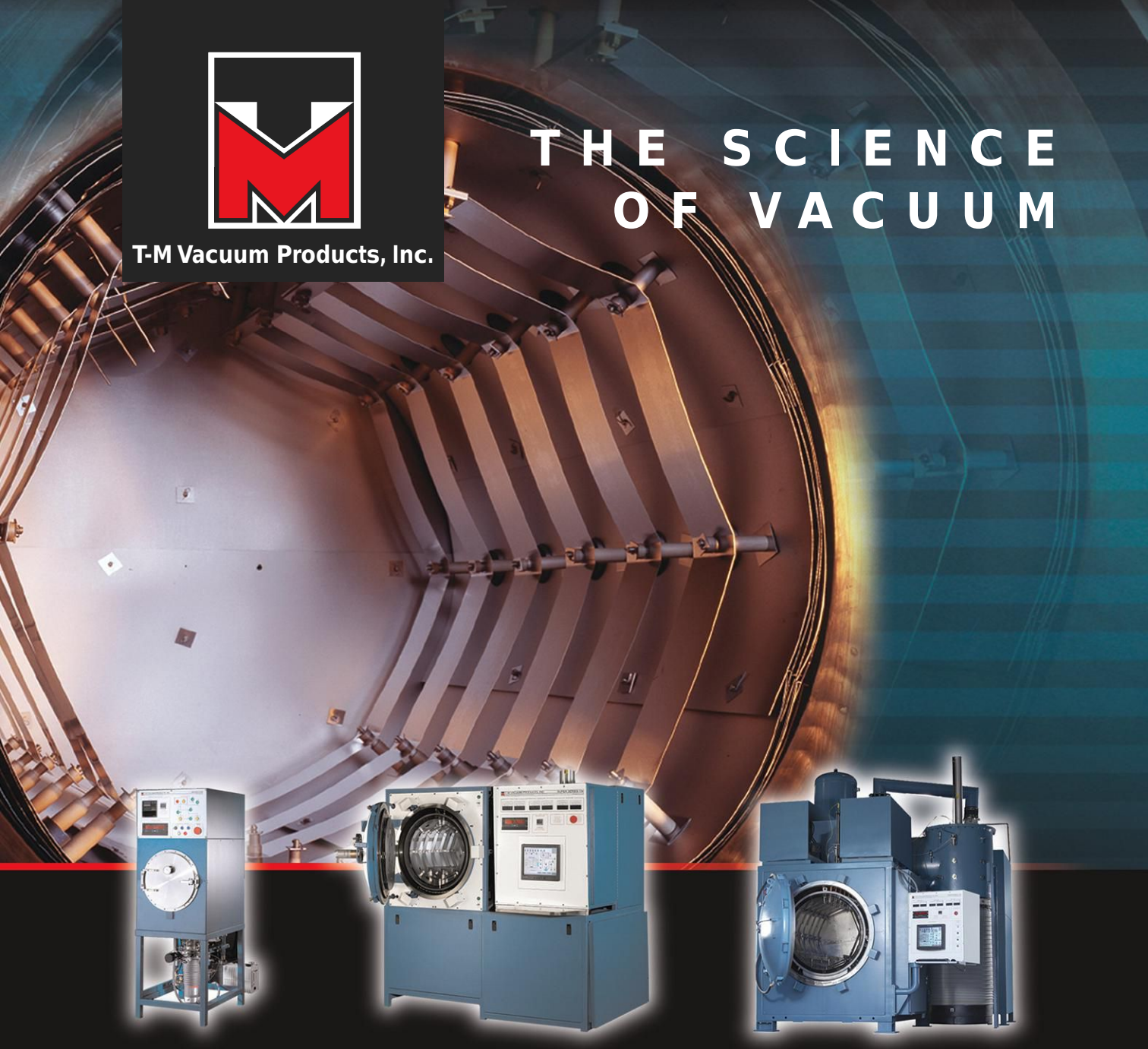

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