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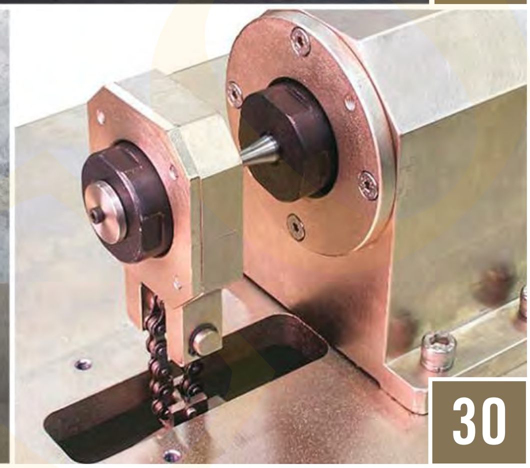
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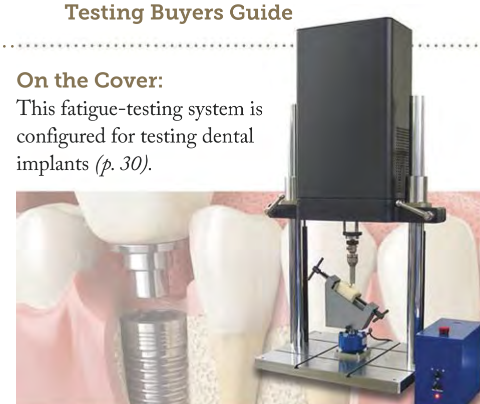
This fatigue-testing system is configured for testing dental implants *(p. 30)*.



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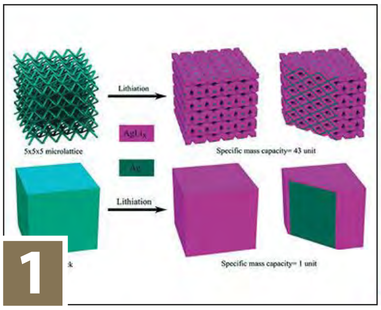

ONLINE

1 Web Exclusive

3D Printing the Next Generation of Batteries

Associate Professor of Mechanical Engineering Rahul Panat and a collaborator at Missouri University of Science and Technology have developed a revolutionary new method of fabricating battery electrodes using Aerosol Jet 3D printing.

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2 Podcast

Vacuum Technology (Part 1): Relationship Between Vacuum Pumpdown, Leak Rate Testing and Rate of Rise

This podcast is a general discussion about how vacuum pressure is measured and how vacuum leak rates and rate of rise testing are monitored in vacuum furnaces.

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3 Video

Creating Thermally Conductive Polymer Nano-wires

Ramesh Shrestha, Carnegie Mellon University Ph.D. candidate in mechanical engineering, explains his research to create polymer nano-wires that have high thermal conductivity.

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Workforce Development

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For those of us running industrial or manufacturing companies, the need for qualified workers might be greater than ever. With unemployment at historically low levels, finding good people is getting harder and harder. There are 6.6 million job openings in the U.S., many of which require advanced skills. In addition, baby boomers are retiring at a rate of 10,000 per day in the U.S. As a result, companies and schools are considering new and different ways to establish a qualified workforce.

Earlier this year, we encouraged the cooperative model between industry and academia. Academia needs to be part of the solution and not continue to do the same old thing. In July, President Trump signed the Strengthening Career and Technical Education for the 21st Century Act, which promotes more effective collaboration between employers and educational institutions when providing technical training to students.

This legislation gives employers input to help determine how federal funding for career and technical education (CTE) is spent. Now is a great time to be heard. Let state education agencies know what your workforce challenges are, partner with high schools and colleges, and encourage work-based learning.

Apprenticeships are a great way to attack this large issue. In mid-July, the U.S. Department of Labor announced $150 million in grants to expand apprenticeships on a national scale. These funds are "intended to increase the level of apprenticeship activity among a range of new employers, particularly small- and medium-sized businesses." They will also "promote a sector-based approach to large-scale expansion of apprenticeships that include a paid, work-based learning component and a required educational or instructional component that results in the issuance of an industry-recognized credential and meets appropriate quality-assurance standards."

"The expansion of apprenticeships makes the greatest workforce in the world – the American workforce – even stronger," said U.S. Secretary of Labor Alexander Acosta. "This funding is an investment in America's workforce, will contribute to competitiveness by helping job creators meet increasing demands for skilled workers and meets the nation's need for family-sustaining careers."

We took a look at the website for the National Association of State and Territorial Apprenticeship Directors and linked directly to see what is happening in Ohio – an industry-intensive state. It's called ApprenticeOhio (AO), and they are encouraging employers to partner with them. We have also read about the "Apprenticeship Connecticut" initiative, which seeks to identify and make "job-ready" thousands of unemployed and underemployed residents – from teens to middle-agers. Check out similar opportunities in your state by going to www.nastad.us and linking to your state to see what is happening there.

Did you notice two terms used by the Labor Department? They indicated that **apprenticeships** will lead to the "issuance of an industry-recognized credential." **Credentialing** is already part of the educational landscape, but it could become a model in our current era of Industry 4.0 (I4.0). A possible scenario is to be trained in a specific field for two years followed by testing to establish the necessary knowledgebase. Since this model could thrive in an online environment, traditional institutions might be seeing the writing on their brick-and-mortar walls.

We believe that having access to apprenticeships and credentialing will help encourage the next generation of workers to move toward industry. It has been shown that the younger generations are interested in developing skills in their jobs.

Will it be more and better apprenticeships, credentialing or some other training technique that meets the current needs of industry? Consider how you and your company can play a role. Whatever the best next step is, it's clear that academia and industry need to partner to develop a model that delivers the right people with the right skills at the right time.

Rebuilding Manufacturing's Labor Force

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A reader called me recently, and we had an enjoyable and useful conversation that needs to be shared here. John Fitzgerald, a veteran and manufacturing business owner, is a founder and participant in Veterans Initiative in Technology, Aerospace and Logistics (VITAL).

This relates to veteran job training for America's industrial workforce. The Manufacturing Institute has found that 80% of U.S. manufacturers cannot find enough qualified people to fill skilled labor needs at production sites. In San Diego alone, where 40,000 veterans annually transition out of military service, a Workshop for Warriors was formed to train veterans in welding, machining and fabrication – but only 40 to 60 students per semester can pass through training classes.

Shortage of skilled workers significantly increases manufacturing costs and is estimated at 11% of annual corporate earnings, or $3,000 per existing employee, due to this talent shortage. Another study estimates corporate losses of $14,000 per unfilled position. In other words, this is not a trivial matter.

