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INSIDE

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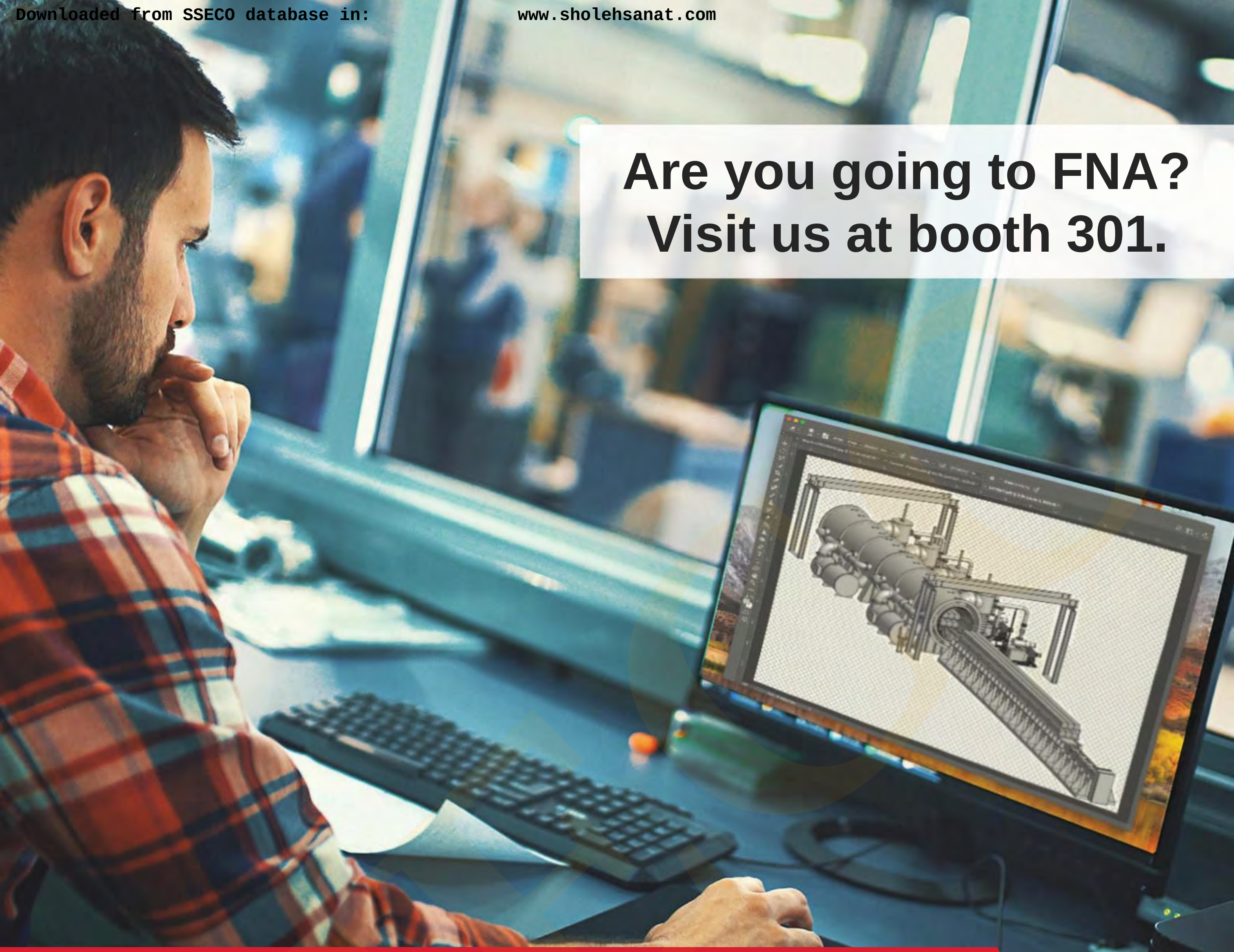

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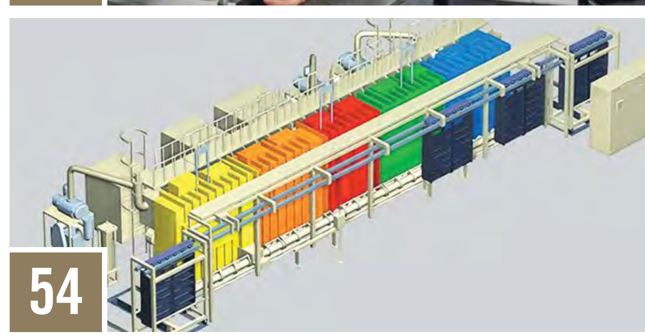

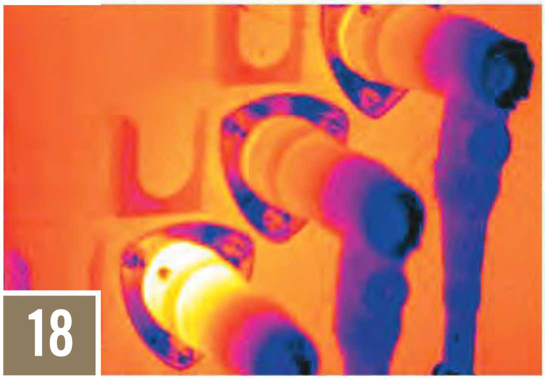

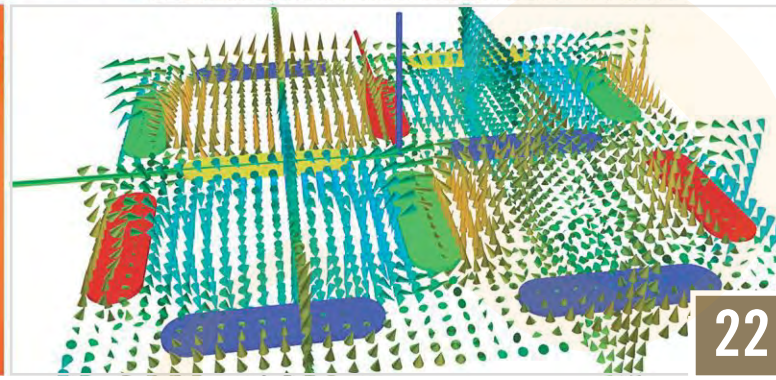

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Additive Manufacturing and PM Awards

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Additive manufacturing (AM) is certainly becoming the "disruptive technology" predicted by some in the industry. Not a day goes by that we don't come across news of AM companies making moves or new parts being designed. Let's gain some perspective by taking a look at some of these stories.

As we have previously discussed, aerospace has been an early adopter of AM technology for several reasons, not the least of which being cost. Early AM work has been expensive and limited to small batches. Neither of these factors are good for the automotive industry, for instance.

A recent news story confirms Boeing's interest in AM. A Boeing representative, Terry McGowan, was recently quoted, "We believe there's going to be huge potential for this technology. We're very, very close to a Star Trek replicator."

The reasons given for Boeing's optimism are as follows.

- **Part cost reduction**: It can allow for unitized assemblies, cutting down the number of parts and thus cutting cost.
- **Part availability**: When you can print your part at the press of a button, lead time and inventory management become a thing of the past.
- **Part performance improvement**: Printed parts allow for designs (e.g., optimized lightweighting) that aren't achievable with traditional manufacturing methods.
- **Improved safety**: The reduced mass and number of parts means safer installation, and AM/3D-printed parts can be made with ergonomics in mind.

EASYCHANGE removable brush holder assembly used in turbine generators for the power industry

An example of the lightweighting feature of AM comes from Airbus. Recent work done with Materialise demonstrates that parts can be 15% lighter in weight due to a more complex design. The complex design would be more expensive and might be impossible with conventional production methods, but that is not so with AM. We will see some of the design intricacies possible in the PM award winners.

The winners in the annual MPIF Powder Metallurgy (PM) Design Excellence Awards were announced during POWDERMET 2018 in San Antonio, Texas, in June. A few are highlighted here.

MPIF Grand-Prize-Winning Parts

GKN Powder Metallurgy took two awards in the categories of Automotive Transmission and Automotive Engine. The transmission part is a planetary reaction carrier made for the all-new GM 9T50 9-speed transmission. The engine part is a copper-steel main bearing cap made for FCA US LLC. It is used in the 2.0 L all-aluminum turbocharged 4-cylinder engine launched in the Alfa Romeo Guilia. The design delivers a part that is 23% lighter while offering 10% better fatigue strength.

One of the 12 Awards of Distinction was presented to ARC Group Worldwide. The part, made for Cutsforth Inc., goes into an EASYCHANGE removable brush holder assembly used in turbine generators for the power industry. The part was previously 100% machined, and you can see the complexity of it. Whether using a conventional MIM process or making a part like this as AM, complexity and detail are not a problem. Redesigning parts with a more-complex design often results in the aforementioned weight savings. In this case, the MIM process reduced the per-part cost by 60%. *Industrial Heating* congratulates all of this year's award winners.

It won't be long until FNA 2018 in Indianapolis. If you plan to attend and have not yet made arrangements, I encourage you to do so soon. If you do attend, stop by booth 624 and say hello. We'll see you there.

Mexico's Crossroads

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This column has recently addressed U.S. problems with China. Now we'll discuss things closer to home – with some similar but more benign and resolvable issues.

Mexico is the third-largest U.S. trading partner after China and Canada and America's second-largest import market after Canada. With a population of 129,000,000, Mexico is the most populous Spanish-speaking nation in the world and third-most populous country in the Western hemisphere. Mexico's GDP is $1 trillion (6% of the U.S.), and the country has a per capita GDP of $17,750 (30% of the U.S.). Total U.S. 2017 exports to Mexico were $144.6 billion and imports were $223.4 billion. U.S. oil and gas imports have steadily declined since 2011 and dropped from $39.9 to $9.8 billion in 2017.

The Congressional Research Service estimates that fully 40% of U.S. imports consist of U.S. value-added content. This aspect of U.S. imports helps sustain industry jobs but has the negative effect of taking away other U.S. jobs and depresses the wages of low-skilled workers. As a summary, Mexico has the 11th-largest economy in the world in terms of GDP, with 82% of their exports going to the U.S.

All of this describes a reasonable relationship between the countries but still one needing improvements. A Heritage Foundation study said that Mexico's economic freedom score is only 64.8, ranking it 63rd in the world and 12th among the 32 countries in the Americas. Remember that the center-left Institutional Revolutionary Party governed Mexico for 70 years until 2000, when it was defeated by the center-right National Action Party. The Democratic Revolution Party just gained national control in the July 2018 presidential election, with a 53% victory margin for new six-year-term President Andres Manuel Lopez Obrador (AMLO), who takes office in December. There are deep and valid reasons for this public expression, and it deals with growing concerns that affect industry and lives on both sides of our border. The key word here is "corruption."

Analyses by Investopedia cite some indicators. A World Bank study found that the average income in countries with high corruption levels is one-third that of low-corruption nations. The former has infant mortality rates threefold higher and literacy rates 25% lower than peers. Corrupt nations are characterized by a disproportionately small middle class and a big divergence between upper- and lower-class living standards. The public has little confidence in the legal system. Government revenues from taxes are inefficiently allocated – in Mexico it was 19.6% of GDP in 2013, the lowest among the 34 OECD countries. There is disincentive for foreign investment, and the cost of education increases while quality decreases.

A bright spot for Mexico appeared May 18 with the creation of CONAMER, a national regulatory improvement commission. The organization's intent is to combat corruption, enhance growth and free trade and spur job creation. Although AMLO is a perennial leftist candidate, he promised to roust out the political mafia that has run the country and to end the growing violence that shakes Mexico. Know that AMLO won 30% more votes than his nearest competitor among the nation's 89 million eligible voters casting ballots. He has said things that resound well with the public and could spell the difference between his success … or could lead to more of the same. AMLO said, "We are not against businessmen. We are against corrupt politicians." Since drug cartels have taken over many police forces and penetrated portions of the national military, the words from this leftist reformist politician could be very significant for Mexican citizens, their national economy and, as a result, America's relationships with Mexican industry.

It is important to understand that great improvements in Mexican government operations and suppression of the corrupt features of their economy should (and probably will) cause re-examination of NAFTA. That the new president is a leftist is of no concern as long as he and the Mexican government make desperately needed changes and improvements. America should see the road to a "yes" or "no" answer within the year. Industry in the U.S. needs to pay attention.

Saving Customers Time, Money and Energy

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Heat treatment is an energy user and all too often an energy abuser. Given the significant amounts of energy needed to run a typical process, this translates into a huge cost to the heat treater. In addition, material choices and specification requirements often dictate cycle temperatures and times, while environmental compliance further adds to the overall cost. How can we, and how should we, go about addressing these issues? Let's learn more.

Energy[1,3,4]

The first step in any energy-management program is to understand where and how much energy is being consumed or wasted. Energy monitoring via gas totalizers or electrical power meters (including peak-demand monitoring) is a good way to start. Thermal imaging (Fig. 1) is another tool to help focus maintenance activities and identify areas for improvement.

A complete energy audit normally consists of five basic parts:[1]

- A description of the facility and all of the equipment involved
- Mapping of the current energy consumption in the plant
- The short-term energy consumption in the plant
- The long-term energy consumption in the plant
- A search for energy-efficiency improvement possibilities

By way of example,[1] an energy audit was conducted at a large commercial heat treater in Europe with the following major findings.

- The plant consumed 9,590 MWh/year of electricity and 120 MWh/year of peak demand costs at the start of the audit.
- 68% of the energy was consumed by primary heat-treatment processes and equipment with the other 32% consumed in ancillary processes.
- The largest portion of the energy consumption was the main 14 integral-quench-style heat-treatment furnaces. The ancillary equipment consisted of over 30 units (preheating and tempering furnaces, parts washers).
- The electricity consumption could be decreased by 7.85% (753 MWh/year) by energy conservation (housekeeping and recipe optimization) measures.
- The electricity consumption could be further decreased by 4.36% (418 MWh/year) and the peak demand eliminated by energy monitoring and energy-saving investment measures.
- The combination of the proposed energy housekeeping measures and energy-saving investment measures reduced the energy cost with savings of approximately $135,000 per year. It also resulted in a reduction of the carbon-dioxide emissions by approximately 740 tons per year.
- If all proposed measures were implemented, the total investment cost would have a payback of three years and a net present value of almost $2.1 million over 10 years using current energy prices.

Environmental

Environmental compliance is a complex subject. I've often seen heat treaters shaking their heads in disbelief as to why they must both pay for water and pay a sewer tax to dispose of it having done nothing more than heat it a few degrees. These types of issues have led to a philosophical debate within the heat-treatment industry as to what constitutes good environmental policy. Stark contrasts can be seen in different countries throughout the world.

In the U.S., for example, environmental policy is viewed as obeying the rules and regulations mandated by federal, state and local governmental agencies. By contrast, many corporations strive to be "good neighbors," often imposing more stringent environmental policies than those mandated by law.

In Europe, there is a strong cultural emphasis placed on environmental issues, which are at the forefront when considering equipment purchases and the way in which heat-treat plants are managed. Emissions are not only carefully monitored, but companies often strive to outdo one another so as to be rewarded rather than

penalized (e.g., the carbon tax) for their environmental choices.

In Asia, as societies continue to evolve, environmental policies will follow suit. For example, one heat treater in Japan has coy fish swimming in his cooling-water system, and each employee is responsible for keeping his fish alive and healthy! By contrast, the smog that surrounds cities in China is a clear indication that we still have more work to do.

Process Optimization

Traditionally, when a load is heat treated in a furnace, the only measurements available to track the cycle progress are furnace control thermocouples or, in some instances, part workload thermocouples. The goal is to heat the entire load to a specific temperature and soak at that temperature for a given period of time.

Ideally, the user would like to know the temperature at the center of the load and the moment that all of the piece parts reach that temperature. If known, cycle times can be optimized. Most heat-treat recipes soak the load longer than necessary to ensure meeting metallurgical and mechanical properties. This adds cost and reduces throughput.

There are currently three principal methods for ensuring a stable and uniform load temperature.

- Manual intervention – visual inspection of the load during processing. This can be done by observing the load through a peep sight or, in some rare instances, by opening the furnace door(s). This method is dependent on the skill of the operator and can disrupt furnace operation.
- Standard automatic control – where the heating process parameters are calculated and the soak time is over-specified to ensure uniformity.
- Process supervision to monitor energy consumption as well as all of the usual parameters, ensuring that the required heating practice is achieved without wasted time and energy.

Companies are creating modeling algorithms and so-called visual supervisors[2] that calculate furnace parameters, allowing for improved temperature uniformity. This in turn allows the cycle time (regardless of the load) to be optimized. This steady-state method results in reduced cycle times and energy costs.

Finally, optimization of all diffusion-based processes (Fig. 2 - online only) can be achieved by increasing process temperature as a means of reducing cycle time. In this case, cost reduction can be achieved by such methods as:

- Modifying material chemistries
- Improving process control to minimize case-depth variation
- Controlling distortion to avoid post-heat-treatment machining operations
- Choosing more-efficient diffusion processes for the application

Cost[1]

Cost containment is a huge issue for the heat treater. The net present value is the difference between the investment and the present value of future cost savings due to the investment. The present value of future cost savings is calculated with an interest rate, usually the cost of capital. The net present value is calculated according to:

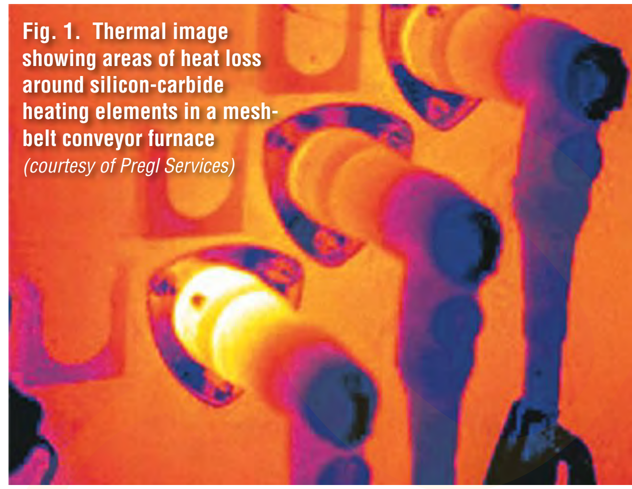


Fig. 1. Thermal image showing areas of heat loss around silicon-carbide heating elements in a mesh-belt conveyor furnace *(courtesy of Pregl Services)*

$$NPV = \sum_{i=1}^{i=t} \frac{a_i}{(1+r)^i} - I \qquad (1)$$

where NPV is the net present value, t is the time frame for the calculation, a_i is the annual cost saving due to the investment, r is the cost of capital and I is the total investment cost.

This method considers the time value of money and accounts for all cash flows during the time frame for the calculation. It can be used to evaluate an investment and to compare the profitability between investments. A good investment will have a high net present value.

Another way to compare investments is to calculate the net present value ratio, which is the net present value divided by the initial investment according to:

$$NPVR = NPV / I \qquad (2)$$

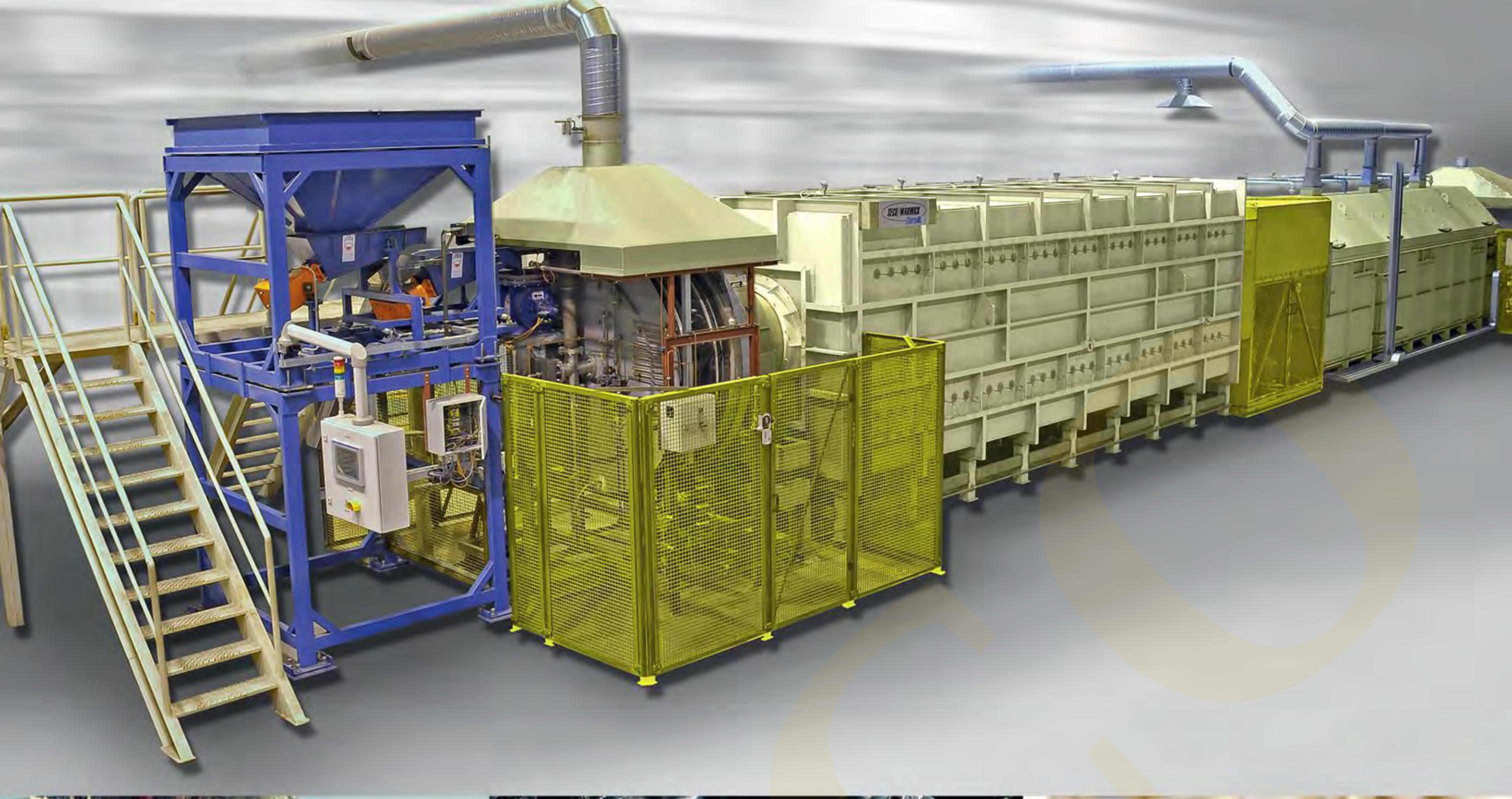
where NPRV is the net-present-value ratio, NPV is the net present value and I is the total investment cost. A higher NPRV indicates a more profitable investment.

Summary

In order for heat treating to be the most cost-effective solution to manufacturing, we must continue to evolve in the areas of technical innovation; improved up-time productivity; and reduction of energy, environmental and process costs.

Simply reducing cost by heretofore traditional methods (e.g., labor reduction, quality relaxation, deferred reinvestment or delayed introduction of new technology) will no longer keep the industry competitive. Applying conservation methods and negotiating more-favorable energy contracts are a good start.

References available online



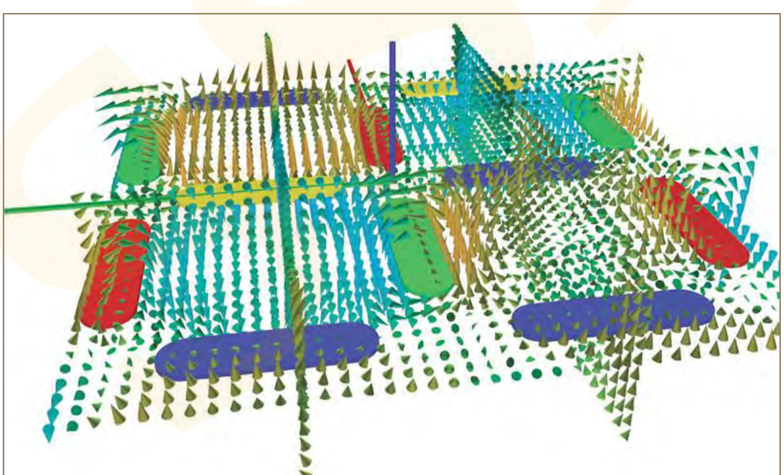
Visualizing Magnetism at the Nanoscale

DR. MARC DE GRAEF
Professor of Materials Science and Engineering, Carnegie Mellon University

Every day we use dozens of electromagnetic devices, from a simple water heater to brew a cup of coffee to cell phones, office computers, light bulbs, elevators, air conditioners and so on. What all of these devices have in common is that they use either electricity or magnetism or, in many cases, both.

None of these technologies would exist today had it not been for decades worth of painstaking experimental and theoretical work by people like Coulomb, Faraday, Gauss, Ampère and others who made it possible for James Maxwell in 1861 to explain all known experimental results in the form of four elegant differential equations. The behavior of all electric and magnetic fields is described very accurately by what we now refer to as Maxwell's Equations.

For many of us, our very first encounter with the basic properties of electrical charges and bar magnets was likely in a middle- or high-school science lab. The instructor would give students interesting hairdos using a static electricity generator or make visible the field lines that surround a bar magnet by pouring iron filings on top of a sheet of paper covering the magnet. Who hasn't played, as a child or even as an adult, with a couple of magnets and wondered about the invisible forces that make poles attract or repel each other?



A 3-D reconstruction of the magnetic vector potential around an array of Permalloy islands. Each island is represented by a colored elongated disk (290 nm long): red and green indicate opposite bar magnets along one direction; yellow and blue along the perpendicular direction. The arrows circle around each of the islands in agreement with theoretical predictions.

Over the last century, physicists and engineers have managed to put these forces to good use, first with the development of powerful electromagnets, transformers and electric motors. More recently, the development of high-density magnetic recording media makes it possible for all of us to preserve for eternity long videos of cute kitties. In the future, we can hopefully harness the power of atomic fusion, for which magnetic containment of an ultra-hot plasma appears to be one of the viable technologies.

The use of magnetic fields and magnets in data recording started in the mid-1950s. Over the years, the size of the "bar magnets" used to store information has steadily decreased, and the latest drives have individual data bits that are formed by magnetic regions of only a few nanometers across.

Developing such technology requires (among many other things) the ability to produce images of the individual bits as well as the magnetic fields surrounding them (i.e., the equivalent of the iron-filings experiment) but at a length scale that is about 10 million times smaller than the classic science-class demonstration. Obviously, this requires the use of advanced materials-characterization tools, and our Materials Characterization Facility (MCF) at Carnegie Mellon University is one of only a handful of labs worldwide that specializes in the use of Lorentz microscopy – a technique that measures the tiny deflections in the trajectories of electrons as they pass through the magnetic fields surrounding magnetic nanoparticles. Typical deflection angles are well below 1/10,000th of a degree!

Lorentz microscopy allows us to determine a 2-D projection of the magnetic-field distribution in and around a small magnetic object or a collection of such objects. These projections cannot be observed directly but must be extracted from experimental images through extensive post-processing of the data. Our research group has contributed significantly to the development of these algorithms over the past two decades, and it is now almost a routine operation to obtain magnetic induction maps with a spatial resolution of a few nanometers.

Check out this column online for more information on the work being done in this area.

Trojan Heat Treat

Plant 4, Heat Treating Services Corporation of America

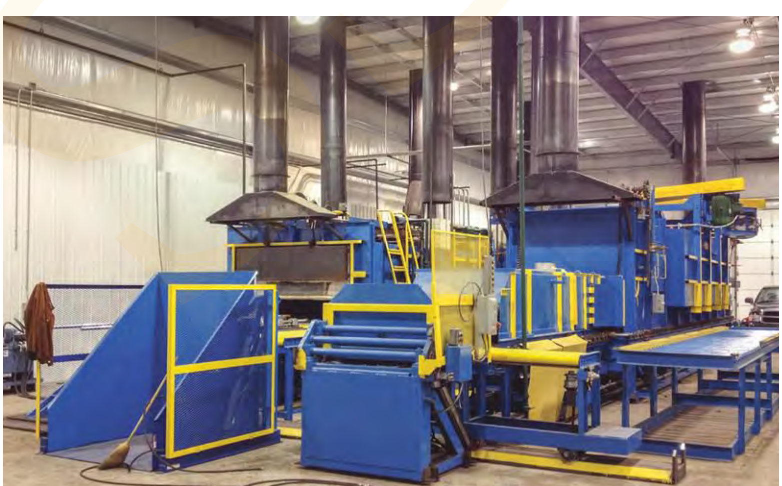
MTI
Metal Treating Institute
904-249-0448
www.HeatTreat.net

What started out as a small captive operation has turned into something much, much more.

Trojan Heat Treat (THT) was established in 1959 by George Petredean, who was a charter member of the American Foundry Society. Originally, the business served as a captive heat treat for Petredean's Calhoun Foundry. Things changed in 1980, however, when THT transitioned into a commercial operation under the leadership of Ron Di Salvio, who has been with the company ever since (that's 38 years) and still serves as president.

In March 2005, THT was acquired by Heat Treating Services Corporation of America (HTS), making it Plant 4 of HTS operations. The choice to sell the business was part of an exit strategy plan already in place as Petredean was preparing for retirement. The company entertained quite a few potential buyers but settled on Heat Treating Services, which, according to Di Salvio, "has proven to be the right choice."

When THT first opened its doors in Homer, Mich., the company operated one pusher furnace line with three employees in a 3,300-square-foot building. Today, the MTI member has 50 employees and eight furnace lines (three belt, three pusher and two car bottom) in 64,000-square feet in two buildings located across the street from each other. This equipment is capable of processing 261 tons of forgings and castings per day.



THT processes iron castings and steel forgings for the automotive, military, heavy equipment and construction industries. Services provided include annealing, normalizing, stress relieving and ISO thermal annealing. The company's in-line recorders are essential to its operations by documenting furnace cycles for customers.

In February 2008, THT increased capacity with the addition of a furnace line from BeaverMatic. The tip-up-type furnace is 40 feet long x 8 feet wide x 8 feet high with a 90,000-pound load capability. In just over three months from installation, over 7 million pounds of product was annealed with a substantial improvement seen in work flow and throughput by stacking and configuring baskets, trays and castings to process daily, back-to-back loads weighing 70,000-90,000 pounds.

THT provides more than heat-treatment services. The company operates three 22-cubic-foot Wheelabrators. These machines use steel shot to remove rust, discoloration, flash, burrs and any other undesirable surface spots from parts. Shot blasting leaves a decorative finish without compromising the integrity of the part.

Today, 59 years after starting up, THT excels through strategic partnerships with its customers – working together to operate more effectively. And by running larger loads, reducing personnel and improving efficiencies, the company has maintained competitive pricing and has been able to absorb much of the increased energy and alloy costs.

As for the future, THT is in the process of combining all electrical services from the two buildings into one metered operation and converting all plant lighting to LED. The company is also considering a project that would connect the two sites. The Homer Village council has already agreed to an abatement that would allow the combination. This project would allow THT to add more furnace equipment and hire more workers.

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IHEA Hosting Fall Seminars in Conjunction with FNA 2018

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IHEA takes educating the industrial heating industry very serious.

"We know how valuable the information we share with the industry is to ensure that furnaces and ovens are operated in a safe environment," said Anne Goyer, IHEA's executive vice president. In conjunction with the Metal Treating Institute's Furnaces North America (FNA 2018), IHEA will offer its three popular training seminars that provide critical and current information to attendees to help them better manage their industrial heating operations. This will be the perfect opportunity for manufacturers to expand their technical knowledge and spend time on the FNA exhibit floor.

The Combustion Seminar, Safety Standards and Codes Seminar and Induction Seminar will take place Oct. 8-10 in Indianapolis, Ind. The Combustion Seminar and the Safety Standards and Codes Seminar will be held all day Monday, Oct. 8 and on the mornings of Tuesday, Oct. 9 and Wednesday, Oct. 10 at the Indiana Convention Center. The Induction Seminar will be held on Tuesday morning, Oct. 9. This seminar schedule is set up perfectly to allow attendees full access to the FNA expo. Attendees from all three seminars will have the advantage of a private networking reception on Monday afternoon with the speakers.

IHEA's 49th Combustion Seminar will provide attendees updated and relevant information from experts in combustion technologies. The seminar is designed for those responsible for the operation, design, selection and/or maintenance of fuel-fired industrial process furnaces and ovens. The seminar consists of 18 comprehensive sessions covering a complete range of topics on combustion systems, controls, parts and maintenance. Seminar topics include: combustion system and flame safety, combustion troubleshooting and optimizing combustion-system performance.

IHEA's Safety Standards and Codes Seminar will provide a comprehensive overview of NFPA 86, including newly released updates for many areas of safety. Sessions will cover the required uses of the American National Standards governing the compliant design and operation of ovens and furnaces. Speakers will also cover the new 2019 Revision of NFPA 86 – Standards for Ovens & Furnaces. This seminar includes detailed presentations on: pulse-fired systems, safety shutoff valves, calculation methods for LFL, loss prevention and product liability.

IHEA's Induction Seminar will offer the basics of induction technology and detail how electrically powered induction technology can create heat in parts, up to and including melting metals. IHEA's Induction Division members have developed the material to support the need for additional induction education.

Register now and plan to attend one of IHEA's Fall Seminars Oct. 8-10 in Indianapolis during FNA 2018. Visit www.ihea.org/page/Fall18 for more information. IHEA members receive significant discounts on seminars. Consider joining IHEA today to save on registration fees. End users receive four vouchers with their membership that can be used to register for seminars for FREE!

CAN'T ATTEND ONE OF THE FALL SEMINARS?

Check out IHEA's Online Fundamentals of Industrial Process Heating course, a six-week training class you can take at your own pace, in your own space. It runs from Oct. 15-Nov. 25. Complete details can be found at www.ihea.org/event/FundFall18.


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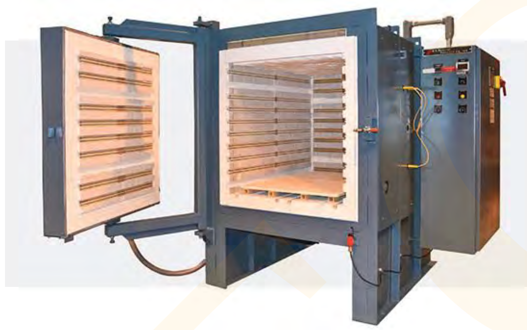
EQUIPMENT NEWS

Box Furnaces

L&L Special Furnace Co. supplied two electric box furnaces to a Midwest machine manufacturer that builds high-speed cutting equipment, tools and supplies for various industries. A benchtop model with interior working dimensions of 14 inches wide x 8 inches high x 11 inches deep will be used to heat treat punches and tool-and-die materials. A larger model with an effective work zone of 34 inches wide x 16 inches high x 32 inches will be used for hardening and annealing a variety of components employed in equipment manufacturing. The benchtop model is equipped with a digital program control and over-temperature protection. The larger box furnace features a complete digital control system, over-temperature protection and counterbalanced vertical door for ease of loading. It can be used for running batches of multiple parts.

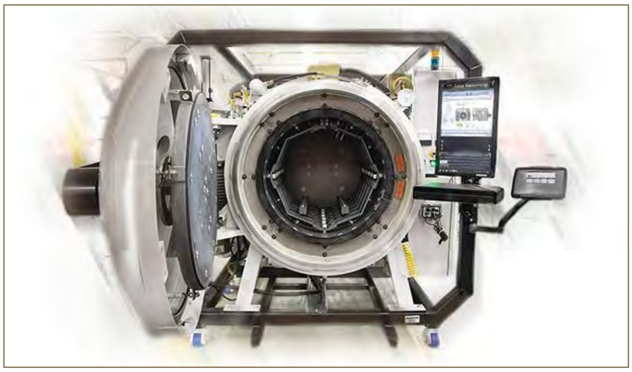


www.llfurnace.com

Fastener Hardening System

Can-Eng Furnaces International Ltd. has been contracted to design and commission a large-capacity fastener hardening system for a Tier 1 automotive supplier based in Detroit, Mich. The system closely integrates a computerized part-tracking and metering system, pre-washer, mesh-belt hardening furnace, oil-quench system, post-washer, temper furnace, soluble oil system, endothermic-gas generator and level 2 automation system. It is engineered to produce at a rated capacity of 6,000 pounds (2,700 kg) per hour. The system will support capacity increases for this fastener manufacturing company, which offers heat-treating, wire-processing, coating and packaging services. This project is currently being processed through manufacturing and is scheduled for commissioning in the first quarter of 2019.

www.can-eng.com



Atmosphere, Vacuum Furnaces

Ipsen USA shipped 18 furnaces to companies in six states in the U.S. and two companies overseas. Ten atmosphere box furnaces were shipped to a company in the aerospace industry, and one temper furnace was shipped to a U.S.-based commercial heat treater. Ipsen also shipped one of the largest vacuum furnaces it has ever built. This horizontal furnace features a 210,000-pound load capacity and is equipped with eight 35-inch diffusion pumps and a stainless steel-shielded hot-zone assembly that is capable of achieving ±5°F temperature uniformity. Other shipments included three TITAN H2 (18 inches wide x 24 inches long x 18 inches high) 2-bar furnaces and three TITAN H6 (36 inches wide x 48 inches long x 36 inches high) 2-bar furnaces. www.ipsenusa.com

Conveyor Oven System

Epcon Industrial Systems designed, built and shipped a state-of-the-art multi-zone conveyor oven system that will be used to cure internal linings for 55-gallon drums. The effective heating zone oven measures 100 feet long x 6 feet wide x 6 feet, 6 inches high. The custom-designed oven has three independently controlled heating zones operating at a temperature range of 350-600°F and three dual-lane conveyor systems to process the drum and the top/bottom lids simultaneously. The dual-lane conveyor systems offer the end-user the advantage of minimizing floor space and reducing the operating cost by approximately 30% compared to a conventional approach of installing separate oven systems for drum and lids. www.epconlp.com

Equipment & Business News

Bench Oven

Thermal Product Solutions (TPS) shipped a custom Gruenberg bench oven to the movable machinery industry. The oven, which is rated for Class B operation per NFPA 86 specifications, will be used in the company's testing and product development department to process various mechanical apparatuses affixed to an electronic shaker. The oven has a maximum temperature rating of 1022°F (550°C) and work-chamber dimensions measuring 36 inches wide x 36 inches deep x 36 inches high.
www.thermalproductsolutions.com

Furnace Line

AFC-Holcroft supplied a complete UBH line to Amsted Rail, a Chicago-based global leader in fully integrated freight-car systems for the heavy-haul rail market, to meet a growing need for additional heat-treatment capacity. The line includes a batch-style carburizing furnace, two expansion modules to increase endothermic-gas generator output, a rotary-hearth reheat furnace for press quenching and a continuous integrated parts washer and temper furnace. The equipment is scheduled to ship to a joint-venture facility in Eastern Europe in the third quarter of 2018. The batch furnace has an effective load size of 72 inches x 72 inches x 56 inches with a gross load capacity of 13,000 pounds.
www.afc-holcroft.com

Walk-in Ovens

Wisconsin Oven Corp. shipped six propane-gas-fired, enhanced-duty walk-in ovens to a material-testing laboratory. The batch ovens, which will be used for hydrogen embrittlement relief of various parts, have a maximum operating temperature of 500°F and work-chamber dimensions of 8 feet wide x 4 feet long x 4 feet high. They were designed with the capacity to heat 1,020 pounds of steel and 220 pounds of a load cart from 70°F to 480°F within 60 minutes when loaded. The recirculation systems of

the ovens utilize energy-efficient blowers and provide horizontal airflow. The heating systems use industrial air heat burners rated at 450,000 BTU per hour and modulating gas control valves. www.wisoven.com

BUSINESS NEWS

Sandvik Acquires Custom Electric Manufacturing

Sweden's **Sandvik** acquired privately owned **Custom Electric Manufacturing Co.** of Wixom, Mich. Custom Electric manufactures original and replacement heating elements for electric and gas furnaces for the North American market. The business will be reported as part of the product area Kanthal within business area Sandvik Materials Technology. The deal will further strengthen Sandvik's position in industrial heating systems. Custom Electric will continue to go to market under its own brand.