So, there is a call for manufacturers and the military to organize and build training centers across the nation to advance the size and quality of all U.S. manufacturing industry's workforce. This is a very big job. Three years ago a Ford Foundation study found 2.3 million advanced manufacturing jobs unfulfilled in America. Over the next decade it is estimated that 2.7 million workers with these necessary skillsets will retire from the labor force.

Replacements, according to a November 2017 *Forbes* article, are best derived from on-the-job training and via apprenticeships. But the learning and transitioning process must begin somewhere, and programs like VITAL establish such a bridge. Military veterans are the best qualified to use this bridge due to the value sets and discipline acquired during service. Over half a dozen years ago the U.S. Chamber of Commerce Foundation began Hiring our Heroes (HoH), which fostered corporate fellowships by companies that paired vets with companies for 12 weeks – 700 were processed through the program with 82% earning immediate job placement. That is nice, but it's only a drop in the bucket. While unemployment among veterans has dropped dramatically, it is still 10-15% according to HoH.

It is suggested that readers join together in a mutual or collective initiative to address the matters described here. Here are several potential approaches.

- There is a shortage of trainers to teach veterans the capabilities needed to get and hold a job in manufacturing. A reader's company could possibly dedicate an experienced employee as a trainer at an existing training facility (such as VITAL).
- Training done at "industrial facilities" usually needs a place for students to be housed during the several months to year training period. Sponsoring such a site addition can make a training facility practical and operational.
- In order to train personnel to operate "equipment" and learn "methods and techniques" that are useful, the training facility requires on-site machines and support devices for real teaching. Reader's companies can dedicate (lend or provide) needed equipment.
- Since many participating veterans have "disabilities" (physical and mental), it is essential that training sites have experienced teachers. Contributing financially to or helping establish a "train the trainers" program and venue would be an across-the-board aid to these efforts.
- Assistance to veterans that the VITAL program has provided needs replication. It would be quite useful to have many more training sites and schools, sponsored and operated by people such as those that read this journal.

Now is the time to think about and act on this important matter. John Fitzgerald can be contacted at df.milvets@gmail.com. Visit www.veteransinitiatives.org to learn more about VITAL.

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Additive Manufacturing – The Next Industrial Revolution

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Some say we are on the cusp of another industrial revolution, namely the decentralization of manufacturing heralded by the growth of additive-manufacturing (AM) technology. The Doctor agrees. So, what is additive manufacturing, how does it differ from other conventional manufacturing technologies and how will it affect the heat-treat community? Let's learn more.

Powder metallurgy has always been an attractive alternative to traditional manufacturing of products from wrought materials, and sintering (the bonding of adjacent powder particles together to form a cohesive metal component) is the thermal-treatment method associated with this technology. The automotive industry in particular has embraced its use. When higher densities are required, other sintering methods such as metal injection molding (MIM) are used.

What is additive manufacturing?

Additive manufacturing is not new, having been first introduced in the 1980s and developed for three-dimensional plastic parts with a thermoset polymer hardened by ultraviolet light. The technology was initially too slow for mass production and primarily used for rapid prototyping. Today, metals have been added to the list of materials that can be used, and the speed of the process has accelerated to the point where it is viable for high-volume manufacturing.

AM refers to a process in which the raw material is added layer upon layer to create a component part. This is the opposite of machining, often now referred to as "subtractive manufacturing," which creates a part by removing material from a raw-material form.

One of the most promising versions of metal AM today is binder-jetting technology. Laser sintering and electron-beam methods are alternatives.[4] Binder jetting of metals is a process in which a liquid binding agent is selectively deposited onto a bed of powder-metal particles as the layers of the component part are being built up. The goal is to reduce the amount of liquid binder used since less binder allows easier access to the pores and more rapid binder removal.

A moving print head (Fig. 1) strategically blends binder into the powder while it is being deposited on the printing bed. After each pass, the bed height is lowered by the thickness of a print layer, 25-100µm, and another layer of powder and binder is added on top of the previous. As this is repeated, layers of bonded metal are successively deposited until the fully formed part is created.

After printing, sintering in a vacuum furnace is required, the same as with MIM technology. Binder jetting is used for creating parts made of Inconel, stainless steel, tungsten carbide, titanium, copper, brass and aluminum, among others. Since the printed layers can be extremely thin, the resulting part can be produced to an extremely high level of detail with very precise physical features.

Typical tolerances and specifications of metal binder-jetting technology include:[2]

- Maximal build envelope of 4,000 mm x 2,000 mm x 1,000 mm
- Minimum feature size of 0.1 mm
- Typical tolerance of ±0.13 mm
- Minimum layer thickness of 0.09 mm
- Fast build speed (in comparison to other additive technologies)

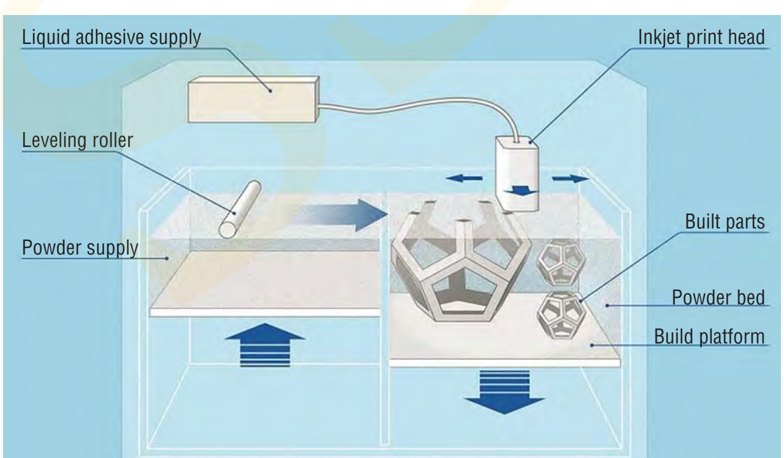

Fig. 1. Function of a binder-jetting printer[2]

Fig. 2. A lightweight drone support structure created using AM[3]

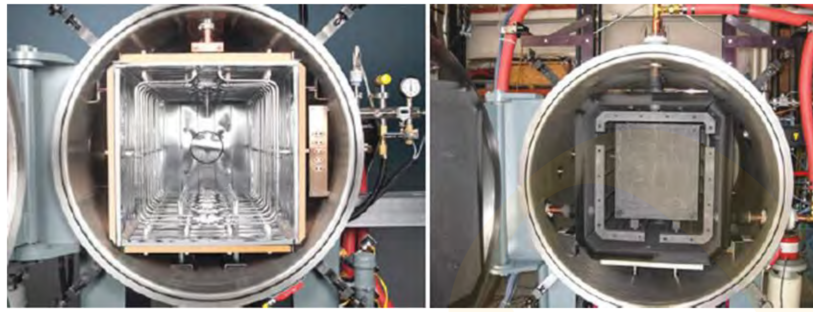

Fig. 3. Vacuum sintering furnaces for AM utilizing all-metal (left) or graphite (right) hot zones *(courtesy of Centorr Vacuum Industries)*

Binder jetting is the fastest metal AM method available. Maximum build speed is currently approximately 2,500 cm^3/hour, and one manufacturer is planning to introduce an 8,200 cm^3/hour machine in 2019. Car bodies and other large composite plastic parts have been printed using AM technology, and it is just a matter of time before this expands to metal printing.