Arconic, Lockheed Martin to Collaborate on Metal 3D Printing

Lockheed Martin and **Arconic** announced a two-year joint development agreement (JDA) to develop customized lightweight material systems and advanced manufacturing processes, such as metal 3D printing, to advance current and next-generation aerospace and defense solutions – including new structures and systems not currently in existence. This JDA is part of an initiative to develop next-generation advanced materials and manufacturing processes. The companies currently collaborate on advanced materials and manufacturing projects such as the development of process modeling; simulation tools; and lightweight, corrosion-resistant alloys.

Bodycote to Open New Heat-Treatment Facility in U.K.

Bodycote announced the opening of a new facility in the Advanced Manufacturing Park (AMP) in Rotherham, Yorkshire, to support the aerospace and power-generation markets in the U.K. and Europe. The plant, which will be fully operational in 2018, will offer a number of heat-treatment processes. In addition, major OEM approvals will be secured along with Nadcap accreditation.

Equipment & Business News

Praxair Sells European Industrial Gases Businesses

Praxair Inc., in accordance with its proposed business combination with Linde AG, signed an agreement to sell the majority of its businesses in Europe to Japan's Taiyo Nippon Sanso Corp. for approximately $5.8 billion. This agreement is conditioned on the successful consummation of the Praxair-Linde merger and other regulatory approvals. The assets to be sold include Praxair's industrial gases businesses in Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the U.K. and include approximately 2,500 employees.

ATI Acquires Metal AM Company

Allegheny Technologies Inc. (ATI) acquired New Britain, Conn.-based Addaero Manufacturing, a metal-alloy-based additive-manufacturing company for the aerospace and defense industries. The acquisition brings together ATI's knowledge and experience in commercial aerospace and its powder-metal manufacturing capabilities with Addaero's technical expertise to produce aerospace-quality parts using various additive-manufacturing technologies.

Steel-Wire Manufacturer Opens in Indiana

Nippon Steel & Sumikin Cold Heading Wire Indiana officially opened its 150,000-square-foot steel-wire production facility in Shelbyville, Ind. The $50 million project is expected to create up to 70 jobs by 2021. The plant, parent company Nippon Steel & Sumitomo Metal Corp.'s first in the U.S. for its bar and wire rod unit, has an annual production capacity of 36,000 tons and is capable of manufacturing steel wires with a maximum diameter of 1.5 inches (40 mm).

INDUSTRY EVENTS

Sept. 25-28

Heat Treat Mexico 2018 – Advanced Thermal Processing Technology Conference and Expo; Queretaro, Mexico
www.asminternational.org

FNA 2018

Oct. 8-10

Furnaces North America 2018
Indianapolis, Ind.
www.furnacesnorthamerica.com

Oct. 8-10

IHEA Fall Seminars (Combustion, Induction and Safety Standards) – Combustion and Safety Standards on Oct. 8-10, Induction on Oct. 9; in conjunction with FNA 2018 in Indianapolis, Ind.
www.ihea.org/Fall18

Oct. 15-17

2018 Die Casting Congress & Exposition; Indianapolis, Ind.
www.diecasting.org

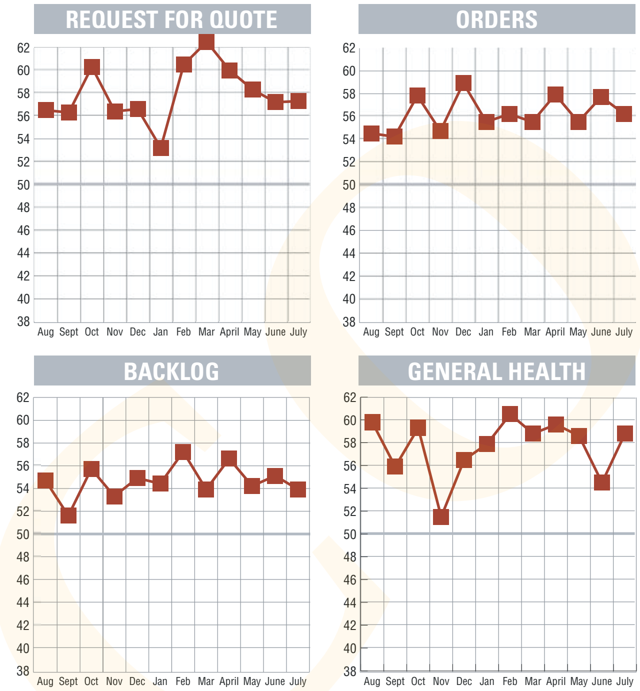
Oct. 28-Nov. 1

ISTFA 2018 – International Symposium for Testing and Failure Analysis; Phoenix, Ariz.
www.asminternational.org

Carpenter Technology to Open AM Technology Center in Alabama

Carpenter Technology Corp. announced plans to add an Emerging Technology Center on its Athens, Ala., campus. The facility will initially focus on additive-manufacturing (AM) technology development, with future investments slated for meltless titanium powder and soft magnetics. The company expects to invest $52 million in the Emerging Technology Center, which will create approximately 60 jobs over the next five years.

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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Risky Business: Vacuum Heat Treating of 3D-Printed Components

Fig. 1. Tensile specimens printed in various orientations to determine the effect on mechanical properties

Robert Hill – Solar Atmospheres of Western PA; Hermitage, Pa.

As additive manufacturing (AM), or 3D printing, continues to evolve, many challenges still plague this exciting new technology.

By remelting and re-solidifying metals in powder or wire form, each printing machine essentially becomes its own foundry. Therefore, precisely defining exact and repeatable mechanical characteristics of the uniquely printed components continues to be the major hurdle for the metallurgist (Fig. 1).

In addition, the vacuum heat treating of printed components is also evolving every day. Since additively manufactured parts display vastly different mechanical behaviors when compared to conventionally produced parts, it is logical that heat treatments associated with this process also vary. Since the majority of metallic printing processes involves high-temperature melting along with rapid cooling rates, parts typically possess extremely high internal stresses.

These inherent stresses can either be an advantage or a drawback to the design of the part. When internal stresses are detrimental to the end product, vacuum stress relieving seems to be the most prevalent and essential thermal process performed on 3D-printed parts. Other less-popular vacuum thermal processes include vacuum annealing and vacuum sintering.

Equipment Needed

As additive manufacturing continues to become more popular, the manufacturer will often contract with the commercial heat treater to perform the critical thermal processing for their jobs. The AM manufacturers continue to seek out only those facilities possessing a wide variety of vacuum furnaces. These furnaces (Fig. 2) must be equipped with diffusion pumps to attain deep vacuum levels and must exhibit extremely tight temperature uniformities (±5˚F).

Since the ultimate goal of printing any 3D component is to produce a part that is "near-net shaped," the vacuum-furnace atmosphere must be pristine. Surface contamination found on finished printed titanium or a nickel-based alloy part could deem the part scrap. Therefore, manufacturers will often insist that only expensive all-metal hot-zoned vacuum furnaces be used to process their parts. Vacuum heat treaters must heed the warning! One must determine the risks associated with such requirements. The main purpose of this article is to inform the heat-treating industry of some of the inherent dangers that we have encountered.

Dangers of Vacuum Heat Treating AM Parts

Direct-Metal Laser-Sintered Processing of Powders

Over the past two years, it is obvious that the direct-metal laser-sintered (DMLS) method of printing AM parts has become the most prevalent technology used in the world today. During this powder-bed-fusion process, a laser or electron

Fig. 2. Vital equipment needed for additive manufacturing: the vacuum furnace

HSCF The carbon fiber company

carbon graphite thermal insulation material

carbon fiber, carbon felt , graphite felt
rigid graphite board, Hot Zone, CFC

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Fig. 3. Titanium powder spewed and fused to molybdenum heating elements

Fig. 4. Internal views of a contaminated pump vs. a clean pump

beam is used to melt and fuse metallic powders together.

A layer, typically 0.1 mm thick of powder, is spread over the reusable build plate or platform. After a laser source fuses the first layer of powder, a new layer of powder is spread across the previous layer using a roller. Further layers or cross sections are fused and added until the entire model is created. Loose and unfused powder is inherent in this process and remains in position. It is imperative that all of this powder not only be removed from the obvious external surfaces, but also from all internal cavities, blind holes and cooling passages.

When these manufacturing precautions are not taken, the vacuum heat treater suffers. Figure 3 shows the resultant damage of vacuum heat treating of a DMLS-printed job that still contained loose powders within the builds. This was a very expensive mistake – a molybdenum hot zone that was severely damaged due to powders escaping from the internal cavities during heat treating. The corrective action is always to invert the plates, blow the entire build out with nitrogen and only process in all-metal hot zones DMLS-printed products that have no empty spaces within the solid build.

Binder-Jet Processing of Powders

The binder-jet process (BJP) utilizes two materials: metallic powders and a binder. The binder acts as an adhesive between the powder layers. After printing, the components are generally "de-lubed" within special atmospheric furnaces. It is within these furnaces where "most" of the binders are burned off or eliminated – but not entirely. Upon subsequent high-temperature vacuum-sintering treatments, the remaining binders immediately evolve and evaporate. These detrimental binders will seek to attach themselves to the coldest areas of the vacuum furnace, which are typically the water-cooled chamber or the pumping systems (Fig. 4). If one is planning to vacuum heat treat BJP-printed parts, a specifically designed vacuum furnace equipped with a cold trap to collect the unwanted binders is a necessity.

Additional AM Lessons Learned

The printing engineer must understand that the best results will be attained when the building platforms (or build plates) match the same material composition of the powder being adhered to it. In addition, the maximum thickness of the

Fig. 5. Crack due to improper match of printed cross section vs. build thickness

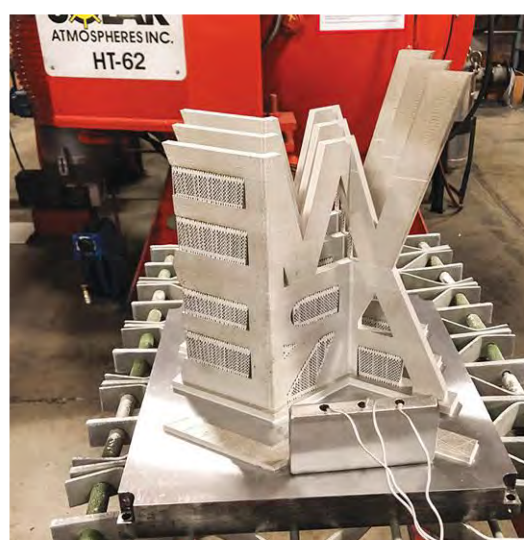

Fig. 6. Never thermocouple the build plate itself

printed part should closely resemble the thickness of the build plate. Matching build-plate compositions and dimensions helps to provide a more-stable, crack-free printed part (Fig. 5).

Additionally, it is most important to have direct thermocouple placement within the printed part. Since AM allows for any design, we often request a 1/16-inch minimum printed hole to be incorporated within the thickest cross section of the printed part. If that is not allowed then a predrilled matching maximum-thickness dummy block should be placed on top of the build plate (Fig. 6). The build plate itself typically will never match the temperature profile of the printed part. Thus, the build plate should never be drilled and wired.

Since printing metallic parts produces unique geometries, one must be very aware of any unvented blind holes, cavities, pockets or sealed cooling channels. Any differential-pressure forces that are built up during vacuum processing may cause a printed part to crack or even explode. Therefore, all printed internal geometries must have a clear path of evacuation.

Prior to vacuum processing any AM parts, the vacuum furnace should have been properly baked out at a minimum of 2400˚F (1316˚C), and the known leak rates should be less than 5 microns per hour. As previously noted, the stresses of many printed builds are immense. Always employ multiple setpoint temperature holds and slow heating and cooling rates.

Fig. 7. Weights strategically placed and used to creep flatten build plate

The customer will often contract the heat treater to creep flatten the build plate in conjunction with the prescribed heat treatment. This is done very carefully with additional weights (Fig. 7). However, never underestimate the value that you are adding to the customer. This plate creep-flattening service ultimately allows multiple reuses after the printed parts are excised from the plates.

Conclusion

While additive manufacturing continues to be a boon for specialized metal aerospace and medical-device components, other industries being somewhat affected by this transforming technology still may seem a way off. AM heat treating currently accounts for only 2% of this commercial heat treaters total heat-treat sales. However, this is 2% more than our total AM sales of the preceding two years!

The ultimate goal of any 3D process is reproducibility. If this can be controlled, it will drive down the cost of production and thus boost reliability. Vacuum heat treating is proving to play a very large role in the success of the entire AM process. As with any new technology, all downstream processors must learn to adapt. However, it is also imperative that certain known information critical to the thermal processing of the printed components gets communicated back to the customer. As we have witnessed, if this information is not shared, the heat treating of AM parts could become risky business.

For more information: Contact Robert Hill, FASM, president, Solar Atmospheres of Western PA, 30 Industrial Road, Hermitage, PA 16148; tel: 1-866-982-0660; fax: 1-724-982-0593; e-mail: info@solarwpa.com; web: www.solaratm.com.


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How Does AMS 2750E Impact Your Furnace Operation, Processes?

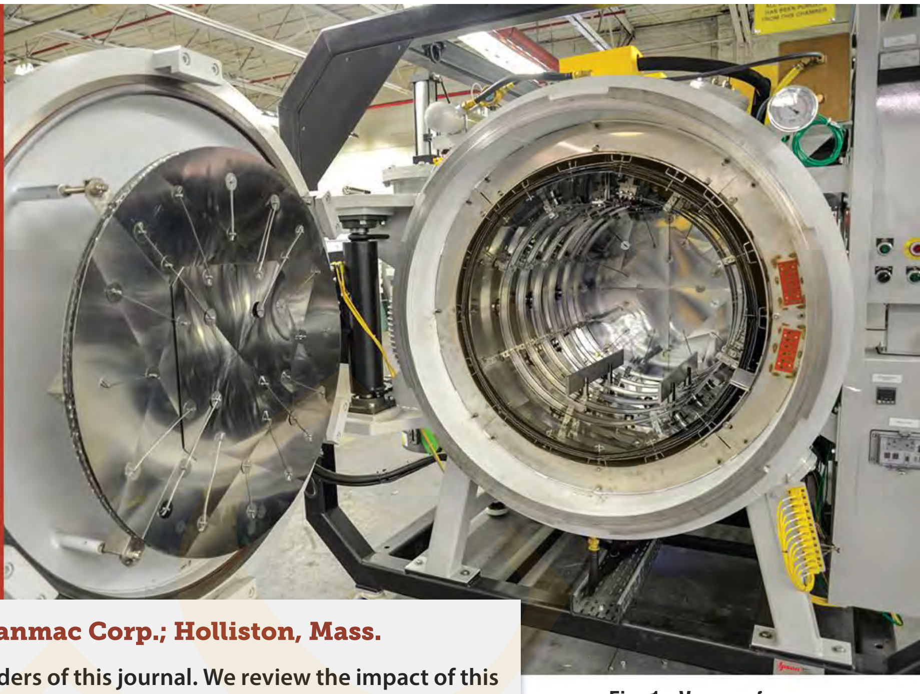

Fig. 1. Vacuum furnace

Herb Dwyer and Randy Clarksean – Nanmac Corp.; Holliston, Mass.

Questions about AMS 2750 are common for readers of this journal. We review the impact of this important pyrometry specification to help you deal with the complexities and unknowns in the high-temperature environment of sintering.

Operating and maintaining industrial heat-treating furnaces is complex and involved. Some factors that are vital to your process and furnace operations include:

1. Position and orientation of the thermal sensors
2. Type of thermal sensors used
   a. Type K is popular.
   b. Type T, R, N and even B are becoming more attractive for certain applications.
   c. Type C is becoming more popular as the sintering temperatures rise, and it still provides excellent accuracy over a much wider temperature range.
3. Range of processing temperatures and atmospheres at temperatures
4. Load density of the furnaces and resultant layering of parts
5. Pressure, vacuum and gas types used

The parts and materials undergoing heat treatment in these furnaces are very valuable. This value often exceeds tens or hundreds of thousands of dollars, which leaves no room for error in the operation of these furnaces.

The calibration of these furnaces for processing aviation-related parts is governed by AMS 2750E. AMS 2750E is very prescriptive and establishes requirements for the testing, use, number of cycles at temperature and reuse of the devices along with the specialized calibration of these complex furnaces.

Furnace Design

Meeting the strict requirements of AMS 2750E starts long before the furnace is turned on for the first time. The process begins at the start of the furnace design, which needs to meet the thermal-cycle range necessary for its type of payload. This may require the ability to ramp the temperature up at a specified rate, provide a controlled hold at a given temperature (e.g., debinding) and maintain a uniform temperature – all of this being performed with specified accuracy. The factors that come into play include:

- Size, location and type of heaters
- Atmosphere circulation and type of gas(s) and flow rates (if not a vacuum furnace)
- Insulation to prevent heat loss and non-uniform heating
- Accurate temperature measurements to characterize the heating process
- Placement of thermocouples to ensure temperature uniformity
- Materials of construction for the furnace
- Types and accuracy of the controllers
- Any algorithms used by the controller in reading the thermocouple temperatures or controlling the furnace

The accurate measurement of temperature is often assumed to be easy and taken for granted. In these high-temperature furnaces, though, the selection, location and operation of the thermocouples is of critical importance.

In a vacuum furnace, for example, radiative heat transfer is responsible for the heating of the temperature probe and the

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Roller Hearth Furnace

Tip-up Furnace

Tenova Inc. designs, supplies and delivers a wide range of innovative Tenova products to the North American market, including the cutting-edge heat treating furnace technology of Tenova LOI Thermprocess.

Heat treating furnace designs include batch and continuous type furnaces as well as complete heat treating lines. We specialize in installing quality furnaces to process plate, pipe, tube, bar, wire, forgings and strip.

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reported temperature. If a probe is placed too near a heating element, it will respond quickly to the heat applied to it. In the other extreme, if the thermocouple is placed behind a metallic support structure, the temperature it reports may lag the actual temperatures of the rest of the system. At steady-state operating conditions during a temperature hold, these issues are not much of a problem as long as there is uniform heating throughout the furnace. The temperature uniformity in the furnace is often controlled by fans and some type of circulation system.

In furnaces where there are recirculating flows, the placement of thermocouples needs to be considered as well. An example is the thermal response of a thermocouple placed in a region where gas flow will be more rapid than that of one hidden behind a support structure. Differences will also occur when an exposed-tip versus an ungrounded-sheath thermocouple is used. As before, once steady state has been reached and the thermal load in the furnace is held at a constant temperature, the variation in readings based on position can be less – as long as there is uniform heating and no regions of excessive heat loss from the furnace.

Thermocouple Selection

Under AMS 2750E, there are a number of applications and classifications listed in Table 1 as follows:

- Reference standard includes type R or S noble-metal thermocouples calibrated every five years.
- Primary standard also requires type R or S thermocouples calibrated every three years (accuracy +/-0.6°C or +/-0.1%).
- Secondary standard base-metal thermocouples calibrated every year (accuracy +/-1.1°C or +/-0.4%); type R or S calibrated before first use and recalibrated every two years (accuracy +/-1.0°C or +/-0.25%); type B calibrated every two years (accuracy +/-0.6°C or +/-0.5%).
- Temperature uniformity survey (TUS) accuracy for noble metal is +/-1.0°C or

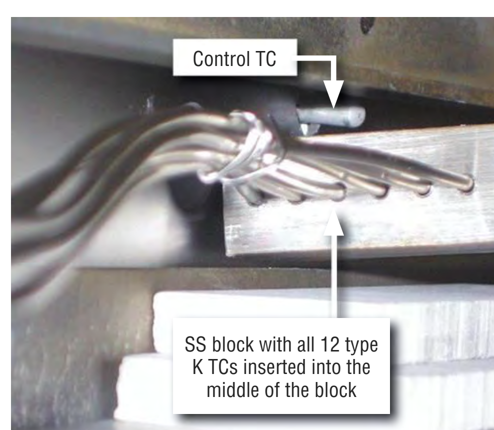

Fig. 2. Thermocouple survey block

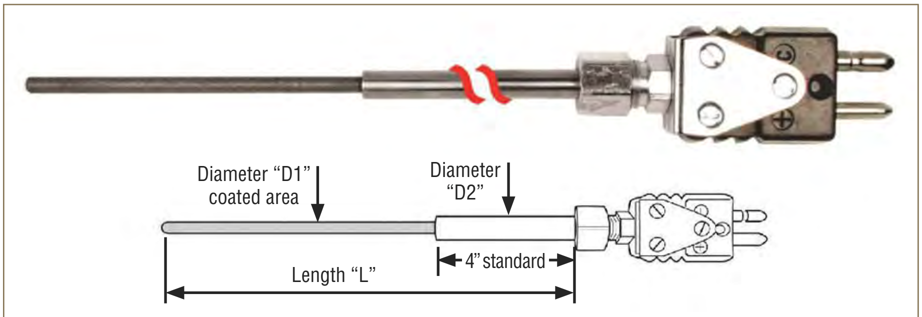

Fig. 3. Thermocouple detail

Fig. 4. Thermocouple in furnace wall

+/-0.25% for type R and D, and +/-0.5% for type B; system accuracy test (SAT) base-metal thermocouples calibrated every three months (+/-2.2˚C or +/-0.75%); type B, R and S calibrated before first use then recalibrated every six months thereafter (accuracy provided here); type E and K are NOT permitted to be used in these tests.

- Control, recording and monitoring system-accuracy tests (SAT) base-metal (accuracy class 1 and 2 +/-1.1˚C or +/-0.4%, class 3 to 6 +/-2.2˚C or +/-0.75%) or types B, R and S, calibrated before first use.
- Load base or types B, S and R (load-sensing LS) calibrated before first use; recalibrated every six months for types B, R and S (accuracy is +/-2.2˚C or +/-0.75%); other base metal not permitted.

Also see the various classifications for maximum-permissible error in Table 1 (ASM 2750) with error ranges provided.

What makes this even more complicated is the potential incorrect use of type K or similar TCs because these are subject (as stated in the AMS standard) to degradation, which depends on the maximum temperature-cycle exposures and can result in drift. Importantly, the AMS standard states that calibration above 1000˚C (1832˚F) reduces life just as use does.

Because of changing sintering profiles, the automatic acceptance of type K as *the* best TC is then questioned based on metal or metal matrixes used. The use of type K thermocouples in the correct location is acceptable if it does not function in a manner that is precluded by AMS 2750E and acts as the types of TCs used in Table 1 outlines. AMS 2750E restrictions on type K thermocouples should be carefully managed by the furnace user and designer.

The operating temperature range then becomes the key factor in selecting and using the correct thermocouple. The type K thermocouple has a usable range (per ASTM E230) of -270˚C to +1370˚C. It is a known fact, however, that performance of type K thermocouples are adversely impacted when regularly used above 1000˚C. The thermocouple alloys change with temperatures above 1000˚C. Therefore, the readings will also change.

Temperature Measurement

As we have already seen, the furnace design can impact the measured temperatures. Therefore, beyond the heat transfer and physics of the furnace itself, the temperatures need to be measured accurately. The accurate measurement of temperature ensures that the furnace payload receives the proper heat treatment.

The uncertainty of a temperature measurement is much more than just the calibration of a thermocouple probe or the wire itself. The total uncertainty of the measurement will depend on the uncertainty of the controller, the type of lead wire used between the furnace and controller, and potentially even the connectors used. Small errors can be introduced if there is a temperature gradient across the connector. These additional uncertainties can be very small, but when AMS 2750E requires TUS testing to have maximum errors of +/-4˚F (+/-2.2˚C), small uncertainties can add up quickly. Attention to detail is required.

In a recent study conducted jointly with a large vacuum furnace manufacturer, a series of thermocouples (type C) were mounted to a frame that would hold the parts that were being sintered up to 1650˚C (3000˚F). A summary of the observed outcomes is as follows:

- A variation of 1/8 to 1/4 inch in location of the thermocouple tip relative to surrounding structures had an impact.
- The type of ceramic insulator had an impact on the cross-furnace result (a measurement of more than eight thermocouple locations fixed to the frame).
- The assembled thermocouple-junction distance from the inside tip of the sheath had a measurable impact.
- As the gas atmospheres changed, the temperatures shown changed up to 4˚C between the various locations and in some cases more than 4˚C for the control and sensor TCs.
- Pressure and vacuum conditions also had an impact on the temperatures measured.

In this case, the manufacturer was working with a customer who required very accurate sintering of turbine blades used in aircraft turbines. While earlier than the recent Southwest incident, it was prescient in working to better control the sintering temperatures.

It was determined and shown that it was possible to improve the properties of these complex parts by addressing and improving furnace operations through design and the furnace measurement and control algorithms. This was accomplished by providing the furnace manufacturer-calibrated type C thermocouples that were accurate to within +/-0.4˚C of indicated temperature. Through this calibration, they were found to actually be better than the previously used type B and also had a wider operating range than the type B (800-1600˚C). The type C range was 300-2200˚C (572-3992˚F), allowing good measurements at the debinding range as well as the higher 1650˚C range.

Summary

To successfully meet the requirements of AMS 2750E requires a well-designed furnace and a thorough understanding of thermocouples and how they interact with the system. In particular, how can the operation of a thermocouple be impacted by its environment and change over time? The take-away from this article is to understand:

- The goal of AMS 2750E is to provide well-defined and characterized furnace operating conditions, which lead to the production of high-quality parts.
- The uncertainty of the temperature measurements in these furnaces depends on the wire; the probe design and connectors; lead wire if used; the accuracy of the controller; and any internal algorithms used by the controller.
- The location, selection and calibration of furnace thermocouples are critical to the successful operation of these furnaces.
- The physics of the heating that occurs within the furnace – vacuum-controlled or dependent on internal gas flow.

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Achieving Consistency and Reliability in Additive Manufacturing

Maintaining a checklist of your processes will help you achieve process uniformity.

Khalid Rafi – UL Global AM Center of Excellence; Singapore, JAPAN

This article outlines the essential steps that must be implemented for a laser-based, metal powder-bed fusion process to help ensure that products/components reliably meet specifications.

Additive manufacturing (AM) has evolved from a platform of simple prototypes to the production of mission-critical components for use in high-tech industries such as automotive, aerospace and medical.

But challenges with achieving a uniform product have delayed the implementation of additive manufacturing by other traditional manufacturing industries.

The need for reliable, consistent parts is just as critical today as it was in the early stages of the industrial revolution. Original equipment manufacturers (OEM) want to know with a high degree of certainty that when they manufacture a part – same design, same material and same machine model – at multiple places or multiple times, they will get the same finished properties.

For AM, reliability is dependent on one's machine, material and a robust or well-weathered procedure to carry out the process. With careful consideration, one can achieve consistency and quality with additive manufacturing time and time again.

Pre-Production Considerations

With more than 150 variables possible during the laser melting process, it is important to examine the possible variabilities and account for the ones that are easiest to control. Sources of variation include, but are not limited to, the optics of the machine; the material placed in the machine; placement and orientation of the part; and the build environment.

The following are some of the considerations you should have at different stages of setting up the process. As a best practice, maintain a checklist to capture potential issues.

Input Material

The input material (metal powder) has a significant impact on the success of the build, as well as on the quality of the printed part. The machine operator needs to ensure that the input material that will be used meets the requirements for the AM process – particle size distribution, density, chemical composition and flowability.

The component manufacturers usually procure the metal powder from the machine OEMs to maintain warranty conditions. However, powder may also be obtained from a third-party supplier to help offset costs. If you prefer to go with a third-party powder supplier, make sure the machine warranty will not be declared void in the event of an operating incident. Consult with and secure approval from the machine manufacturer prior to using any third-party material. They will help you determine if the powder meets the machine's requirements and has the characteristics required for AM.

Once you receive the material, review and document the details such as alloy designation, material vendor, the certificate of conformance/analysis or associated test reports.

Storage and Handling of Powder

The metal powder needs to be handled and stored properly once

Ensure your input material meets the machine's requirements and has the characteristics required for AM.

it is received from the vendor. Proper handling includes documentation of the powder batch number or the lot number, storing the powder in humidity-controlled conditions and keeping the powder in its original canisters.

You should also record the date when the canisters are opened. Accurate record keeping is crucial during all stages of the process because it will help ensure material traceability. The powder should be handled in a clean and moisture-free environment to avoid contamination and the accidental pickup of oxygen and hydrogen.

Follow all safety requirements while handling the powder because it not only may cause injury to the handler but it could also create a condition that could trigger an explosion due to particle cloud formation by ultra-fine particles.

The Safety Data Sheet (SDS), a document that provides detailed safety handling requirements for every powder material, is an essential point of reference for anyone working with potential hazards.

Input Material Characterization

Refer to the material data sheet supplied by the vendor because it provides the details of the characteristics of the powder supplied. Features include the minimum required attributes of the raw material.

However, the details provided by the vendor may not be comprehensive, so you will have to perform the powder characterization and document the results before the use of the powder in the machine.

Characterization of the input material will help you identify the material's chemical and physical properties, which can then be compared with the fabricated part's properties. Incorporating this action into your process allows you to evaluate the influence of any process characteristics.

Characterization includes a chemical analysis, determining the powder particle size distribution, powder morphology, density analysis and flow characteristics.

Additionally, stock material will need to be strained with a sieve to remove any agglomerates or impurities. Make sure the sieve mesh is corrected to the material's particle size to ensure proper sifting of the material.

Qualify Machine for Printing

Installation qualification ensures that the process equipment is compliant with the appropriate codes and approved parts' design intentions. To qualify your machine, you need to make sure the machine not only functions as it was intended to by the manufacturer but also that the machine's build environment is properly prepared for production as discussed here.

Machine Preparation

Starting with a clean machine is very important because leftover residue can stick to the machine, possibly contaminating the process and affecting subsequent builds.

Additionally, the presence of moisture in a machine can adversely affect the tensile strength of a product. Ensuring the machine is clean and dry is essential to the quality of the final printed part.

Select Build Plate

Select the correct thickness for the build plate to avoid issues of warping. You will also need to examine the build plate for any warping or deformity from the previous build. Ask yourself if the build plate is smooth. If yes, you are ready for the next step, which is to install the build plate over the build platform. Finally, you will need to document the dimensions of the build plate and its surface condition.

Utility Supply

Check to ensure you have enough gas to complete the operation process. Running out of gas in the middle of a build will adversely affect the final part.

Next, check for the proper flow of inert gas within the build chamber by properly setting the pressure gauge, the proper build plate temperature and the build-chamber ambient temperature.

Final Inspections

Examine the recoater. If the recoater blade is damaged, the powder will spread irregularly in

Sieving will remove any agglomerates or impurities from your material.

a non-uniform manner.

Verify that the powder is spreading homogeneously on the table. This exercise will have to be repeated for several layers to make sure it is covering correctly.

Next, inspect the oxygen sensor to determine if it is working correctly, then examine all other interfaces between your machine and your control software.

Finally, check the powder bin to ensure you have enough powder to complete the run. If you do not, the machine will stop abruptly and may not give you a consistent part.

In addition, make sure that equipment maintenance record, calibration record and preventive-maintenance schedule are maintained for ready reference.

Best Practice

By following a procedure you can identify the risks that could arise at each stage of the process. Document the risk and develop corresponding mitigation plans. The knowledge of how the variability at different processing steps affects the part quality is critical to refine your process and ensure quality at every step in the process.

Post-Processing Considerations

With post-processing, there are two significant actions to perform: retrieval of used powder and removal of the processed part; and heat treatment and finishing operations.

Powder Retrieval

Depending on the critical nature of the final application, you might be able to reuse leftover powder in future AM runs. In order to avoid confusion on the condition of the powder during the processing stages, categorize the powder conditions into four groups.

- Virgin powder: actual raw material you receive from the vendor
- Used powder from build chamber: the powder that just came out of the machine immediately after finishing the print
- Sieved powder: the powder that is taken out from the build chamber and sieved to remove any agglomerates or impurities
- Blended powder: a mix of virgin powder with the sieved powder

There are many opportunities for a mixup if you are not maintaining or storing the powder properly with correct labeling or proper bins.

If any of the powder gets mixed up, your entire process will be a mess because typically one cannot recognize between used, sieved, virgin or blended powder.

Additionally, storing all four categories of powder separately and properly labeled helps protect from contamination or accidental mixup in the future.

Heat Treatment

Before removing the part from the build plate, you must perform a stress-relief heat treatment. Failure to complete this will result in a deformed part. The key is heat treat, then remove.

Use an electrical discharge machining (EDM) or metal sawing operation to remove the part from the build plate, followed with the removal of support material from the part using hand tools.

Once you remove the part the real post-processing starts as the printed part may not have the required properties. You can achieve the required properties by doing another heat treatment based on the intended application.

The heat-treatment cycle, which is specific to each metal alloy, is highly dependent on the operation conditions where the part is going to be used. For example, the heat-treatment requirement is different for a titanium alloy when applied to aerospace or medical applications.

Best Practice

A heat-treat procedure needs to be in place that clearly explains the heat-treat cycle to be followed. The correct heat-treat cycle is specific to each metal alloy and highly dependent on the operational conditions in which the component is going to be used. It is essential to follow the specified heat-treat cycle to help ensure the quality and reliability of the final components.

Dimensional Tolerance

The next step is to determine if the part you printed has dimensions within the tolerance limits. With this step, you compare the printed part dimensions with the actual design. Are they in agreement?

Next, check the surface finish of the part by performing a surface-finish measurement and documenting the results. Be sure to check the surface finish from the top, on the vertical and the curved surface because the finish in all these regions will be different.

Finishing

Finishing operations such as machining, grinding, polishing, etc., may be performed to obtain the required surface finish. Document all the post-processing steps and make a note if the post-processing affected the final part in any manner.

Final Part Acceptance

Once the part is complete, it will need to be tested to determine if it has the right properties.

Acceptance activities can be performed by both destructive and nondestructive methods. Destructive methods include tensile, hardness, impact, compression, fatigue and metallography tests. Nondestructive methods consist of computer tomography, ultrasound, radiography, penetrant testing and eddy current.

Best Practice

Frame up an acceptance criteria before performing tests on the samples printed out during the qualification process.

Make sure the tests are performed according to established standards and the data is recorded in specified format. Nondestructive examination techniques can be used for verification of the final geometry and for evaluating defects in the parts. Keep an accurate record of the data because it will be the basis for actual part production.

Getting to uniformity means maintaining the process at all times. Referring to the checklist will help you stay on task, resulting in the best production process possible.

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Helium Leak Testing of Vacuum Brazing Furnaces: Troubleshooting Tips and Techniques to Minimize Downtime

Evan Sohm – ULVAC Technologies, Inc.; Methuen, Mass.

When large industrial vacuum brazing furnaces begin to produce customer parts that show discoloration instead of a pristine stainless steel finish or joints where the brazing material has refused to flow properly, production is quickly halted. Easy-to-find-and-fix leaks can take the furnace down for a half of a day, and more downtime is likely. The topics presented in this article will help make your next leak-checking search a quick and successful one.

Vacuum brazing furnaces, whether continuous in-line or batch machines, are large complicated systems that must be able to pump down to the required vacuum level to produce high-quality heat-treated parts (Fig. 1). It is important that these machines be vacuum-leak-free if they are to produce parts with void-free braze joints and flawless surface finishes. Ideally, these requirements would suggest that routine leak detection be a part of the regular maintenance schedule on these machines. Yet real-world production demands force some users to occasionally delay regularly scheduled preventive-maintenance tasks and instead operate their equipment to failure.

A poorly maintained vacuum heating furnace can have multiple problems, making troubleshooting that much more difficult. These concerns and operational issues apply to all types of vacuum heating furnaces, whether used for vacuum melting, sintering, quenching, annealing or tempering work.

Different Characteristics Between In-line vs. Batch Systems

An in-line vacuum furnace like the type shown in Figure 2 can have five individually pumped sections.

The preparation chamber is the entrance load-lock section of the in-line furnace. It contains the same vacuum hardware found in single-chamber batch systems (Fig. 3). Like a batch system, the preparation chamber is pumped from atmosphere to a required vacuum level each time a set of carriers is loaded. However, the three central chambers – preheating, heating and radiation – are able to remain under vacuum (and high temperatures) continuously. The gas-cooling chamber also functions as the exit load-lock chamber of the system, which means it is pumped from atmosphere to vacuum and vented back to atmosphere (just like the preparation chamber) for each set of carriers that are processed through the machine.

In a batch vacuum heating furnace (Fig. 3), this single

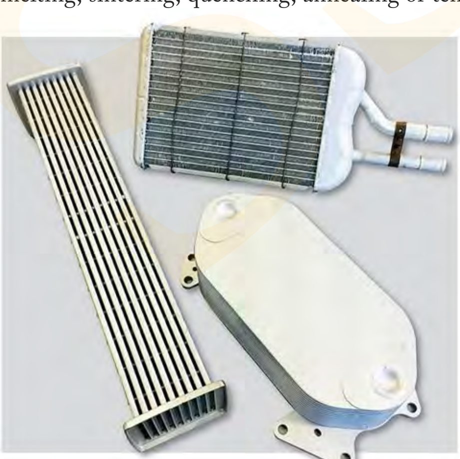

Fig. 1. Vacuum brazed components

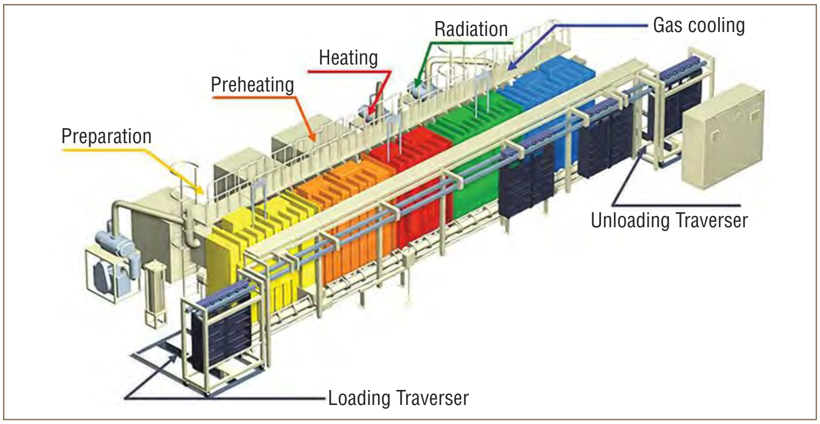

Fig. 2. A multi-chamber continuous in-line vacuum heating furnace

chamber is pumped, heated, cooled and vented all during the course of each run. As such, the mechanical and thermal stresses and strains on these single-chamber systems can be even greater than those experienced by larger in-line systems.

During periods of heavy production usage, it is quite likely that certain somewhat-obvious preventive-maintenance tasks – like a noisy bearing in a vacuum pump, leaking oil or a questionably operating water-flow switch, or an intermittently operating vacuum gauge – will be ignored in favor of "keeping the machine running production." This mindset can be risky because production can come to an absolute halt when parts begin to come out of the machine with defects. This unscheduled downtime becomes totally disruptive to factory output and causes a lot of unwanted excitement for the maintenance engineer.