AM is considered by most in the industry as a "disruptive" technology; one that will revolutionize many industrial sectors as it becomes faster and less expensive. It will also fundamentally affect how, when and where heat treatment is performed since sintering will become part of an AM manufacturing cell. As AM becomes more sophisticated and as understanding and awareness grows among manufacturers, machine shops as we know them will be fundamentally changed. AM offers clear advantages in that:

1. Small runs of unique or complex parts can be produced quickly and at low cost. Unlike MIM, casting or forging, no expensive molds are required. This reduces time to market, a very valuable commodity today.
2. Shrinkage is significantly less than that of MIM-produced parts, increasing accuracy and repeatability. One description of AM is that it is a MIM process without the distortion.
3. AM has the ability to pursue new innovations without extending the design cycle. This allows for many generations of design changes in the time that it would normally take to make a single change using conventional technologies. This might be the most revolutionary aspect of the technology.
4. Honeycomb designs are possible, reducing part weight while maintaining or even increasing strength.
5. AM offers the ability to make on-the-fly changes. If there's one thing design engineers can count on, it is customer revisions and design changes. With AM technology, the designer simply makes a change in the 3D digital model, and it is downloaded to the printer for manufacture.
6. Highly complex parts can be produced (Fig. 2) that would be literally impossible with any other technology. There are some shapes and intricate features that cannot be cast, molded or machined but can be printed. This opens up new possibilities for designers.
7. A high degree of customization is possible without added cost. AM technology allows the manufacture of one-of-a-kind designs like medical implants that are custom made to fit a specific individual.
8. AM generates no waste. Since it is an additive technology, only the material that is needed is actually used. When printing very expensive metals such as titanium, this makes a huge difference in the price of the finished product and the feasibility of the project.

AM has always been an attractive choice when production volumes are low, changes are frequent and complexity is high. As print speed increases and costs come down, AM applications will expand to include more mainstream component parts. Machine shops and in-house manufacturing departments will then be able to choose the most cost-effective technology, with sintering being performed as part of the AM manufacturing cell as opposed to a heat-treatment department or an outsource location. This will lead to new opportunities and challenges for heat treaters because more parts will require secondary debinding and sintering under vacuum.

For example, one of the primary challenges for vacuum furnaces (Fig. 3) used for sintering is dealing with the binder liberated from the material during the secondary debinding process. Dry pumps are preferred since the binder can contaminate the oil used in rotary oil-sealed pumps requiring frequent oil changes.

There must also be provisions made for removing the binder. One approach is to locate a binder trap prior to the pump, which collects the binder and requires periodic removal and cleaning. Manual or automated traps are available – the latter heats up to liquefy the binder residue, which then flows to the bottom of the trap. A valve is opened to allow residue to be collected. A third method involves the use of a condensing filter.

Summing Up

The additive-manufacturing revolution has begun! It will soon have an impact on all types of industries and their manufacturing strategies, representing a paradigm shift in design and engineering that will affect every process in the factory, including heat treatment.

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Way back in 1956, a group of scientists wanted to develop high-performance temperature sensors focused on rocket-engine testing for government research and military applications. With that goal in mind, Nanmac Corp. was formed.

Today, over 60 years later, the Holliston, Mass.-based company manufactures thermocouples and RTDs with accessories for measurement of thermal events up to 2300°C (4172°F) used in a variety of applications. The veteran-owned MTI associate member holds patents on temperature sensors, erosion gauges and multifunction sensors.

Nanmac serves the following industries: aerospace/defense, heat treatment/thermal processing, medical, OEM furnace manufacturing, oil and gas, petrochemical, pharmaceutical, power generation and semiconductor.

With the advent of newer material systems and requirements for better and more precise temperature controls under varying atmospheres, suppliers are now faced with the need to up their temperatures and process controls. Newer thermocouple materials and more robust sensors – along with the need to ensure you are running at the most optimum point – requires manufacturing excellence, material expertise and the very best calibration service support. Nanmac Engineering, which boasts more than 50 years of experience working at the leading edge of thermal technology, meets those requirements.

Nanmac works out of a 12,000-square-foot facility in Holliston, where all operations are set up as lean processes, reducing labor and increasing throughput. This has reduced turnaround from 10 days about 24 months ago to less than three days at present. The average employee has more than five years of experience at Nanmac. All employees are trained on new methods and assembly techniques, which leads to reduced scrap and less than 2% rework. The company has earned ISO 9001:2015 registration, and its calibration lab is accredited under ISO 17025 for direct comparison calibrations to 1700°C.

The company has had a busy year. Over the past 12 months, Nanmac has completed projects for:

- Turbine testing at very high temperatures and in harsh environments using devices up to 2000°C and in wind conditions approaching Mach 0.6
- Sintering processes at 1650°C for turbine blades, with control of temperatures to within +/-5°C
- Rocket-nozzle testing and in-situ engine testing with very high speed TCs
- A molten salt storage facility using various thermal devices, some of which were invented to meet the requirements

Nanmac is continuing to identify new materials (insulators for temperatures over 1700°C), better thermocouple elements and related thermocouple construction processes to optimize existing and evolving thermal sensing and measuring systems. Patented technologies in very dense thermocouples for use in medical and ultrahigh-temperature applications (12 TCs in a 1-inch sheath) are leading to continued developments that were initially only affordable for R&D and military applications. However, volume and performance are moving them rapidly into the commercial market, where the risk to the user is reduced considerably because the use data is developed under more extreme environments.

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Industry leaders and executives gathered in Atlanta July 30-Aug. 1 for the second ITPS (International ThermProcess Summit), and by all accounts and comments, the event delivered a wide array of timely and critical information.

Anne Goyer, IHEA's executive vice president, noted that attendee evaluations showed executives felt the speakers and their presentations were very valuable. "I have been involved in organizing conferences and summits for more than 35 years," Goyer said. "This year's ITPS was one of the highest evaluated events we've ever produced."

From the opening session where attendees learned about the "Factory of the Future" from Dr. Irene Petrick of Intel, to the closing presentation on "Transitioning Your Business to the Next Generation" by The Brainzooming Group founder Mike Brown, the audience was engaged throughout the entire event.