Things that Can Go Wrong that Might Seem like a Vacuum Leak

Starting at the beginning of an industrial heating process, let's consider one troubleshooting example where the furnace will not pump down to the required vacuum level. In this case, the operator reports to the maintenance engineer that the machine may have a leak because it is either pumping too slowly or simply won't reach the required starting vacuum level. The maintenance engineer knows the mechanical pumps have been noisier than usual and begins to wonder if the oil in the rotary pump needs changing or possibly the mechanical booster pump is failing. What does the maintenance engineer do first?

The first thing he should do is change the rough vacuum gauge sensor head. Typically, these are Pirani-gauge sensors that have thin wire filaments inside that are subject to contamination and can break easily. Replacing this gauge is the single-fastest, least-expensive thing a

Fig. 3. A single-chamber batch vacuum heating furnace

Likelihood of pump problems	Zero	Ultimate vacuum level might be a little higher.	Pump may soon become damaged.	Trouble can occur.	Serious trouble can occur.
Take the following action	Do not bother to change the pump oil.	Pump is still okay. Maybe some water in the oil. Change oil soon.	Change pump oil now to prevent downtime.	Change/flush pump with new oil.	Time to rebuild this pump. Swap it out with a spare pump.

Pump oil color

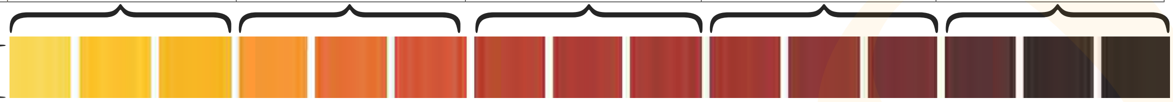

Fig. 4. Pump-oil color chart

maintenance engineer can do to try to rule out the possibility that the system is working fine and the problem is only that the vacuum gauge has become defective. If the system pumps properly with the replacement vacuum gauge installed, then the problem has been solved. The "bad vacuum" problem was a bad vacuum gauge – simple. If the replacement vacuum gauge doesn't fix the problem, however, it's time to look elsewhere.

The next step before bringing out the leak detector could be to perform a simple rate-of-rise test on the vacuum chamber. The procedure is easy. Just pump the unit as low as it will go, record the vacuum level and then close the valve to the pump and begin to record the chamber pressure (vacuum level) versus time from the moment the chamber is isolated from the pumps. The idea is to see if the pressure rises quickly, which could indicate the presence of a real leak.

A very useful idea is to benchmark the rate of rise of the vacuum chamber when the system is working normally. The rate of rise formula is $Q = (P_1 - P_0) \times V/t$, where:

P_0 (Torr) is the vacuum gauge reading when the valve to the pumps has closed.
P_1 (Torr) is the vacuum gauge reading after "t" seconds has elapsed after closing the valve to the pumps.
V (liters) is the volume of the vacuum chamber.

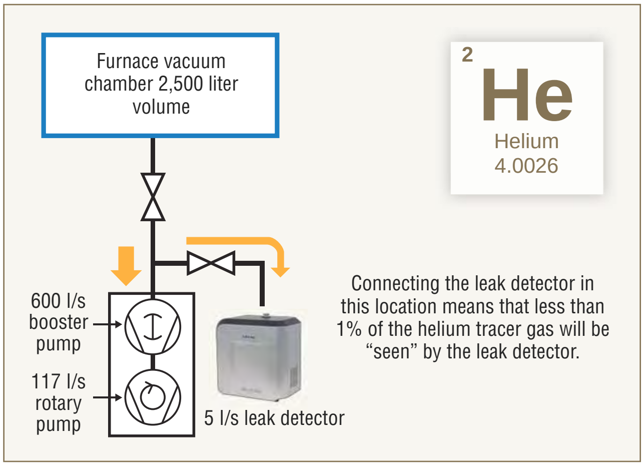

Fig. 5. Location of leak detector affects results

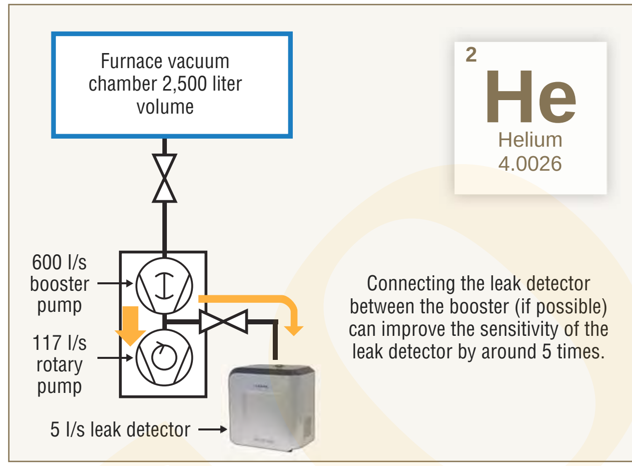

Fig. 6. Better location for leak detector

Q(Torr-liters/sec) is the rate of rise in the chamber that is caused by leaks and outgassing inside the vacuum chamber. This number is big if there is a leak and smaller if the measurement is mostly outgassing.

For example, a vacuum chamber with a 2,500-liter volume is evacuated to 3×10^{-3} Torr. The valve to the pump is closed. After one hour, the chamber pressure rises to a level of 1×10^{-2} Torr. What's the rate of rise?

Calculation: $Q = (1 \times 10^{-2} \text{ Torr} - 3 \times 10^{-3} \text{ Torr}) \times 2{,}500 \text{ liters}/3{,}600 \text{ seconds}$

$Q = 4.86 \times 10^{-3}$ Torr-liters/second

Because industrial furnaces are loaded with heating electrodes, thermocouples and thermal insulation – all of which outgas at considerable rates – there is no standard value of what an acceptably small leak rate is using this rate-of-rise test. The acceptable rate-of-rise value must be determined in advance for each individual chamber when it is known to be leak-tight. It is useful to run this test weekly to track the degree of outgassing and buildup of debris inside the heating chamber that can lead to poor vacuum levels without the presence of a real atmospheric vacuum leak.

It is important to mention the accepted truth that “everything leaks.” Even leak-tight vacuum chambers have permeation leaks, possibly some virtual leaks and definitely a considerable degree of outgassing that limit the ultimate pressure and slow the pumping speed of vacuum systems.

To limit outgassing (i.e., the release of contaminants on surfaces inside the vacuum chamber, such as cleaning solvents or moisture from the air), it is advisable to always keep the chamber door closed and the system pumped down whenever possible. The thermal insulation inside these chambers can be very hydroscopic, and pumping the humidity out of those materials can look as if there is a vacuum leak.

Be especially aware of this situation on hot, humid days in facilities that are not air-conditioned. These different types of “virtual leaks” are annoying in that they slow pumping times. However, the damaging leaks are the real atmospheric leaks that introduce oxygen and water vapor inside the heating chamber that can spoil the product in a heating run.

What to do After the System Passes the Rate-of-Rise Test

If the rate-of-rise test shows that the pressure in the chamber remains stable and low (but just not low enough), then there is a possibility the vacuum pump(s) could be faulty, which would also not be a vacuum leak but might look like one to the system operator. It's also possible the problem could be a leak in the vacuum piping (foreline) between the pumps or somewhere in the suction line leading from the pumps to the isolation valve.

To troubleshoot this section of the furnace (the pumps, vacuum lines and valves leading to the chamber), it helps if there are extra connection ports in those sections where a vacuum gauge or helium leak tester can be connected for testing. First, connect a vacuum gauge in the foreline and read the pressure. If the vacuum reading is bad in this line, you're close to finding the problem. Examine the pumps. Check their oil level and color.

Referring to the color chart in Figure 4, if the oil is dark, change it. If the oil appears to be the color of coffee with cream, there is very likely a lot of water in the oil. Water can accumulate in the pump oil over time when pumping atmosphere that is very humid.

During the hot, humid summer months, customers who don't regularly change their oil frequently report “pumping problems” because of the buildup of water in the oil. Simply draining the oil and replacing it with fresh oil will immediately solve this problem (which is also not a leak!). If the oil is fine in the pumps and if all the flange bolts, clamps and wingnut fittings are tight, then it is finally time to get out the helium leak detector.

Quick Tour of Helium Leak-Detector Operations

When a helium leak detector is connected to a vacuum chamber or line that is pumped by a large pump, the apparent sensitivity of the leak detector can be dramatically reduced because a lot of the helium that enters through the leak is pumped away by the large pumps before it's able to reach the leak detector (Fig. 5).

It's helpful to know the pumping speed of the system pumps compared with the pumping speed of the leak detector itself if the pumps can't be valved off (isolated) from the equipment being leak checked. If the ratio of pumping speed of the system pumps versus the leak-detector pumps is 10:1, then 90% of the helium tracer gas entering a leak will be removed by the system pumps, and only 10% of that helium will make its way into the leak detector, registering a leak. The apparent size of the leak will likewise be comparatively reduced by the same amount due to this reduction in signal-strength intensity. For this reason, it is a good idea to design a furnace system with a lot of test-port flanges and isolation valves throughout because building them in will greatly help when it is necessary to find a vacuum leak with a helium mass spectrometer leak detector.

Let's look at this relationship in a little more detail. The leak detector has a pumping speed at the test port of 2.5 liters per second, whereas the vacuum pumping system (mechanical-pump package) has a pumping speed of 2,400 cubic meters per hour, which is 40,000 liters/minute (667 liters per second). That ratio of 667 liters/sec to 2.5 liters/sec is 267:1.

This means 99.6% of the helium tracer gas that makes its way through the leak will be swallowed by the pumps, while only 0.4% of that helium tracer gas will find its way into the leak detector and get recorded as a "leak" signal. Connecting the leak detector to the wrong spot in the vacuum system could cause the operator to believe that a large leak is a much smaller one. For the leak detector to only record 0.4% of a 2×10^{-4} atm-cc/sec leak (a big leak) means it would display that leak size as being approximately 267 times smaller, or just 7.5×10^{-7} atm-cc/sec.

A better place to connect the leak detector would be between the booster pump and the oil rotary pump, if possible (Fig. 6). In that location, the pumping speed is 420 m^3/hour, or 7,000 l/minute or 117 l/sec. Compared with 2.5 l/sec speed from the leak detector, that ratio of pumping speeds is 47:1. This means a 2×10^{-4} atm-cc/sec leak would measure 4.3×10^{-6} atm-cc/sec. All these numbers mean that connecting the leak detector *between* the booster and oil rotary pump will give 5.7 times more sensitivity than connecting it up in front of the booster pump.

Of course, the best-case scenario is to have an isolation valve located just before the booster pump so the vacuum lines can be tested by the leak detector by itself, but few systems are so equipped. It turns out that most leaks do not occur in the vacuum piping but rather in the main vacuum chamber because there are so many more potential leak paths.

Vacuum leaks in chambers typically occur in areas such as feedthroughs of all sorts: water-cooling lines, heater feedthroughs, thermocouple feedthroughs and gas-inlet or rotary-drive feedthroughs. Other locations include but are not limited to the chamber door seal, valves, welds, bellows joints, threaded joints and other O-rings.

Big leaks can sometimes be found using alcohol and a spray bottle. Just spray the suspected leak area with alcohol and have the operator watch the Pirani gauge reading on the chamber. With luck, if the leak is large enough, the alcohol will weep into the vacuum chamber and instantly vaporize, causing a sudden and immediate jump in the rough vacuum gauge reading, indicating the location of the leak.

Knowing Your System Speeds Up Leak Detection

When attempting to locate a vacuum-chamber leak using a helium mass spectrometer leak detector, you should have an idea about the response time of the system, which will qualify that the leak detector is "working" and is able to sense the leak from where you have the detector installed on the system. Let's assume the leak detector is installed at the near end of the chamber.

At the far end of the system (or the far end of the chamber being tested), you should install a helium-calibrated standard leak with a valve. This way, with the chamber pumped down as far as it will go, the helium leak detector connected in test mode and all other valves closed, open the valve to the calibrated-standard leak, which introduces a known helium leak signal into the system.

It is important to understand the time lag required for the leak detector to register this leak (count the number of seconds it takes from opening the valve until the leak detector "sees" the leak). This way, you will know how long to wait between spraying suspect areas of the chamber until the leak detector should respond. Spray helium on the outside of the chamber.

Using a low-pressure spray pistol, begin spraying at the top of the system and work methodically down from there. It is very important to begin leak checking at the top of the chamber because helium floats. You might be testing joints that are leak tight if you were to start at the bottom, but the leak detector could start registering a leak, or an increase in the background leak signal, because the helium sprayed on the bottom of the system rises and can get pulled into a leak that is located higher up on the chamber. Set the spray pistol to deliver just a barely detectable puff of helium.

Less is more when leak checking with helium to avoid filling the room with helium, which will increase the background signal recording on the leak detector and reduce the chances of being able to detect very small leaks. Ideally, the response time of your system should be no more than a few seconds. Connecting the leak detector in the line between the booster and rotary pumps will very often shorten response time, making it the recommended location. Furnaces are full of insulation, which can slow the response time of the leak detector. Therefore, performing this check with a standard leak can be very useful. Also, compare the recorded leak rate with the value stamped on the standard leak to be sure these two values are known. They are almost always different.

Parts with Unexpected Colors can Provide Information

Industrial heating furnaces are unique in that the surface appearance of the parts they heat treat (or their carriers/fixtures/tooling) can be changed if the part is located in the system near the vicinity of an atmospheric air leak. Air leaks in furnace chambers admit oxygen, nitrogen gas and water vapor in high concentrations in the vicinity of the leak, which can color the parts that are located in that area of the furnace. These unwanted gas inlets (leaks) can lead to the formation of oxides, nitrides or hydroxides on the surface of the parts in that area of the furnace.

The spatial positioning of your off-color parts inside the system will give you a head start as to where to begin looking for a potential air leak in the vacuum chamber. Typically, blue staining of parts indicates an atmospheric air leak. The larger that leak, the darker the blue staining, which can range from very light to almost black in color. Yellow-stained parts can also indicate small air leaks. Greenish-stained parts tend to be caused not by air leaks but by excessive moisture in the chamber, either from leaving the chamber door open too long between runs on humid days (outgassing) or loading wet parts into the system. Of course, water leaks from cooling lines into the vacuum chamber would be another very real concern.

Find Leaks Fast, Keep Production Running

Leak testing of large, complicated industrial heat-treating machines can be a task very much like playing a challenging game of hide and seek. The question is, "Where's the leak?" The leak is often well hidden, and it is the maintenance engineer's job is to find it. Because the production clock is always ticking, it is imperative that you find the leak quickly.

By knowing the straightforward and simple interrelationships of vacuum-system performance and the vital signs of these systems – including chamber cleanliness, preventive-maintenance upkeep, pump-oil changes, vacuum-gauge condition, rate-of-rise measurements and part color or carrier condition – you can get a significant head start on finding any vacuum-system leak before you must resort to helium leak testing, which should always be your last option.

Unless the maintenance engineer is well-trained and experienced and understands the science and art of helium leak testing, it might be wise to contract a professional helium leak-testing company. It may be your most efficient way to find a tough leak quickly and keep production running.

For more information: Contact Evan Sohm, Director of Advanced Vacuum Technology for ULVAC Technologies, Inc., 401 Griffin Brook Drive, Methuen, MA 01844; tel: 978-686-7550 x244; fax: 978-689-6300; e-mail: esohm@us.ulvac.com; web: www.ulvac.com. Special thanks to Frank Mason of T.RAD North America for assistance with content of this article.

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Considerations for Choosing the Optimum Fixtures

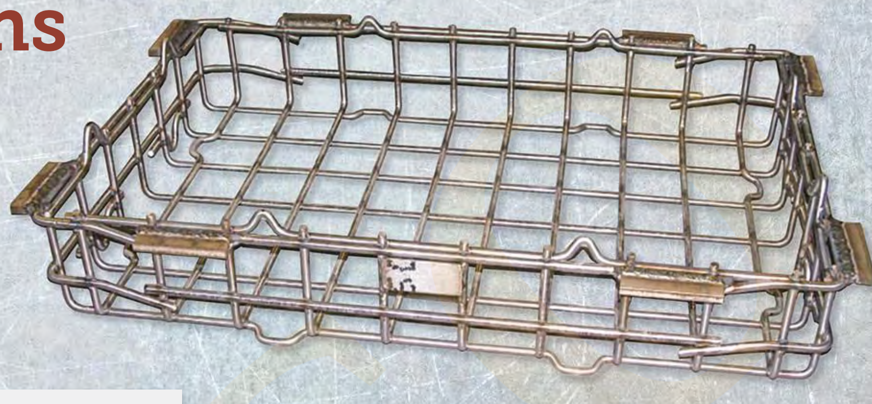


Fig. 1. Typical wire-bar heat-treating basket

Marc Glasser – Rolled Alloys; Temperance, Mich.

There are many types of heat-treating fixtures, trays, racks, boxes and other part holders in the market. They are generally castings, wrought fabrications or hybrids.

How is the heat treater supposed to decide which fixture is best? There is no easy answer. It is usually a combination of cost and design. Often, only initial cost is considered, and life-cycle costs are overlooked. Cost per pound of heat-treated product is a concept that gets almost no thought, but it should be a very important consideration.

There are distinct advantages of cast materials over wrought, and there are also distinct advantages of wrought materials over cast. Table 1[1] summarizes the pros and cons of each.

The most commonly referenced advantages of cast materials are a low cost per unit, the ability to add more of certain beneficial elements such as Cr and C, higher creep strength and the ability to be cast into complex shapes ready to be used.

Wrought alloys, on the other hand, can be used in much thinner sections, are repairable/weldable, resist thermal fatigue better and have better surface finish. The ability to use thinner sections can mean a lower-weight fixture and less BTUs to heat the fixture.

Baskets: Wrought and Cast

Baskets are one of the most common heat-treating fixtures. A typical basket is shown in Figure 1.[2] This simple basket, made entirely from wrought round bar, is commonly referred to as a wire-bar basket. This type of basket is used extensively in heat-treating facilities. For small parts like hardware, wire-mesh liners are inserted on all five sides to prevent parts from dropping into the furnace. Facilities will also use fully cast baskets or wrought-cast hybrid baskets.

Cast baskets and hybrids would require more material and therefore result in a heavier fixture. They would be used to support heavier loads than the wrought wire-bar basket can handle. The wrought basket with lower carbon and a grain structure has good thermal-shock resistance, which means it can be quenched and heated many times, whereas the cast basket will eventually crack from the thermal cycling.

The wrought basket will remain shock-resistant until a case is built up in case-hardening operations. The cast baskets, with their higher carbon, have better creep strength and therefore keep their shape better. However, they will show signs of cracking much sooner than wrought. The economics of expected service life and cost per pound to heat treat will be the key factors of the decision.

Trays

Trays often support heavier parts. This article discusses two traditional types of trays and a newer-design tray. The traditional tray is cast, consisting of straight legs connecting to round tubes.

A serpentine grid has snakelike bent pieces bordered by straight lengths, all held together with threaded round bar with nuts welded to each end. A gap is allowed at one end between the last straight section and the end nut so that the individual pieces can expand and contract freely without constraint. The serpentine grid can be fabricated from relatively thin sheet (11 gauge). Higher strength can be achieved by increasing the top-to-bottom grid thickness.

The final tray design is a honeycomb pattern made by Duraloy where each leg is relatively thick. As a result, this heavy-duty grid can hold heavier weights than the traditional cast grid. These grids are being seen in more heat-treat shops as a result of their ability to hold a lot of weight. These three trays are all shown in Figure 2.

Design

In both baskets and trays, an important design decision must be made about how thick the supports should be. The thicker the supports, the more weight the fixture should be able to hold.

Optimization

To get the most out of a fixture, however, consideration must be given to furnace capacity. Use of a tray with thick support members is not necessarily the best answer because a furnace has a weight-capacity limit. A fixture that is strong enough to support a lot of weight might not be able to do so because the weight of the fixture plus the weight of parts it can support is well above furnace capacity.

If you can't run a full load, the strength of the fixture is wasted. In reality, the optimum situation is to use the fixture with the highest utilization (i.e., best ratio of part weight to total weight as possible). Too small a fixture and the furnace can't be filled to near capacity; too heavy a fixture and the number of parts is limited. Too many furnace BTUs are being used to heat the fixture.

Damage

In many heat-treating shops, the forklift is the number-one cause of basket or fixture failure, especially when case-hardening operations are being performed. The high hardness of the cast tray combined with its cast microstructure and high carbon content tends to embrittle the fixture. It has high strength but low ductility and limited impact resistance. A wrought material will have good impact resistance until enough case is formed to through-carburize the microstructure.

Custom

The final type of fixture would be custom-designed. One common fixture is called a daisy wheel because of the shape of the grid. Once again, the use decision is based on the ability to support parts as well as the expected life. Cast fixtures have a tendency to split in the joint areas.

Welded wrought fixtures have more ductility and will not break as quickly in the welds. A wrought fixture is shown in Figure 3. Welds are evident, and most are holding up well. The broken areas can be re-welded.

One can also see stiffeners in this fixture. Stiffeners should be used with extreme caution. Stiffeners are often shielded from the heat, and they tend to heat up and cool down more slowly, creating thermal gradients. The stiffener will then restrict movement of other pieces. Such restrictions will cause material to bend, buckle, crack or a combination thereof. Stiffeners should be avoided unless some means of movement are provided.

Table 1. Advantages of wrought and cast alloy

	Cast	Wrought	
Initial cost	✖		Since cast parts avoid most fabrication techniques, the price per pound of a fixture could be lower.
Pattern cost		✖	A pattern must be made for each different cast part design. This is fine for production runs with thousands of parts but not very economical for one or two parts at a time.
Weight		✖	Cast parts are invariably thicker and heavier than the equivalent fabrication. This simply increases the dead weight that goes through each heat-treat cycle. With radiant tubes and muffles, thicker cast walls increase fuel costs for the same volume of work heat treated. Wrought alloys are available down to nearly foil thicknesses. Thinner sections often permit weight reductions of 50% or more.
Availability and delivery		✖	Wrought heat-resisting alloys are immediately available from stock in numerous product forms. Fabrications are quickly produced to minimize expensive downtime. When equipment is out of service, fabrications can be delivered in a couple of days to get back on line. This is rarely true of castings.
Shapes	✖		Certain shapes can be cast that are not commonly available as hot rolled or that cannot be fabricated economically from available wrought product forms.
Soundness		✖	Wrought materials are normally free of the internal and external defects such as shrink and porosity that are common problems in castings.
Composition	✖		Some alloys are available only as castings because they lack sufficient ductility to be worked into wrought forms. This is particularly true of the very high-chromium alloys.
Repairability		✖	To repair any stainless steel or nickel alloy, the material must have retained some amount of ductility. While cast parts can fail from corrosion, the most common failure is brittle cracking, making them very difficult to weld repair. Many cast alloys quickly become very brittle in service. They are unable to withstand rough handling when cold, and weld repair is very difficult.
Creep strength	✖		Similar compositions are inherently stronger at high temperatures in the cast forms over wrought grades. This is because of the microstructure, as well as the higher carbon contents that are typical in a casting.
Thermal fatigue		✖	Thinner sections reduce the amount of internal thermal stresses within the material. This allows for inherently greater ductility in wrought materials, which promotes better resistance to thermal cycling and thermal shock.
Surface finish		✖	The smooth surface of wrought alloy helps avoid focal points for accelerated corrosion by molten salts or carbon deposits.

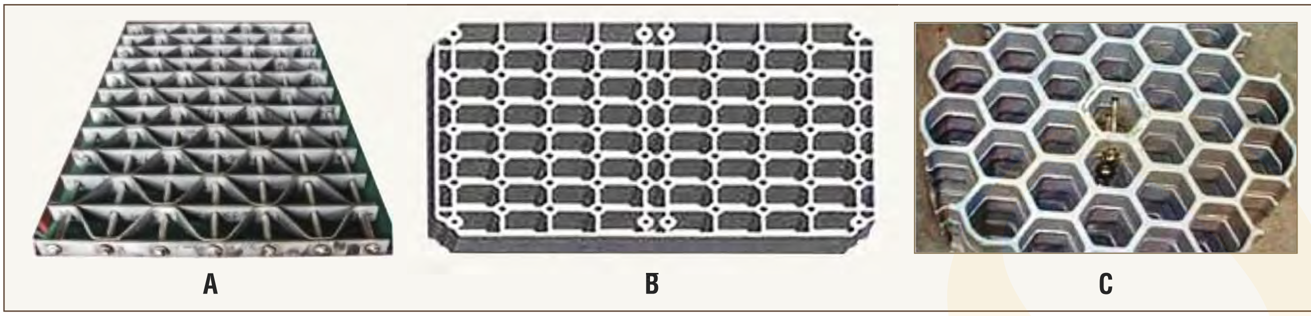


Fig. 2. Serpentine grid (A), typical cast tray (B) and new-design cast tray (C)

Materials

In the heat-treating industry, many fixtures and baskets are fabricated from RA330®, which is a very versatile alloy. It exhibits oxidation resistance to 2100˚F (1150˚C) and usable creep strength to at least 1800˚F (982˚C). Most steel heat treating is done below 1750˚F (954˚C), and many operations are done below 1600˚F (871˚C). Below 1600˚F, sigma phase forms in some fixture materials. At room temperature, sigma phase is quite brittle. Even slight impacts, such as hitting with a forklift, can cause failure. RA330 with 35% nominal nickel is immune to sigma-phase formation, as are nickel alloys with even higher nickel content.

RA330 is also resistant to surface-hardening operations like carburizing and nitriding. Over time, carbon and nitrogen will penetrate the protective oxide and diffuse into the base metal. As a general rule, RA330 fixtures will last approximately one year in carburizing atmospheres and should last longer in nitriding environments. They will warp from continued use. While cast fixtures will hold their shape better, they are more prone to crack sooner. Daily liquid quenching will make cast fixtures crack more rapidly. RA330 is resistant to thermal fatigue.

There are other options for wrought materials, but the cost is often higher than RA330. RA253 MA® is a stainless steel with very good creep strength, and it costs less than RA330. Because it is a stainless steel with less nickel, however, it is subject to sigma-phase embrittlement and will not offer much in the way of resistance to carburization or nitriding.

Fig. 3. Daisy-wheel fixture – a round shaft would go through the center and either be welded to a plate below or directly to the groove in the center.

If the fixture will only be used for neutral hardening in an inert atmosphere or vacuum, RA253 MA may be a good, cost-effective alternative. RA602 CA® has performed very well as a fixturing material for the highest-temperature vacuum heat-treating operations to temperatures just below 2300˚F (1260˚C).[3] This alloy has one of the highest creep strengths of all potential wrought products.

RA330 is still the most economical alloy for heat-treating fixtures. There are going to be occasions where a higher-strength alloy might be considered, particularly where final heat-treat part dimensions are critical and straightness specifications are tight. Other alloys could then be considered, and any such fixtures would be restricted to the one application. IH

For more information: Contact Marc Glasser at Rolled Alloys, 125 West Sterns Road, Temperance, MI; tel: 800-521-0332, e-mail: metallurgical-help@rolledalloys.com; web: www.rolledalloys.com. Various welding and fabrication manuals found on www.rolledalloys.com/technical-resources/ and from James Kelly's *Heat Resistant Alloys* were utilized. 602 CA® is a registered trademark of VDM Metals.

References

1. "Cast vs. Wrought." https://www.rolledalloys.com/technical-resources/fabrication-information/cast-vs-wrought/
2. Glasser, M., "RA330: Versatile Nickel-Based Alloy for Heat Treating," *Industrial Heating,* Sept. 2016
3. "RA 602 CA® Chosen for Heat Treat Baskets for Extreme High Temperature Vacuum Heat Treating." https://www.rolledalloys.com/shared/library/case-histories/RA-602-CA-Chosen-for-Heat-Treat-Baskets_CH_US_EN.pdf

Furnaces North America 2018 • Oct. 8-10 • Indianapolis, Ind.

2018 will mark the 13th Furnaces North America (FNA) produced by the Metal Treating Institute and its media partner, *Industrial Heating*. Established in 1995, FNA has become synonymous with bringing top suppliers and heat treaters, both captive and commercial, from around the world to one location for technical education, networking and the latest developments in furnace equipment, accessories and services.

Held Oct. 8-10 at the Indiana Convention Center in Indianapolis, FNA 2018 is a truly global event, with heat treaters and suppliers from nearly 40 states and over 17 countries expected to be in attendance. This year's event will offer 35 technical sessions, a featured keynote speaker, a two-day trade show with over 170 exhibitors and two high-energy networking sessions.

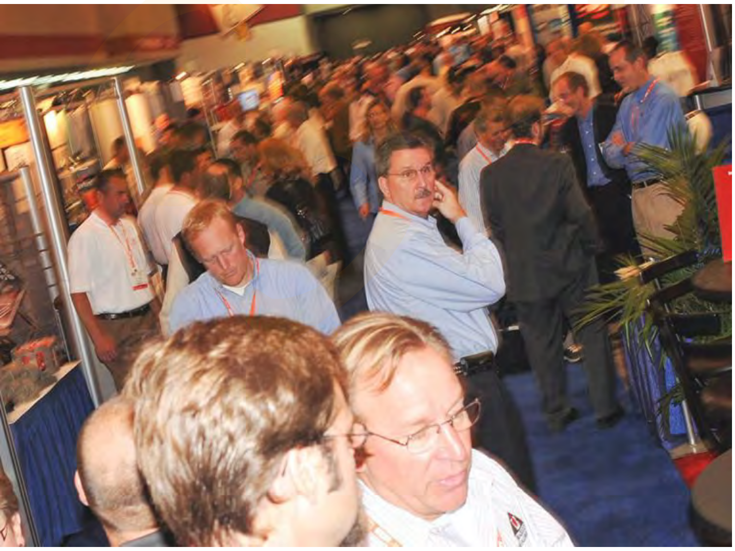
The educational program at FNA 2018 features content on the latest technology and trends shaping the industry. Designed by a team of heat treaters and suppliers, sessions include 10 technical tracks: Productivity & Data; FNC/Nitriding; Emerging Technologies; Maintenance; Heat-Treat Business; Quenching and Cooling; Processes; Equipment; Standards & Pyrometry; and Controls and Materials.

On the show floor, heat treaters and suppliers connect to learn about each other, what heat treaters are challenged with and how suppliers can solve those issues. With top suppliers from every facet of thermal processing exhibiting, FNA's two-day exposition is a must for any owner, general manager, plant manager or manager in maintenance, quality or production. FNA 2018 encourages companies to bring their key management team to help introduce them firsthand to the new technologies shaping the future of heat treating.

FNA 2018 attendees will also experience a set of exciting social functions that allow heat treaters to connect with one another to discuss the new ideas they learn about throughout the conference. FNA social events help suppliers get away from the trade-show booth and listen to heat treaters' needs in a more informal environment.

Show/Technology Profiles

Pages 68-76 serve as profiles for companies that will be exhibiting at FNA 2018 … and for some that will not be in attendance. Get a look at what these businesses have to offer and what they will be showcasing at their booths in Indianapolis.



SCHEDULE

MONDAY, OCT. 8	
7:00 a.m.-6:00 p.m.	Registration and badge pickup
7:00 a.m.-6:00 p.m.	Exhibitor move-in
6:00-8:00 p.m.	Welcome reception
TUESDAY, OCT. 9	
7:00 a.m.-5:00 p.m.	Registration and badge pickup
8:00-11:15 a.m.	Technical sessions
11:15 a.m.-5:30 p.m.	FNA 2018 business expo
4:00-5:00 p.m.	Trade-show floor reception
WEDNESDAY, OCT. 10	
7:00 a.m.-1:30 p.m.	Registration and badge pickup
7:00-7:45 a.m.	MTI annual business meeting (MTI members only)
10:45 a.m.-2:30 p.m.	FNA 2018 business expo
2:30-10:00 p.m.	Exhibitor move-out
6:00-11:00 p.m.	MTI final night dinner (MTI members only)

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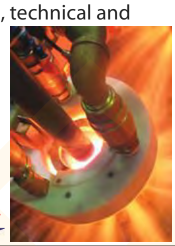

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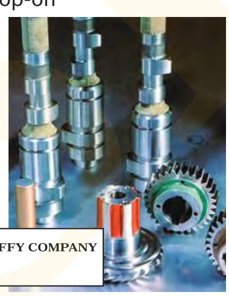

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Induction Tooling Inc.

Booth #327

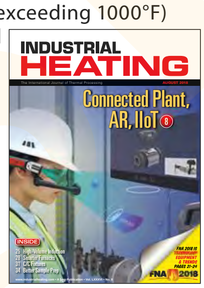
Since opening our doors in 1976, Induction Tooling Inc. has evolved into the premier manufacturer of selective hardening inductors, bus bars, quenches and modular quick disconnect induction products. We supply the commercial and captive heat-treat industry, automotive, aerospace, mining, wind energy, agricultural, medical and large equipment manufacturers. We specialize in bearings, gears and driveline components. Our decades of experience and diverse expertise make us a trusted resource. We have expanded that expertise into induction process development with a fully equipped commercial metallurgical laboratory that is ISO 17025 certified. **www.inductiontooling.com**

INDUCTION TOOLING, INC.

***Industrial Heating* Magazine**

Booth #624

Industrial Heating is the world's largest and most comprehensive integrated media resource focusing on high-temperature (applications exceeding 1000°F) thermal-processing technology and practical applications. Visit our booth to pick up a copy of our September and October issues and/or to subscribe to our publication. Please stop by if you have any questions or if you just want to see what Industrial Heating has to offer. **www.industrialheating.com**



INDUSTRIAL HEATING

Ipsen

Advanced Engineering Solutions

Booth #301-303

Ipsen's Engineering Team has the experience and resources to design and manufacture innovative, highly technical atmosphere and vacuum solutions that allow our customers to perform virtually any specialized job. Our commitment to delivering quality solutions extends to every project, regardless of scope – from developing proprietary software and controls to taking in-field measurements, designing upgrades and retrofits (including custom-engineered solutions for non-Ipsen equipment) and assisting with technical support inquiries. **www.ipsenusa.com**

Irwin Car and Equipment

Ph: 724 864-8900

Irwin Car has custom furnace cars for environments up to 1200°F and car bottoms for 2300°F and over temperatures. Products include standard/extra-high-temperature wheel assemblies, transfer and mobile quench cars with capacities from 20-500 tons. With more than 15,000 wheel/assembly/car designs in service, we've likely solved your problem.
www.irwincar.com

IRWIN
IRWIN CAR AND EQUIPMENT

Kanthal, Part of Sandvik Group

Booth #502-504

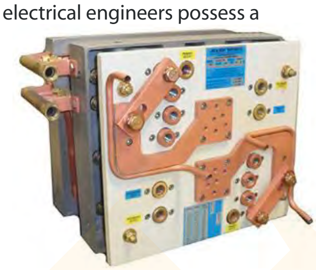
Kanthal® is the world leader in providing a complete portfolio of heating elements and modular heating systems for high-temperature applications ranging from medical to renewable energy. Our product portfolio of metallic, silicon carbide Globar® and Kanthal® Super molybdenum disilicide heating elements covers applications to 3360°F. Kanthal® now produces the world's highest-temperature electric air flow heater (up to 2012°F). Other recent product developments include new product forms (tubes, plates, bars) and components for high-temperature process systems such as furnace rollers, kiln furniture and retorts for PM sintering.
www.kanthal.com

Jackson Transformer

Booth #433

Jackson Transformer is an ISO 9001:2008-registered company that has been developing, designing and manufacturing a wide variety of air-cooled and water-cooled magnetic products since 1955. Our electrical engineers possess a combined experience of more than 125 years in magnetics. Our products include transformers, chokes, and AC and DC reactors.
www.jacksontransformer.com

JACKSON TRANSFORMER CO.
Quality Magnetic Products



Karl Dungs Inc.

Booth #143

Karl Dungs Inc. of Blaine, Minn., will be displaying our MPA41 family of flame safety products at FNA 2018. The MPA, a programmable, microprocessor-based burner control, is extremely flexible and can be programmed for nearly every type of industrial burner application. The MPA is also designed for use with multiple types of flame monitoring – including flame rod, UV scanner, or self-check UV scanner – using the same basic control. Please stop by Booth 143 at FNA for more information on the MPA.
www.dungs.com

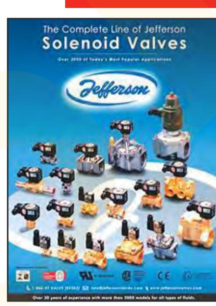
DUNGS®
Combustion Controls

Jefferson Solenoid Valves

Ph: 305 249-8120

Solenoid Valves
Jefferson Solenoid Valves offers over 3,000 different valves for applications such as boilers, burners, cooling towers and many others. We also offer a diverse range of liquids and gases such as water, air, steam, oils, oxygen, liquid nitrogen, corrosive fluids and many others. Our products have approvals in accordance with UL 429, UL Hazardous Locations, CSA and is ISO 9001 certified. **www.jeffersonvalves.com**

Jefferson



L&L Special Furnace Co.

Booth #216

L&L Special Furnace Co. is the leader in high-uniformity batch furnaces, ovens, kilns, quench tanks and heat-treating systems. All manufacturing and engineering is done in-house from one location just south of Philadelphia, Pa. L&L sells and services worldwide.
www.llfurnace.com

L&L Special
FURNACE CO, INC

JPW Industrial Ovens & Furnaces

Ph: 570 995-5025

JPW is a manufacturer of industrial ovens and furnaces for markets such as aerospace, medical, finishing and heat treating. JPW's mission is to offer the right solution at the right price, whether it is a standard offering or solution-based. We offer a selection of standard batch ovens with temperature ranges up to 1400°F and continue to evolve through our diverse offerings for batch, continuous and solution-based heat-process systems. We look forward to solving customer challenges.
www.jpwdesign.com

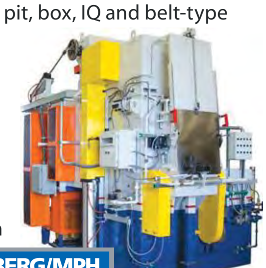
JPW INDUSTRIAL OVENS & FURNACES

Lindberg/MPH

Booth #411

Lindberg/MPH is a leading manufacturer of standard and custom industrial heat-treat furnaces. Their line of furnaces includes pit, box, IQ and belt-type designs for the ferrous and nonferrous markets. In addition to heat-treat furnaces, Lindberg/MPH designs and manufactures a full line of melting and holding furnaces for nonferrous alloys. Nonferrous melting and holding equipment designs offered include wet hearth melting, stack melters, dry hearth, crucible/pot melting, aluminum holding and autoladle dosing.
www.lindbergmph.com

LINDBERG/MPH



National Element Inc.

Ph: 800 600-5511

Since 1960, National Element Inc. has partnered with major manufacturers to create solutions for their industrial heating needs. We customize products to perform in a diverse variety of furnaces. National Element Inc. supports a full line of industrial electric heating elements. Our 30,000-square-foot manufacturing facility in Brighton, Mich., includes fabrication, machine, welding and a large inventory of resistance alloys – from standard to custom-engineered for the heat-treating industry. **www.nationalelement.com**

National Element
American Industrial Heat Engineers

Nel Hydrogen

Booth #139

Nel Hydrogen is a global company dedicated to delivering optimal solutions to produce, store and distribute hydrogen. We serve industrial, energy and gas companies with leading hydrogen technologies. Nel Hydrogen provides solutions that meet global hydrogen requirements for material-processing applications including powder metallurgy, MIM, heat treating, thermal spray and float glass manufacturing. With more than 3,500 reliable, cost-efficient electrolysers installed around the globe, Nel Hydrogen is the recognized leader of alkaline and proton exchange membrane (PEM) water electrolysers. **www.nelhydrogen.com**

Pfeiffer Vacuum

Booth #523

Rugged, Fast Leak Detection

The Pfeiffer Vacuum ASM 340 is an easy-to-use, high-performance and durable leak detector providing short cycle times and high throughput. It performs helium and hydrogen leak detection with sensitivity down to $5x10^{-12}$ mbar l/s in vacuum mode and $5x10^{-9}$ mbar l/s in sniffing mode. Featuring a vibrant color touch-panel display with SD card, the detector is easy to set up and use. A wireless remote control enables operation from a distance of up to 330 feet. The ASM 340 comes with an outstanding two-year warranty. Come see the ASM 340 at our booth. **www.pfeiffer-vacuum.com**

PFEIFFER VACUUM

Praxair Inc.