The diverse general-session program was packed with topics of significant relevance to today's manufacturing leadership. Additive manufacturing expert Todd Grimm offered insights into how this growing technology might impact manufacturing operations, while Georgia Tech's Thomas Kurfess introduced the audience to Manufacturing USA initiatives that bring together industry, academia and government partners to grow advanced manufacturing innovation. Chad Hunt, special supervisory agent for the Atlanta Field Office of the FBI, provided tips to help manufacturers prevent and react to cybersecurity threats. Noel Ginsburg, CEO of CareerWise Colorado, shared the journey of establishing a state-wide apprenticeship program that promises to address workforce development challenges faced by most manufacturing organizations.

Dr. Amber Selking held the attention of attendees through her presentation on building championship mindsets.

The program would not have been complete without addressing the latest happenings in Washington, D.C. and economic indices that impact manufacturers. Omar Nashashibi of the Franklin Partnership shared the latest information out of Washington, including the status of tariffs of concern to manufacturers. In this environment of constant political change, Nashashibi was literally updating his presentation information as he took the stage. Supplementing his Washington update was IHEA's economist, Chris Kuehl, who addressed the topic of managing in an unpredictable economy.

The general program was enhanced with a breakout session that focused on the thermal-processing industry. Honeywell's Tim Lee addressed opportunities and threats in the industry, and Chris Della Mora, risk consultant with HUB International Risk Services, discussed risk management strategies for industrial combustion systems. John Deere's Chad Spore provided an OEM's perspective on thermal processing, and a consultants' panel provided a peek into the industry's future.

The program's highest-rated presentation came from Dr. Amber Selking of the Selking Performance Group. She addressed ways for executives to drive consistent performance excellence within their companies. Dr. Selking dove into the science behind how the brain works and what leaders should do to develop their staff to drive a workforce that feels empowered.

Along with the outstanding program, ITPS included the opportunity for attendees to socialize and mingle with speakers and industry peers during evening gatherings. It was the perfect combination of business and networking for all those in attendance.

IHEA has offered many conferences and educational opportunities over its 89-year existence, but 2018's ITPS was among its best-rated events ever. Diverse and unique in the industry, those who attended felt it was extremely worthwhile.

EQUIPMENT NEWS

Front-Loading Furnace

Onex Inc. of Erie, Pa., received an order for a front-loading forge furnace from a North American forging company. The furnace has workspace dimensions measuring 17 feet deep x 23 feet wide x 8 feet high and features a combination module roof that is less costly than a full polycrystalline lining and shrinks less than ceramic fiber containing zirconia. It also includes an engineered lintel system that is more durable than traditional refractory lintels, providing longer life. www.onexinc.com

Annealing Furnace

Wisconsin Oven Corp. shipped an electrically heated annealing furnace to a firearm manufacturer. The conveyor furnace, which has a maximum temperature rating of 1400˚F (760˚C) and a normal operating temperature of 572-1202˚F (300-650˚C), will be used for annealing an assortment of brass and bronze firearm caps. Work-chamber dimensions measure 3 feet wide x 9 feet long x 6 feet high. When preheated, the furnace has sufficient capacity to heat 496 pounds (225 kg) of product per hour. www.wisoven.com

Vacuum Furnace

SECO/VACUUM, a SECO/WARWICK company, received an order from a global manufacturer to supply a second vacuum furnace to its U.S.-based operations. This second furnace, a vacuum temper furnace for tempering and stress relieving metal parts, is part of the company's U.S. expansion and becomes a centerpiece in a new processing line. The horizontal, front-loading furnace has an all-metal hot zone for clean vacuum processing. The unit includes a convection fan and a pressurized gas quench for quick cooling. www.secovacusa.com

Box Furnace

L&L Special Furnace Co. Inc. supplied an electric box furnace to a global supplier of large industrial valves for various industries. This is the fifth L&L furnace supplied to this facility, which is located in Louisiana. The unit, which has an effective work zone of 34 inches wide x 34 inches high x 32 inches deep, is used to both heat treat and temper various rings and seals deployed in the manufacture of valves used in the power-generation field. It is also used for general heat treating of various steels prior to machining. www.llfurnace.com

Box Furnaces

Armil CFS Inc. of South Holland, Ill., supplied two gas-fired box furnaces with afterburners to a California-based aerospace manufacturer. The furnaces, which are designed to operate at temperatures of 450-2200°F (232-1205°C), will be used to preheat and dewax molds used in the investment casting process. Workspace dimensions of each furnace measure 6 feet wide x 5 feet deep x 4 feet high. Operators will interface with the furnaces utilizing a PC-based industrial HMI. www.armilcfs.com

UBQ, UBT Furnaces

Canadian commercial heat treater Thermetco expanded its heat-treatment production capability with the purchase of an **AFC-Holcroft** UBQ (universal batch quench) furnace and a UBT (universal batch temper) furnace. The equipment, which was delivered in the first quarter of 2018, was installed and commissioned at Thermetco's new manufacturing facility in Chateauguay, Quebec. The furnaces will be used for general heat treating and offer the capability of providing metallurgical processes such as carburizing, carbonitriding, annealing, tempering and stress relieving. www.afc-holcroft.com

Combination Furnace, Oven

Lucifer Furnaces delivered a large dual-chamber unit – a hardening furnace over a tempering oven – to a metal stamping manufacturer in the Midwest. The upper hardening chamber heats to 2300°F with 6.5 inches of multilayer insulation throughout the chamber. Heat is supplied through heavy-gauge, coil-wound wire elements in holders on the sides, back and door of the furnace. The lower-chamber tempering oven heats to a uniform 1200°F with a rear-mounted fan circulating air past the side-mounted heating elements. www.luciferfurnaces.com

BUSINESS NEWS

Premier Thermal Solutions Acquires Al-Fe Heat Treating

Premier Thermal Solutions (PTS), acquired Al-Fe Heat Treating, a commercial aluminum heat treater with four plants in Defiance, Ohio; Saginaw, Mich.; Wadsworth, Ind.; and Wabash, Ind. PTS provides commercial metal heat-treating services to a variety of industries through its wholly owned subsidiaries, Atmosphere Annealing and NitroSteel. PTS has five facilities in four locations across the Midwest.

Oerlikon Balzers Opens Heat-Treatment Facility in Slovakia

Oerlikon Balzers opened a second production facility in Slovakia. The new plant provides automotive manufacturers state-of-the-art heat-treatment processes that offer very good friction properties and outstanding corrosion resistance, and it marks another stage in the company's growth strategy in the automotive industry. Oerlikon Balzers now employs nearly 300 specialists between the two facilities.