Booth #241

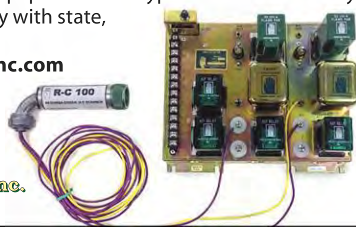
Praxair Inc. is a leading industrial gas company in North and South America and one of the largest worldwide. Praxair produces, sells and distributes atmospheric, process and specialty gases, as well as high-performance surface coatings. Praxair will feature atmosphere technologies that will provide attendees a better understanding of protective furnace atmospheres, gas flow optimization, and the integration of proper gas supply and gas flow control. Praxair's industrial gases are key components of metal production and metal-processing applications like heat treating, annealing and inerting. **www.praxair.com**

Protection Controls Inc.

Booth #137

Protection Controls Inc. has been manufacturing electrical safety equipment for over 61 years. We have a complete line of single and multiple burner PROTECTOFIER combustion safeguards for supervision of fuel-fired burners in industrial process-heating equipment. This type of electronic safety control is required to comply with state, local and national codes.

www.protectioncontrolsinc.com



Protection Controls, Inc.
Electrical Flame Safety Equipment

Safe Cronite

Booth #105-107

North American Cronite, a division of Safe Cronite, is a manufacturer and designer of cast and fabricated heat-resistant alloy furnace parts. The company specializes in handling fixtures, cast base trays and baskets, radiant tubes, rolls and corrugated boxes.

www.safe-cronite.us

Safe Cronite
L'esprit industriel

PVT Inc.

Booth #117

PVT Inc., an Inductotherm Group Company, features its third generation of software controls specifically designed for aerospace applications on all of its new vacuum aluminum brazing systems. The state-of-the-art controls provide enhanced recipe options, customization and input on a reliable, consistent and serviceable platform. This, combined with five decades of furnace manufacturing experience, results in a robust Class 1, Type 2 furnace that has the temperature uniformity, quick crossover and deepest vacuum for the most demanding aluminum heat exchanger and cold plate brazing applications. **www.pvt-vf.com**

SBS Corp.

Booth #332

For over 40 years, SBS Corp. has supplied cutting-edge technology in the development of equipment designed specifically for the rigorous needs of the heat-treating industry, including quench oil coolers, quench oil filters, oil moisture monitoring instruments and endothermic gas coolers. Every product offered is made in America by workers who care about building the finest equipment in the world. SBS Corporation exports to over 20 countries and now offers the CE mark on all of its products.

www.sbscorporation.com

SBS CORPORATION

Qual-Fab, Inc.

Booth #532

Qual-Fab, Inc. is a custom fabricator specializing in the fabrication of high-quality products utilizing high-nickel and stainless steel alloys. We offer a variety of products, including fabricated muffles (flat and corrugated), carburizing retorts, heater tubes and fans. Our fabrication facility and capabilities allow us to manufacture some of the largest and longest products available.

www.qual-fab.net

SECO/WARWICK

Booth #426-428

If you are looking for state-of-the-art industrial heat-treating furnaces, as well as the peace of mind that you'll have a fully committed team behind you to service and maintain that equipment, then SECO/WARWICK Corp. should be on your list of stops. Supplying vacuum, atmosphere, aluminum melting and controlled atmosphere brazing equipment, SECO/WARWICK is one of the leading suppliers of heat-treating equipment around the globe. Our local service capabilities give you additional peace of mind.

www.secowarwick.com

Russells Technical Products

Booth #417

Russells Technical Products is a global supplier of environmental test systems. We offer heavy-duty industrial mechanical refrigeration freezers that cool to -120°F (-85°C) and heavy-duty industrial liquid nitrogen freezers (LN2) that cool to -300°F (-185°C) for ultra-cold applications. Standard sizes are available from 15 to 60 cubic feet … or Russells can custom-design a freezer to meet your exact needs.

www.russells-tech.com

SKAKO VIBRATION A/S

Ph: 260 450-1754

SKAKO VIBRATION is a highly professional and experienced business partner, specializing in the design, development, supply and marketing of vibratory equipment, which activates, transports and separates bulk solids. SKAKO is the leader in vibratory equipment and systems for heat-treatment lines. Our proven systems provide for gentle and efficient handling, including highly interlocking parts. The programmable SKAKO Weigh System offers process optimization through controlled feeding and dosing.

www.skako.com

Solar Manufacturing

Booth #211-213

Solar Manufacturing has led the heat-treating industry with advances in hot zone designs, improved energy efficiency, state-of-the-art furnace controls and high-performance gas quenching. We continually strive to improve thermal efficiencies and extend the service longevity of our furnaces. We will have our compact, economical Mentor® furnace on display at FNA 2018.

www.solarmfg.com

SOLAR MANUFACTURING

Super Systems Inc.

Booth #201-203

Your trusted leader in heat-treat control solutions is improving shop-floor decision making again, now with cutting-edge mobile applications. SuperDATA PRO and its suite of products provide access to notes, process data and load information on mobile devices. Mobile charting provides up-to-the-second data in tabular and chart format with the ability to view historical information and chart notes. Whether you are implementing a SCADA package or are an existing SuperDATA customer, call 513-772-0060 or visit Booth 201-203 at FNA 2018 to get more details on how to take advantage of this functionality. **www.supersystems.com**

SuperSystems

Surface Combustion

Booth #200-202

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. Surface strives to build customer relationships that endure long after the initial equipment purchase. When you require a thermal-processing partner who can draw from a broad portfolio of proven designs, including pioneering atmosphere and vacuum products, let us show you the Value of Surface.

www.surfacecombustion.com

Surface Combustion

T-M Vacuum Products

Ph: 856 829-2000

A pioneer in the high-vacuum heat-treating industry, T-M has been manufacturing high-vacuum furnaces and ovens since 1965. Our furnaces come in a range of work-zone sizes ranging from 2-36 cubic feet with operating temperatures up to 2000°C (3632°F) with +/-3°C temperature uniformity and vacuum/pressure levels to 10^{-8} torr/6 bar. Our furnace systems come with full computer control, and our ovens come with PLC/color touch-screen interface control.

www.tmvacuum.com

TAV VACUUM FURNACES

Booth #238

TAV VACUUM FURNACES designs and manufactures top-quality vacuum furnaces for a wide range of industries and applications worldwide, always focusing on constant innovation and following the most stringent criteria and procedures to ensure high-temperature uniformity. Our customers are the leading companies in the aerospace, automotive, commercial heat treatment, gas turbine and additive-manufacturing industries and the most prestigious R&D laboratories. For more information, please visit our booth at FNA. **www.furna.care**

TAV VACUUM FURNACES

VAC AERO International Inc.

Booth #337

VAC AERO INTERNATIONAL INC.

VAC AERO designs and builds vacuum furnace systems and controls with the highest quality standards that will fulfill any of your specialized processing needs. From small horizontal laboratory units to large vertical models, VAC AERO vacuum furnaces are ideal for a broad range of vacuum-processing applications of specialty alloys and engineered materials. VAC AERO vacuum furnaces operate worldwide in diverse applications in aerospace, power generation, medical, nuclear, tool & die, research and other high-tech industries. **www.vacaero.com**

Tenova Inc.

Booth #126

Tenova Inc. designs and supplies advanced heat-treating furnaces for plate, pipe, wire, strip steel, forgings and specialty applications. We also provide a complete range of dedicated technical services, including equipment upgrades and revamps, studies, tune-ups, energy audits, automation system upgrades and spare parts. **www.tenovacore.com**

tenova

Wisconsin Oven Corp.

Booth #413

Wisconsin Oven Corp. has been designing, engineering and manufacturing industrial ovens, furnaces and other heating equipment since 1973. Their custom and standard equipment are available in batch and continuous designs and are used for a multitude of applications, including metal finishing, preheating, composite curing, drying, aging, heat treating and shrink-fitting. Many of the industries they serve require specific temperature uniformity and equipment performance documentation. Their experienced design team is able to meet even the most stringent standards. **www.wisoven.com**

Thermcraft, Inc.

Booth #122

Thermcraft is an international leading manufacturer of custom industrial furnaces and ovens. With over 43 years of experience, we can help you find the solution that best fits your needs. From concept to finished product, whether it is a pilot-scale project or full-blown production project, we can guide you through the entire process. Thermcraft also manufactures component heating elements in vacuum-formed ceramic fiber and ceramic refractory materials, both for high-temperature applications. **www.thermcraftinc.com**

WS Thermal Process Technology Inc.

Booth #218

Recognizing deficiencies of conventional gas burners, WS developed the REKUMAT® high-velocity self-recuperative burner series. Ranging from 15,000 to 1,100,000 BTU/hr, REKUMAT® burners are equipped with integrated heat exchangers of either metallic or ceramic composition. The burners' recuperators use hot exhaust gases to preheat combustion air and can thereby achieve efficiencies up to 75% LHV. Our newest development is the patented gap flow recuperator, enabling efficiencies up to 90% LHV. **www.flox.com**

WS Thermal Process Technology

Thermocouple Technology

Ph: 215 529-9394

Thermocouple Technology (TTEC) is an experienced group of professionals dedicated to providing precision temperature measurement and control devices across all industries. Our pledge is to provide our customers with reliable products that exceed accuracy and quality standards while providing industry-leading customer service and lead times. TTEC's wealth of engineering and design resources ensure that we can provide you with an optimal solution for your application. **www.tteconline.com**

York Wire & Cable, Inc.

Booth #445

Since our beginning in 1987, we have been a global leader in high-temperature lead wire and thermocouple wire. We also offer other types of electrical wire and cable – everything from fiberglass sleeves to portable power cable, welding cable, RTD wire and thermocouple conductors. York Wire & Cable serves all industry sectors, including military, OEMs, aerospace, energy, automotive, government, shipbuilding and manufacturing. Our products can be found in every industry sector located around the world. **www.yorkwire.com**

YORK Wire & Cable, Inc.

Induction Heaters

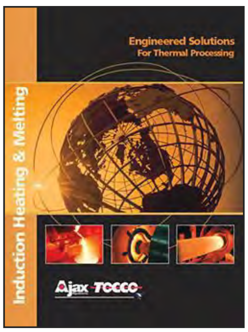
Across International

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

Vacuum/Atmosphere Furnaces

C.I. Hayes, A Gasbarre Furnace Group Co.

Since 1905, C.I. Hayes designs, manufactures and services heat-treating equipment to meet a wide range of thermal-processing needs. Our vacuum line features modular heating and quenching (oil or pressure), batch and continuous furnaces. Our atmosphere line features conveyor belt, humpback, pusher and tube furnaces. Common applications include: annealing, brazing, carburizing, hardening and tempering. www.cihayesfurnace.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

Advanced Roller-Hearth Technology

CMI Industry Americas Inc.

Industrial furnace manufacturer offering EPC contracts focused on complete shop erection. Our company is part of an international group with over 3,500 employees. We offer the most advanced roller-hearth technology for bright annealing, normalizing and stress-relief anneal, featuring advanced alloy construction, jet cooling and the latest in refractory systems.
www.cmigroupe.com

Process Technologies, Equipment, Plants and Systems

ANDRITZ METALS Group

ANDRITZ METALS Group is a combination of leading suppliers that can offer equipment and services for all of your processing and finishing needs in stainless steel, carbon and nonferrous metals. In addition, the group supplies turnkey furnace systems, services and upgrades for the steel, copper and aluminum industries.
www.andritz.com

Solutions for Heat Treaters

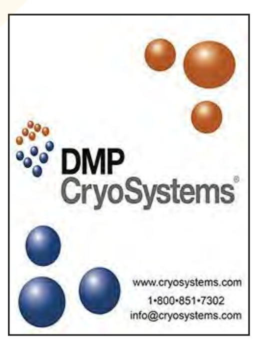
Diablo Furnaces

Keep your heat-treat equipment up and running with practical maintenance tips and techniques, along with recommended and optional upgrades to extend furnace longevity. Learn from personnel with 30 years of hands-on experience.
www.diablofurnaces.com

Materials Testing Equipment

Applied Test Systems

This brochure gives an overview of ATS' extensive line of affordable yet uncompromising materials testing equipment. ATS is large enough to offer an extensive line of standard products. However, it is and always will be flexible enough to custom-tailor any systems for a specific application.
www.atspa.com



Cryogenic Processing

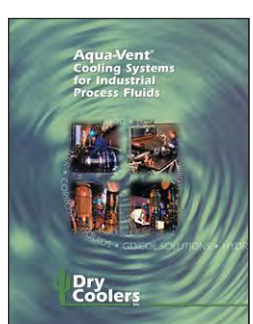
DMP CryoSystems

We offer several types of cryogenic processors. The CryoFurnace is the first and only cryogenic processor available with a temperature range of +1200˚F to -300˚F. The Cryo-Temper has a temperature range of +550°F to -300°F. The newest addition to our product line, the CryoFreezer, offers a temperature range of ambient to -300°F.
www.cryosystems.com

Furnaces

Can-Eng Furnaces

Since 1964, Can-Eng has been designing and manufacturing industrial heat-treating equipment for commercial and captive heat treaters, stamping and fastener companies, automotive component producers, the iron and steel industries, and aluminum foundries. Take a closer look at the systems we have to offer.
www.can-eng.com



Process Cooling Systems

Dry Coolers Inc.

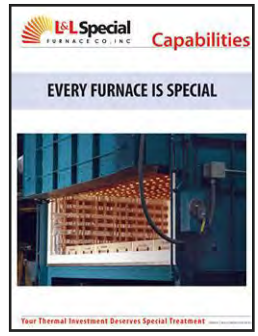
Informative six-page brochure describes closed loop water systems including air-cooled heat exchangers, evaporative cooling towers and mechanical refrigeration chillers. Contains information on complete systems with pumping stations, electrical control panels and optional equipment. Request Aqua-Vent bulletin AV-105.
800-525-8173
www.drycoolers.com

LITERATURE & WEBSITE SHOWCASE

Low-Pressure Vacuum Carburizing Furnaces

ECM USA

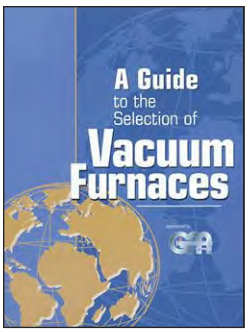
ECM Technologies started manufacturing heat-treatment furnaces in 1928. Since that time, ECM personnel have been committed to extending their knowledge in the field of temperature control, high pressures, vacuum and the behavior of materials. Call 262-605-4810 to see how ECM USA can improve your process. www.ECM-USA.com



Furnaces & Ovens

L&L Special Furnace Co. Inc.

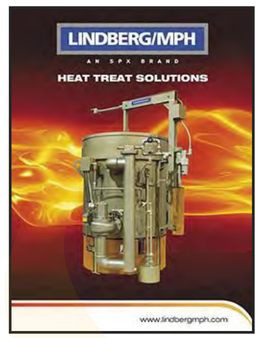
L&L Special Furnace Co. Inc. designs and builds high-temperature furnaces, ovens, kilns, quench tanks and heat-treating systems. We specialize in batch production furnaces and ovens, particularly applications requiring high uniformity and controlled atmosphere. L&L sells and services equipment worldwide. www.llfurnace.com



Vacuum Furnace Selection Guide

G-M Enterprises

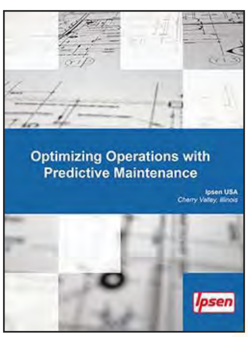
An (8) eight-page, full-color handout for prospective furnace buyers. The handout is a checklist of considerations when purchasing a new vacuum furnace. Please call for our "Guide to the Selection of Vacuum Furnaces." Phone: 951-340-4646 www.gmenterprises.com



Heat-Treat Solutions

Lindberg/MPH

Lindberg/MPH produces standard and custom industrial heat-treat furnaces, including pit, box, IQ, vacuum and belt-type for the ferrous and nonferrous markets. These markets cover a wide range of industries, including aerospace/military, automotive, commercial heat treating, energy/oil, electronics and forging. www.lindbergmph.com



Optimizing Operations with Predictive Maintenance

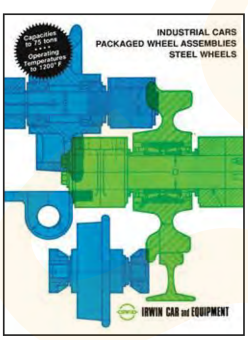
Ipsen

What if your vacuum furnace could tell you that it isn't operating properly? With a focus on solving this what if, the PdMetrics® software platform was developed. This predictive maintenance technology features monitoring and diagnostics that integrate with critical systems and allow you to improve the health and integrity of your equipment. www.IpsenUSA.com/Predictive-Maintenance

Vacuum Heating and Brazing Systems

PVT Inc., An Inductotherm Group Company

PVT Inc. has been in the specialty vacuum furnace business since 1965. The vacuum aluminum brazing furnaces manufactured by PVT serve as the standard for aerospace applications. In 2003, it became a subsidiary of Consarc Corp., An Inductotherm Group Company. For more information, call 609-267-3933 or e-mail sales@pvt-vf.com. www.pvt-vf.com



Material-Handling Equipment

Irwin Car and Equipment

Get specifications for the industrial cars, wheel assemblies and steel wheels we custom-engineer and manufacture for heat-treating applications. Our assemblies can carry loads up to 75 tons per wheel and turn on roller bearings at temperatures up to 1200°F. At Irwin, we help you maximize safety and productivity. www.irwincar.com

Stainless Steel, High-Nickel Fabrications

Qual-Fab, Inc.

Qual-Fab specializes in fabrications for the heat-treat and powder-metal industries. The focus is on radiant tubes (all styles/sizes), cast and fabricated tubes and corrugated muffles. Qual-Fab also produces furnace rolls, serpentine trays, corrugated baskets, retorts, fans and furnace fixtures. www.qual-fab.net

Industrial Ovens

JPW Industrial Ovens & Furnaces

JPW is a U.S. manufacturer of industrial batch and continuous process ovens as well as furnaces. We offer a wide range of temperature options and solution-based products designed to meet the most demanding process requirements. www.jpwdesign.com

Freezers

Russells Technical Products

Russells Technical Products is a global supplier of environmental test systems used in research, quality control and product testing. Russells' experience in low-temperature refrigeration is being used in the introduction of cryogenic industrial freezers. The low temperatures required are provided by mechanical refrigeration to -120°F and by vaporizing liquid nitrogen to -300°F. www.russells-tech.com

Quench Process Control Solutions

SBS Corporation

SBS is your partner in the pursuit of perfect process control for your heat-treat facility. We offer American-made quench oil coolers, endothermic gas coolers, quench oil filters, Cloud-based condition monitoring and more. Find us at FNA 2018 in Indianapolis at booth 332.
www.sbscorporation.com

Vacuum Furnaces

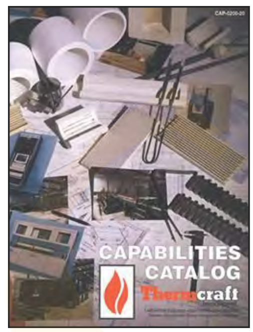
TAV Vacuum Furnaces

Specializing exclusively in the manufacture of high-temperature vacuum and high-vacuum furnaces, TAV Vacuum Furnaces has developed an accurate knowledge of these technologies and their performance. This allows us to provide special solutions and bespoke systems to process innovative materials and sensitive products. We have the know-how that's needed to increase your productivity and efficiency.
www.tav-vacuumfurnaces.com

UniCase Master

SECO/WARWICK Corp.