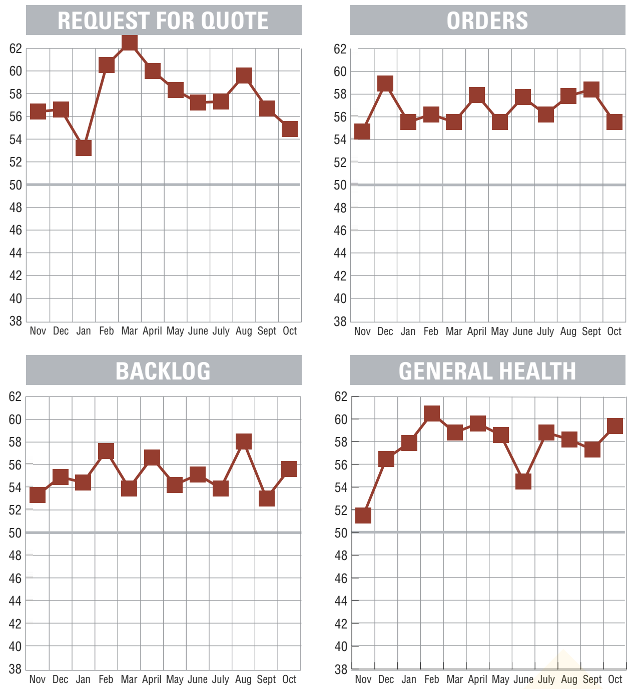
Air Products to Build Liquid Hydrogen Plant in Texas

Air Products announced plans to build a new liquid hydrogen plant at its La Porte, Texas, industrial gas facility to meet increasing product demand from several markets. The facility will produce approximately 30 tons per day and will draw its hydrogen to be liquefied from Air Products' existing Gulf Coast hydrogen pipeline system network. Once liquefied at La Porte, the hydrogen will be delivered to customers in industries including metals and electronics. The plant is scheduled to be on-stream in 2021.

Kaiser Aluminum Acquires Metal Additive Manufacturer

Kaiser Aluminum Corp. acquired Imperial Machine & Tool Co., a provider of multi-material additive manufacturing and machining technologies for aerospace, automotive, defense and general industrial applications. Columbia, N.J.-based Imperial Machine & Tool provides multi-material expertise in aluminum, titanium, tantalum, molybdenum, nickel alloys, tungsten, cobalt chromium and stainless steel.

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

Vacuum Aluminum Brazing – What Matters Most

Craig Moller and Jim Grann – Ipsen USA; Cherry Valley, Ill.

Vacuum aluminum brazing is a careful balance of time, temperature and vacuum level. These parameters are controlled to maintain the fundamental brazing success parameters – load the parts, heat the parts, get the braze joints clean, melt the braze filler and get the parts out.

Fig. 1. Vacuum aluminum brazed radiator *(courtesy of API Tech)*

Vacuum aluminum brazing is done in a specific work environment utilizing sophisticated controls to ensure fast pumping, low parts per million (PPM) of oxygen and exceptional temperature uniformity combined in one synergistically designed vacuum furnace system.

Types of Aluminum Brazing

Aluminum brazing can be done with or without flux and includes many different methods for creating the bond.

In flux brazing, the flux flows into the joint and is displaced by the liquidus filler metal entering the joint in order to remove oxides on the part to create a strong, solid braze. Flux comes in several different forms: paste, liquid or powder. Some brazing rods are coated with flux or have a flux core in order to apply necessary flux during the brazing process. Flux brazing processes include torch brazing (manual and automatic), induction, salt bath (dip brazing) and controlled atmosphere (CAB).

Brazing performed in a vacuum furnace is considered fluxless brazing because it does not use flux to create the joint. Fluxless brazing processes can be performed using inert-gas atmospheres or in vacuum furnaces. Such processes include but are not limited to semiconductor manufacturing, ceramic-to-copper brazing and so on. Due to the cleanliness of the vacuum environment, flux is not needed. Magnesium is used as an additive, or getter, in the vacuum aluminum brazing process.

Vacuum Aluminum Brazing

Benefits of Vacuum Aluminum Brazing

Brazing has many advantages when compared to other metal-joining processes. Given that brazing does not melt the base metal of the joint, it allows for more precise control of tolerances and provides a clean joint with no need for additional finishing. The meniscus (crescent-shaped) formed by the filler metal in the brazed joint is ideally shaped for reducing stress concentrations and improving fatigue properties.

Ideal situations for brazing include:

- Joining parts of very thin or thick cross sections
- Compact components containing many junctions to be sealed (e.g., heat exchangers) or deep joints with restricted access
- Joining dissimilar metals such as copper and stainless steel
- Assemblies with a large number of joints

Specifically, vacuum aluminum brazing minimizes distortion of the part due to uniform heating and cooling as compared to a localized joining process. This type of brazing creates a continuous hermetically sealed bond. Components with large surface areas and numerous joints can be successfully brazed.

Hardening can also be accomplished in the same furnace cycle if hardenable alloys are utilized, and the furnace system is integrated with a forced-cooling system, thus reducing cycle time.

Vacuum furnace brazing offers extremely repeatable results due to the critical furnace parameters that are attained with

Fig. 2. Vacuum brazed evaporator

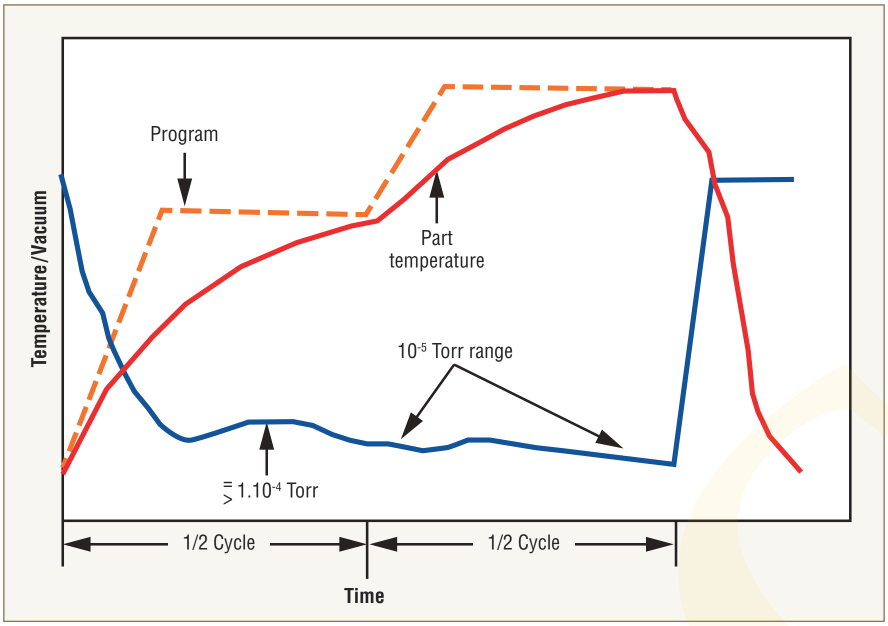


Fig. 3. Typical vacuum aluminum brazing cycle

Fig. 4. Clamp-type fixturing

every load (i.e., vacuum levels and temperature uniformities). Capillary joint paths (even long paths) are effectively purged of entrapped gas during the initial evacuation of the furnace chamber, resulting in more-complete wetting of the joint.

Vacuum aluminum brazing is ideal for oxidation-sensitive materials. Vacuum brazing is considered a flux-free process that eliminates corrosive flux residue. Post-brazed parts are clean with a matte-grey finish. The process is relatively non-polluting, and no post-braze cleaning is necessary.

Examples of Vacuum Aluminum Brazed Parts

Examples of vacuum aluminum brazed parts often include heat exchangers, condensers and evaporators used in automotive, aerospace, nuclear and energy industries. Some of these parts are shown in Figures 1 and 2.

Vacuum Aluminum Brazing Process

The vacuum aluminum brazing process is usually a relatively short cycle due to the fast pumping and heating characteristics of the furnace, the excellent temperature uniformity at soak temperatures and the high thermal conductivity of the aluminum parts being brazed. Figure 3 shows a typical vacuum aluminum brazing cycle.

Vacuum Pumping

The vacuum pumping capacity must be adequately sized in order to minimize the pump-down time of a new load to a deep vacuum level; to initiate the heating cycle; and to have adequate throughput to keep up with the significant outgassing that takes place during the heating cycle due to magnesium vaporization. A deep vacuum level is an important process parameter because it ensures a relatively pure environment for brazing (less PPM of oxygen). Table 1 illustrates the change in purity levels in relation to the various vacuum levels.

Magnesium

A key component of vacuum aluminum brazing is the use of magnesium as an additive to the filler metal and/or the base metal of the parts to be brazed. It is necessary in this fluxless brazing environment for the following reasons:

- When the magnesium vaporizes starting at around 1058°F (570°C), it acts as a "getter" for oxygen and water vapor, thus improving the purity of the brazing vacuum.
- Magnesium will also reduce the aluminum oxide (alumina) that exists on the surface of the aluminum to promote uniform accelerated wetting of the joint surfaces.

The following reactions occur during the vacuum brazing process:

$$Mg + H_2O \rightarrow MgO + H_2$$
$$2Mg + O_2 \rightarrow 2MgO$$
$$3Mg + Al_2O_3 \rightarrow 3MgO + 2Al$$
$$3Mg + N_2 \rightarrow Mg_3N_2$$

Also known as a "mag burst," the vaporization of magnesium produces heavy outgassing for a short period of time. The slower the heating rate, the smaller the magnesium vaporization rate. Due to this gas load, the vacuum pumps must be adequately sized to maintain a good working vacuum (10^{-4} to 10^{-5} torr range).

Heating Control and Temperature Uniformity

Second to the deep vacuum level, precise temperature control

Table 1. Vacuum protection from undesirable gases

Pressure in mbar	Total Vol.-%	O_2 Vol.-%	N_2 Vol.-%	O_2 ppm	N_2 ppm
1013	100	20	79	200*103	790*103
1	0.1	0.026	0.1	264	1040
10^{-1}	0.01	0.0026	0.01	26.4	104
10^{-2}	0.001	0.00026	00001	2.64	10.4
10^{-3}	0.0001	0.000026	0.0001	0.264	1.04
10^{-4}	0.00001	0.0000026	0.00001	0.026	0.1

and uniformity are also important process parameters. Accepted temperature uniformity during a brazing cycle is +/-5˚F (3˚C) of setpoint.

Aluminum brazing has a very narrow window of acceptable brazing temperatures. The governing rule for aluminum brazing is that the filler metal has to liquidize before the base metal reaches its solidus temperature. This temperature difference may be as small as 10-18˚F (5-10˚C).

For example, a base metal 6061 alloy will have a solidus temperature of 1099˚F (593˚C) and a liquidus temperature of 1206˚F (652˚C). Brazing temperature range would be 1049-1085˚F (565-585˚C) depending on the filler metal used.

It is necessary to use a heating step at a soak temperature just below the solidus point of the filler metal to ensure all the parts and joints to be brazed reach the correct temperature at approximately the same time. At this time, the ramp to brazing temperature starts, the filler metal begins to melt and the capillary wetting of the braze joints occurs.

Braze-temperature time duration must be kept to a minimum because the melted filler metal is vaporizing in the deep vacuum as it is trying to wet the braze joints. Too much loss of filler metal to vaporization will result in poor joint wetting and subsequent loss of joint strength and sealing ability.

After the brazing temperature soak duration is complete, it is followed by an immediate vacuum cooling cycle, which solidifies the filler metal in the braze joints and stops the vaporization of material.

The type of precise temperature control and uniformity needed for vacuum aluminum brazing is achieved through the use of several heating control zones around the parts while at the same time maintaining the surface temperatures of the heating elements as near to the part temperature as possible. A large delta in temperature between the heating elements and the parts would result in overheating of the parts' surface, possibly above the solidus temperature for the material as the filler metal begins to melt.

Braze-Joint Fundamentals

Types of Braze Joints

In general, the difference between the favorable and unfavorable

Fig. 5. Band-type fixturing *(courtesy of API Tech)*

types of joints is the amount of overlapping that results in a good braze joint. A stronger braze joint has a large surface area that is wetted by the filler material. Too much overlapping is detrimental to the joint because the filler material will not cover the entire surface when it flows into the joint.

Braze-Joint Strength

Braze-joint strength is dependent on two primary mechanical characteristics: joint wetted surface area and the size of the gap into which the filler metal flows. Gaps of between 0.003-0.008 inch (0.08-2.0 mm) work best for vacuum furnace brazing. Joint gaps are controlled by the manufacturing tolerances of the parts to be brazed and by proper clamping (pre-loading) of the part assemblies to be brazed.

Fixturing of Parts

Part assemblies must be fixtured properly for brazing in order to maintain joint gaps, joint alignment, flow passage alignment and overall assembly tolerances. Some examples of fixturing for assemblies are shown in Figures 4 and 5.

Fixturing materials must be chosen carefully due to different coefficients of expansion for varying materials. Fixture designs are also extremely part-dependent, thought out in great detail and proprietary in some cases since they are an integral part of the manufacturing process.

Cleaning of Parts

Along with good joint design and fixturing, brazing requires part assemblies to be cleaned properly prior to assembly and then handled with care so as not to introduce contamination prior to the brazing cycle. All grease, oil and particulates must be cleaned from the parent and filler-metal surfaces. Assemblers must be careful not to transfer oils from their skin to these surfaces when stacking the parts together. Typical types of cleaning methods are vapor degreasing, hydrocarbon wash, aqueous washing, acid etching and vacuum de-oiling.