Single-piece-flow vacuum case hardening technology designed for high-volume gear and transmission part manufacturers. Up to 1,000,000 parts per year in this new and truly revolutionary, continuous vacuum process. Get the benefits of single-piece processing with exceptional uniformity and minimal quenching distortion.
www.secowarwick.com



Furnaces/Ovens/Heating Systems

Thermcraft Inc.

Thermcraft Incorporated offers a wide range of standard products that includes: ceramic refractory or vacuum formed ceramic fiber heaters, control systems, as well as industrial oven and furnace systems including mechanical handling equipment. Thermcraft Incorporated is also a recognized leader in custom heat-treating, industrial systems.
www.thermcraftinc.com

Vacuum Furnaces

Solar Manufacturing

Solar Manufacturing designs and fabricates a full range of vacuum furnaces for heat treating, brazing, carburizing, nitriding and sintering. Energy-efficient hot-zone designs, advanced SolarVac controls and improved quench technologies provide maximum performance.
www.solarmfg.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

Thermal-Processing Systems

Surface Combustion

This brochure introduces Surface Combustion and its overall capabilities as a provider of diverse products for the thermal-processing industry. Surface's capabilities also include a wide array of aftermarket services and support activities. Whatever your heat-processing needs, Surface can put its over 85 years of experience to work for you.
www.surfacecombustion.com

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www.tmvacuum.com

Drop-Bottom Furnaces

Wisconsin Oven

Wisconsin Oven manufactures drop-bottom furnaces, quench tanks, age ovens and related equipment for solution treatment of aluminum extrusions, sheet metal, castings and other parts. We serve the automotive, aerospace and other industries. Our equipment is designed to the most stringent specifications.
Contact: 262-642-3938
www.wisoven.com

Thermal Processing Products

Multi-Loop Controller

Future Design Controls

MCT4, a ¼ DIN multi-loop controller with a 4.3-inch color touchscreen user interface, combines the functionality of multiple devices. The standard unit includes: an easy to use touchscreen; up to 3-loop controls; paperless recorder; trend and data file viewer; email/SMS text messaging on alarm; remote access via VNC and web page; Modbus Serial and TCP/IP communication; and file transfer via USB, email or FTP. MCT4 provides exceptional control for applications in markets where control, monitoring and/or data logging is required, including automotive, heat treating and laboratory. www.futuredesigncontrols.com

Mobile App for Heating Process

Otto Junker

JuDyi4.0 is a web-based mobile application designed for JunkerDynamicHeater MC, a heating process for extrusion billets. Whether or not the app is installed on a smartphone or tablet PC, it will show current process data or historical data in the form of a daily, weekly or monthly record anytime, anywhere based on a complete system overview. Selected components are tagged with QR codes. Focusing the camera on the code will identify the component. Descriptions, bills of material, drawings – all information is available at a glance. www.otto-junker.com

Augmented Reality Technology

SECO/WARWICK

SECO/LENS is an application that uses augmented reality (AR) technology. It has several applications in any manufacturing environment, such as training, factory planning or maintenance. Benefits include more intuitive device operation, increased mobility, increased efficiency and reduced response times to service requests. www.secowarwick.com

Pipe Markers

Graphic Products

Premade, self-adhesive pipe marking labels can help facility managers quickly label pipes or systems in line with common ANSI/ASME A13.1 and IIAR standards. From fire quenching to flammable or oxidizing systems, more than 255 pipe markers are available. Standard premade pipe markers are offered in five sizes with the option of a detached arrow to allow the user to indicate direction of flow. Whether identifying pipe systems for emergencies, maintenance or construction operations, safety managers can quickly order the right pipe markers with fast shipping. www.graphicproducts.com

Bricking Machine

Bricking Solutions

The Ez Flexx50 bricking machine offers the highest load capacity on the market – as much as 13,200 pounds with a 17.1-foot work deck. It can be used to quickly and safely install the upper half of refractory brick in kilns. Easily adjustable screw jacks support the unit's arch, eliminating the need for tools. The arch is mounted to a trolley cart that travels the entire length of the deck on wheels. Pneumatic cylinders push bricks into place, vastly reducing the risk of injuries from unsupported overhead bricks. The machine is available in standard, high-capacity and small sizes, each with available upgrades. www.brickingsolutions.com

Hot Stamping Furnace Technology

GHI

OnStamp by GHI is a technology designed for moving blanks through the furnace. Based on an original system comprising a double mechanism for forward movement and elevation, it has been tested, used and validated in several plants by a global supplier of hot stamped parts for the automotive industry. OnStamp by GHI offers high precision and repeatability in parts output, avoiding misplacement and preventing unnecessary movements. In addition, the need to replace and maintain rollers is removed, which reduces the cost of furnace operation. Available in different configurations, there are a range of furnace sizes that cover different production scales – with the capacity to process batches of up to eight blanks. www.ghihornos.com

Emissions Analyzer

E Instruments International

The E8500 PLUS emissions analyzer is a complete portable tool for EPA-compliance-level emissions monitoring and testing. It is ideal for regulatory and maint i f burner, engine, turbine industrial combustion requiring accurate low- measurements. Custom with up to nine gas sen it includes a real-time P software package with Bluetooth and a wirele remote printer. The expanded internal mem can hold up to 2,000 te www.e-inst.com

The Microstructure of Ni-Based Superalloys

ON DEMAND WEBINAR

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The webinar will cover the microstructure of cast and wrought Ni-based superalloys plus PM superalloys. Examples of microstructures in various conditions including: as-cast, as-hot worked, as-cold worked, and solution annealed, plus solution annealed and aged will be shown in B&W and with color etchants. The influence of solution annealing temperature on the grain size of superalloys will be illustrated. Various phases that can form in superalloys, such as carbides, delta and Laves phase will be shown. High-magnification images of and strengthening phases will also be shown. Results using electron backscatter diffraction (EBSD) on superalloys solution annealed at different solution annealing temperatures to reveal the austenite grain structure will also be shown.

KEY TOPICS:

- Specimen preparation and etching (black and white and color)
- As-cast microstructures and Powder Metallurgy microstructures
- Wrought, hot-worked microstructures and solution annealed and then cold-worked microstructures
- Delta phase, Laves, carbides, gamma prime and gamma double prime phases
- Influence of solution annealing temperature on grain growth

Speaker:
George Vander Voort
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PARK THERMAL
Park Thermal Gas Fired Car Bottom Furnace, 6' wide x 6' high x 12' long, 1,300°F Max., 12,000 Lbs capacity, 1,500,000 BTUH, fiber lined, North American burners, exhaust, combustion blower and controls.

CAR BOTTOM FURNACE
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.

BEAVERMATIC
Beavermatic Gas Fired Car Bottom Furnace, 4' wide x 6' long x 4' high, 1,400°F max., 15,000 LB capacity, finer lined, powered car complete with ceramic piers, exhaust, blower and Honeywell controls.

BEAVERMATIC
Beavermatic Gas Fired Car Bottom Furnace, 5' wide x 12' long x 5' high, 1,400°F max., 30,000 LB capacity, fiber lined, powered car complete with ceramic piers, exhaust, blower and Honeywell controls.

ABAR
ABAR HORIZONTAL VACUUM FURNACE, 2 BAR, 24"W X 18"H X 36"L, 2,400°F, 1,000 LBS, 150 KW complete with Nitrogen or Argon Atmosphere, Spencer Blower, Varian Diffusion Pump, Stokes Mechanical Pump, Roots Blower Moly Elements, controls, circular hot zone and loader.

ABAR
ABAR HORIZONTAL VACUUM FURNACE, 2 BAR, 24"W X 24"H X 36"L, 2,400°F, 1,000 LBS, 150 KW complete with Nitrogen or Argon Atmosphere, Spencer Blower, Varian Diffusion Pump, Stokes Mechanical Pump, Roots Blower Moly Elements, controls, circular hot zone and loader.

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 Box Furnace, 3' W x 3' H x 4' L, 1,200°F, 500,000 BTUH, pneumatic vertical rising door, powered rollers and 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.

PARK THERMAL
Park Thermal Electric Salt Bath Nitriding System complete with 30" Dia. X 36" deep Pre-Heat Furnace, Nitriding Salt Bath, 38" x 38" x 30" deep Oxidation Quench Tank, 30" x 40" x 36" deep Oxidation Quench Tank, 2 Wash Tanks, 3 Rinse Tanks, 4 Air Cool Stations and Controls.

SALT BATH TRANSFORMERS
WPI Main Aluminum Scott T Dry Type Transformer, 250 KVA, 460 VAC 3 PH Primary, 60 HZ, 25/28/31/34/37/40 VAC 2 PH Secondary
WPI Teaser Aluminum Scott T Dry Type Transformer, 250 KVA, 460 VAC 3 PH Primary, 60 HZ, 25/28/31/34/37/40 VAC 2 PH Secondary

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.

SURFACE COMBUSTION
(2) INTEGRAL QUENCH FURNACES, 30"W x 30"H x 48"L, 1,750°F, 1,000,000 BTUH, Trident Tubes, Endo/Natural Gas/Ammonia, SSI Atmosphere Controllers, SSI Gold Probes, Oil Filters And SBS Coolers. System Comes Complete with a Gas Fired Temper, Washer and Charge Car.

SURFACE COMBUSTION
INTEGRAL QUENCH FURNACE, 5000 lb. Payload Each, 36"W x 36"H x 72"L, Recuperated Rear Handler And Controls.

SURFACE COMBUSTION
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.

HUBER
Huber Gas Fired Car Bottom Furnace, 10'-4"W x 8'H x 12'-8"L, 1,800°F, 5,200,000 BTUH and controls.

HOLCROFT
Holcroft Gas Fired Mesh Belt Furnace, 24"W x 9"H x 14' 8"L, 400,000 BTUH, 750°F c/w controls.

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1,500CFH	Endothermic Lindberg (Air)	Gas
2,000CFH	Ammonia Dissoc. Drever (3)	Elec
3,000CFH	Endothermic Lindberg (3) - Air	Gas
3,600CFH	Endothermic Surface (2)	Gas
5,600CFH	Endothermic Surface (2)	Gas
6,000CFH	Gas Atmos. Nitrogen Generator	Gas

BOX FURNACES

12" × 24" × 10"	Lindberg (Atmos.)	Elec 2000°F
12" × 24" × 10"	Lindberg (Atmos.)	Elec 2500°F
12" × 24" × 12"	Hevi Duty (2)	Elec 1950°F
12" × 32" × 12"	L&L (Retort)	Elec 2000°F
13" × 24" × 12"	Electra Up/Down	Elec 2000°F
17"×14.5"×12"	L&L (New)	Elec 2350°F
18" x 30" x 13"	Hevi-Duty	Elec 1850°F
18" x 36" x 18"	Hevi Duty	Elec 2000°F
18" x 36" x 18"	Lindberg (Fan)	Elec 1850°F
20" x 48" x 12"	Hoskins	Elec 2000°F
24" × 36"× 20"	L&L Up/Down	Elec 2000°F
24" × 48"× 20"	Lindberg	Elec 2200°F
36" × 36"× 48"	Grieve "Top Load" – NEW	Elec 2000°F
36" × 72"× 42"	Eisenmann (Car Bottom)	Gas 3100°F
60"×216"×48"	IFSI (Car Bottom)	Gas 2400°F
60"×156"×60"	Lindberg Car Bottom	Gas 1850°F
126"×420"×72"	Drever "Lift-Off" (2) (Atmos.)	Gas 1450°F

PIT FURNACES

14" Dia × 60"D	Procedyne Fluid Bed	Elec 1850°F
28" Dia x 48"D	Lindberg	Elec 1250°F
28" Dia x 48"D	L&N Nitrider	Elec 1200°F
28" Dia x 48"D	Lindberg	Elec 1250°F
72" Dia x 72"D	Flynn + Dreffein (2) (Atmos.)	Elec 1400°F
48" Dia x 60"H	"Bell" Nitrider (Retort)	Elec 1200°F

VACUUM FURNACES

24" × 36" x 18"	Hayes (Oil Quench)	Elec 2400°F
24" x 36" x 24"	TM - Temper	Elec 1400°F
48" x 48" x 24"	Surface (2-Bar)	Elec 2400°F
48" x 48" x 36"	Ipsen "Like New"	Elec 2400°F
60" Dia x 96"H	Ipsen "Bottom Load"	Elec 2400°F
72" Dia x 96"H	Abar "Bottom Load"	Elec 2400°F

INTEGRAL QUENCH FURNACES

24" × 36" × 24"	AFC (Top-Cool-Line)	Elec 1850°F
30" × 48" × 20"	Surface (2)	Gas 1750°F
30" × 48" × 24"	Surface	Gas 1750°F
36" × 48" × 36"	Surface	Gas 1750°F

BELT FURNACES/OVENS

24" × 18'L	Thermal Basic Belt Line	Gas 1750°F
32" × 24' × 12"	OSI Slat Belt	Gas 450°F
36" × 24' × 8"	Surface Cast Belt (Line)	Gas 1750°F
60" × 40' × 14"	GE Roller Hearth (Atmos)	Elec 1650°F
60" × 40' × 14"	Wellman Roller Hearth (Atmos)	Elec 1650°F
Just Added: 72" × 25' × 12"	Wisconsin	Gas 500°F

MISCELLANEOUS

Combustion Air Blowers (All sizes)		
24" × 36"	Lindberg Charge Car (Manual)	
30" × 48"	Surface Charge Car (SE-ER)	
SBS Air/Oil Coolers (4)		
24" × 36" × 24"	Salt Quench Tanks (2)	Elec 1000°F
30" × 48" × 30"	Surface Washer	Gas
30" × 48" × 36"	Surface Washer	Gas
(2) Bell & Gossett "Shell & Tube" Heat Exchangers		
26" x 15' x 15"	Belt Washer/Dryoff	Gas
36" x 48"	AFC Charge Car (DE)	Elec
24" Wide Table	Surface rotary Hearth	Gas 1750°F

MISCELLANEOUS *(continued)*

30" x 30" x 30"	Subzero	-105 to 375°F Elec.
SBS Air/Oil Coolers (4)		
AFC Pusher Line (Atmos.)		Gas 1750°F
36" Wide Table – Rotary Hearth (Atmos.)		Elec 1850°F
30" x 48"	Surface Roller Table	
36" x 48"	Holcroft Charge Car (DE)	
48" x 60" x 60"	Steel "Roll-in" Carts (3)	
54" Dia x 108" H	Ebner Bell (Atmos.)	Gas 1650°F

OVENS/BOX TEMPERING

8" × 18" × 8"	Lucifer	Elec 1250°F
12" × 16" × 18"	Lindberg (3)	Elec 1250°F
14" × 14" × 14"	Blue-M	Elec 1050°F
14" × 14" × 14"	Gruenberg	Elec 1200°F
14" × 14" × 14"	Blue-M	Elec 650°F
14" × 14" × 14"	Gruenberg (solvent)	Elec 450°F
15" × 24" × 12"	Sunbeam (N_2)	Elec 1200°F
20" × 18" × 20"	Blue-M	Elec 400°F
20" × 18" × 20"	Despatch	Elec 650°F
20" × 18" × 20"	Blue-M	Elec 650°F
20" × 18" × 20"	Blue-M (2)	Elec 800°F
22" × 18" × 15"	Precision Quincy	Elec 1000°F
24" × 20" × 20"	Blue-M	Elec 1000°F
24" × 24" × 24"	Grieve	Elec 650°F
24" × 24" × 36"	New England	Elec 800°F
24" × 24" × 48"	Blue-M	Elec 600°F
24" × 36" × 24"	Grieve	Elec 500°F
24" × 36" × 24"	Demtec (N_2)	Elec 500°F
24" × 36" × 24"	AFC (N_2)	Elec 1250°F
24" × 36" × 24"	Trent	Elec 1400°F
25" × 20" × 20"	Blue-M	Elec 650°F
24" × 36" × 48"	Gruenberg	Elec 500°F
25" × 20" × 20"	Blue-M (Inert)	Elec 1100°F
26" × 26" × 38"	Grieve (2)	Elec 850°F
30" × 30" × 60"	Gruenberg	Elec 450°F
30" × 30" × 48"	Process Heat	Elec 650°F
30" × 38" × 48"	Gruenberg (Inert) (2)	Elec 450°F
30" × 48" × 30"	Surface (2)	Elec 1400°F
30" × 48" × 24"	Surface	Gas 1250°F (Just Added)
30" × 48" × 36"	Surface (Atmos)	Elec 1400°F
30" × 48" × 30"	Surface	Elec 1250°F
30" × 48" × 24"	Surface	Gas 1250°F
36" × 36" × 36"	Grieve (Solvent)	Elec 500°F
36" × 36" × 36"	Blue M Enviroment Chamber (-18°C to +93°C)	
36" × 42" × 72"	Gruenberg	Elec 450°F
36" × 48" × 36"	Pollution Control Burn Off	Gas 850°F
36" × 48" × 36"	Grieve	Elec 350°F
36" × 48" × 36"	Despatch (Horizontal Quench)	Elec 1200°F
36" × 48" × 36"	AFC	Gas 1250°F
36" × 36" × 60"	Despatch	Elec 500°F
36" × 48" × 36"	TPS (Environmental)	Elec -40°C to +200°C
36" × 60" × 36"	CEC (2)	Elec 650°F
36" × 84" × 36"	Lindberg (1996)	Gas 800°F
37" × 25" × 37"	Despatch	Elec 500°F
37" × 32" × 48"	Hotpack	Elec 750°F
38" × 20" × 26"	Grieve	Elec 500°F
42" × 72" × 36"	Despatch	Elec 1350°F
48" × 48" × 20"	Lindberg (Hyd. Press)	Elec 1250°F
48" × 34" × 52"	Heat Mach. (2)	Elec 500°F
48" x 48" x 48"	TPS - Environmental	Elec 392°F
48" x 48" x 48"	Trent	Elec 1250°F
48" x 52" x 60"	Despatch	Elec 500°F
48" x 48" x 60"	Grieve	Elec 350°F
48" x 48" x 72"	Despatch	Elec 650°F
48" × 72" × 36"	Lindberg - Car Bottom	Elec 1600°F
50" × 50" × 50"	Grieve	Elec 1250°F
55" × 30" × 60"	Precision Quincy	Elec 350°F
60" × 96" × 72"	OSI	Gas 500°F
68" × 72" × 72"	Gruenberg (3)	Elec 450°F
72" × 120" × 78"	Grieve	Gas 500°F
72" × 252" × 60"	Precision Quincy "Car Oven"	Gas 500°F
84" × 96" × 84"	Precision Quincy	Gas 500°F
108" × 96" × 65"	Eisenmann (4)	Gas 1200°F

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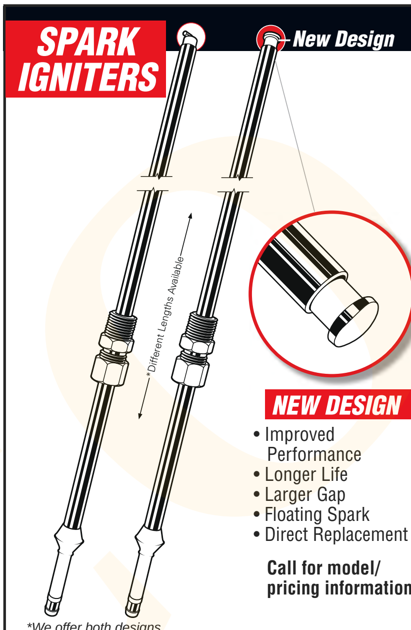

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