Conclusions

What matters most in vacuum aluminum brazing? The key process parameters are deep vacuum levels, precise temperature control and excellent temperature uniformity, which are all provided by optimum furnace design and controls. Keys to successful part brazing include proper joint design with regard to joint surface area and joint gaps, cleanliness of the parts and correct fixturing of the part assemblies.

For more information: Contact Ipsen, Inc., 984 Ipsen Road, Cherry Valley, IL 61016; tel: 815-332-4941; fax: 815-332-4995; e-mail: sales@IpsenUSA.com; web: www.IpsenUSA.com. Author Jim Grann is senior technical manager and Craig Moller is chief engineer. For technical assistance, call 1-844-Go-Ipsen. For more maintenance advice, how-to guides and instructional videos, visit our blog at www.IpsenHarold.com.

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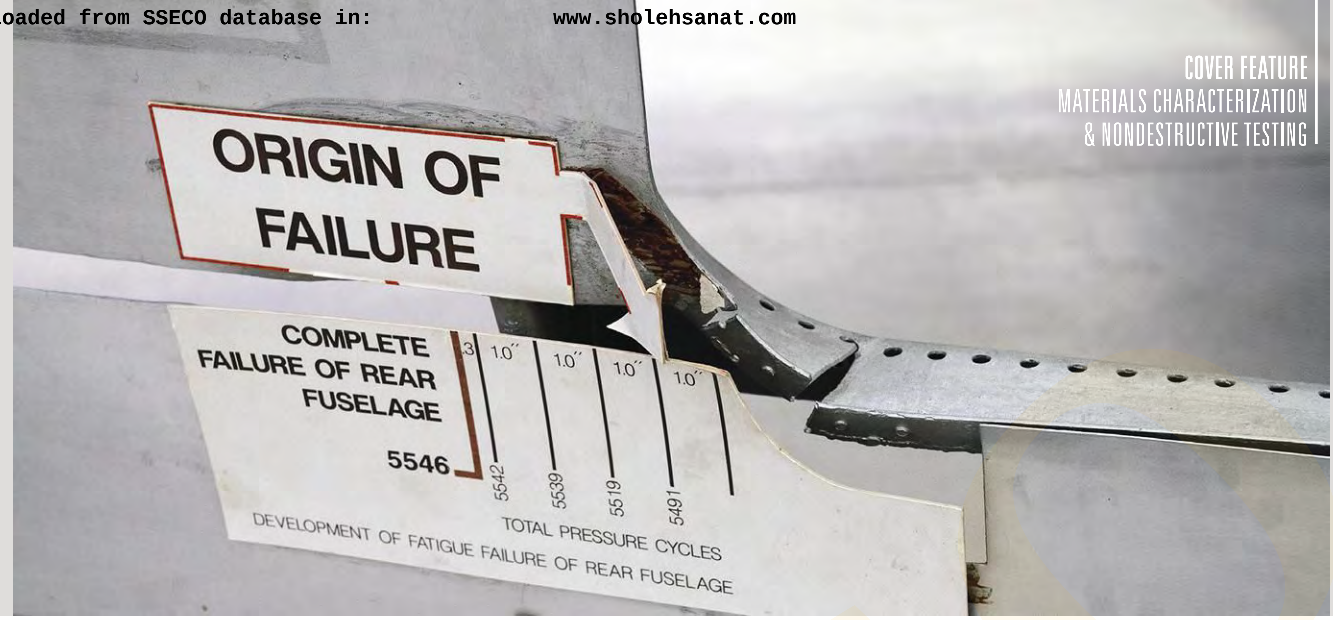
Use this QR-Code to read blogs discussing vacuum aluminum brazing or use the following link: www.industrialheating.com/VABblogs.



Stress-Life Fatigue Testing Basics

Richard Gedney – ADMET Inc.; Norwood, Mass.

The many variables associated with material type, sample geometry and in-service use of a part or component complicate the design and implementation of an appropriate fatigue testing regime.

Fig. 1. The de Havilland DH 106 Comet was the world's first commercial airliner and featured a pressurized cabin designed for transatlantic flights. In 1954, approximately a year and a half after entering service, three Comets broke up mid-flight resulting in the loss of passenger and crew. Following the accidents, the forward fuselage was tested for metal fatigue by repeatedly pressurizing the cabin in a water tank. The pressurized cycle tests identified locations of high stress at the corners of the windows due to their square shape. In order to minimize the stress concentrations in these regions, the plane's designers made the windows more round or oval. *(Maurice Savage/Alamy Stock Photo)*

Since 1850 we have known that metal subjected to fluctuating stresses will fail at a stress much lower than required to cause fracture on a single quasi-static pull to break. Failure usually occurs without warning and results in a brittle-appearing fracture with no significant deformation. Metal fatigue is a multi-step process and is often described as having four stages.

Stage 1: Crack Initiation – A part becomes damaged as a microcrack forms at a point of high stress concentration. High stress concentration points are usually located at notches, sharp edges or corners. Annealing is used to repair metals damaged in stage 1.

Stage 2: Slip Band or Stage I Crack Growth – The initial crack deepens on planes of high shear stress and becomes well-defined.

Stage 3: Stage II Crack Growth – The well-defined crack grows in a direction normal to the maximum tensile stress.

Stage 4: Ductile Failure – When the crack reaches a critical length, the remaining cross section cannot support the applied forces and the part fails.

Cycle Testing

Fatigue tests are most frequently carried out under stress-based constant-amplitude loading. Test samples can be subjected to a variety of waveform geometries. However, sinusoids are most prevalent. Fig. 2 depicts a stress-based sinusoidal waveform showing fully reversed stress cycles. The maximum and minimum stresses are equal and opposite in a fully reversed cycle test. By convention, compressive stresses are negative.

Most stress-based fatigue testing is conducted using fully reversed loading. However, many examples exist where fully reversed loading is not performed either because it is not possible or during normal service a component is only subjected to forces in one direction. Examples of repeated stress-cycle loading include compression-only fatigue tests on hip implants and tension-only tests on sheet steels (thin materials buckle in compression).

Waveform Properties

The following definitions and equations are used to express a stress-based waveform. (Refer to Figs. 2 and 3 for further explanation.)

Stress Range, S_r – difference between the maximum and minimum stress.

$$S_r = S_{max} - S_{min}$$

where: S_{max} = maximum stress
S_{min} = minimum stress

Stress Amplitude, S_a – one half of the stress range, S_r.

$$S_a = S_r/2 = (S_{max} - S_{min})/2$$

Mean Stress, S_m – average of the maximum and minimum stress.

$$S_m = (S_{max} + S_{min})/2$$

Stress Ratio, R – equals -1 for fully reversed loading.

$$R = S_{min}/S_{max}$$

Amplitude Ratio, A – infinite for fully reversed loading.

$$A = S_a/S_m = (1-R) / (1+R)$$

Force Application

Most fatigue tests are conducted by applying fluctuating bending forces, axial forces or torsional forces to a specimen. The formulas for calculating stress for each mode of loading is as follows.

Bending Stress

The maximum bending stress occurs on the surface of the specimen where c is greatest.

$$S_{bending} = Mc/I$$

where: M = moment (force x distance)
c = distance from neutral axis to a point
I = moment of inertia (formula based on shape of specimen, round = / $R^4/4$)

Axial Push-Pull Stress

$$S_{axial} = P/A$$

where: P = axial force
A = cross-sectional area of specimen.

Torsional Stress

The maximum torsional stress occurs on the surface of the specimen where r is greatest.

$$S_{torque} = Tr/J$$

where: T = torque (force x distance)
r = distance from center to a point
J = polar moment of inertia (formula based on shape of specimen, round = $\pi R^4/2$)

Stress-Life Testing

Between 1852 and 1870, the first systematic fatigue tests were carried out on specifically designed laboratory specimens by August Wohler, a German railway engineer. These tests enabled Wohler to relate his experimental results to the stresses in locomotive axles. In 1870, Wohler compiled a report of his experimental work that contained several conclusions known as Wohler's laws.

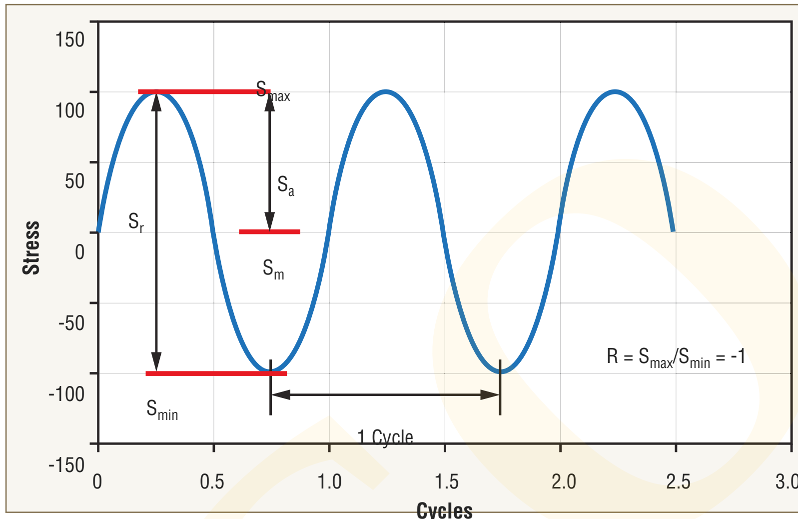


Fig. 2. Fully reversed stress-based cycle

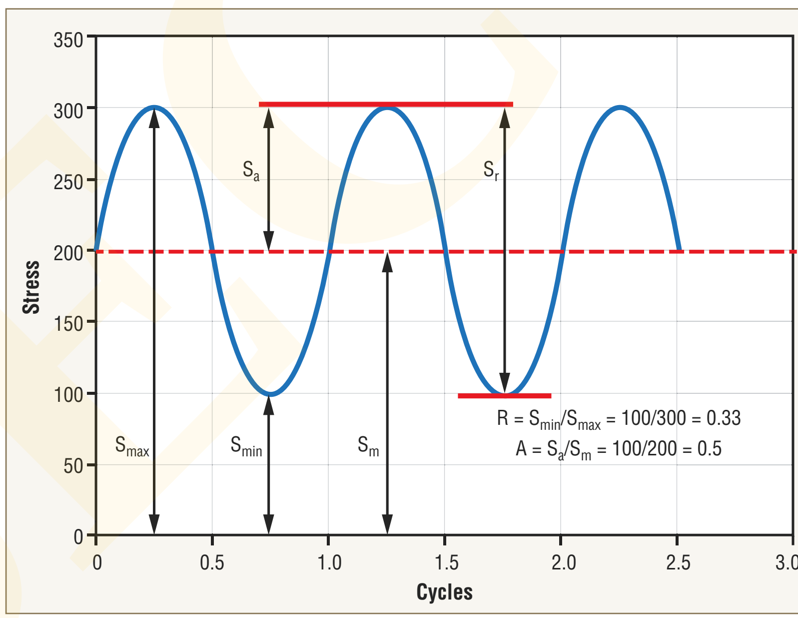


Fig. 3. Repeated stress cycle in which the maximum stress and minimum stress are not equal in magnitude. Both stresses are in tension, but they could also be in tension and compression or compression only.

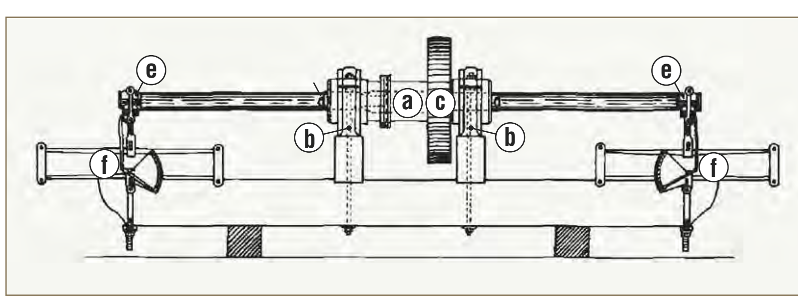


Fig. 4. Wohler's fatigue testing machine. A spindle (a) in the center of the machine is supported by two bearing blocks (b) and rotated at approximately 15 rpm. Two axles (test specimens) were mounted to both ends of the rotating spindle and bending forces were applied to the axles through a spring mechanism (f) located at both ends of the machine. During each revolution, both axles were subjected to a fully reversed bending stress. The magnitude of the bending stress was adjusted by the tension in the spring mechanism.[2]

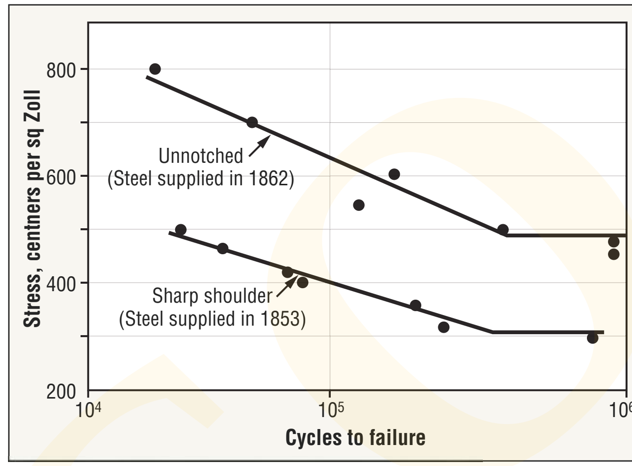


Fig. 5. Wohler's S-N curves for Krupp axle steel.[2]

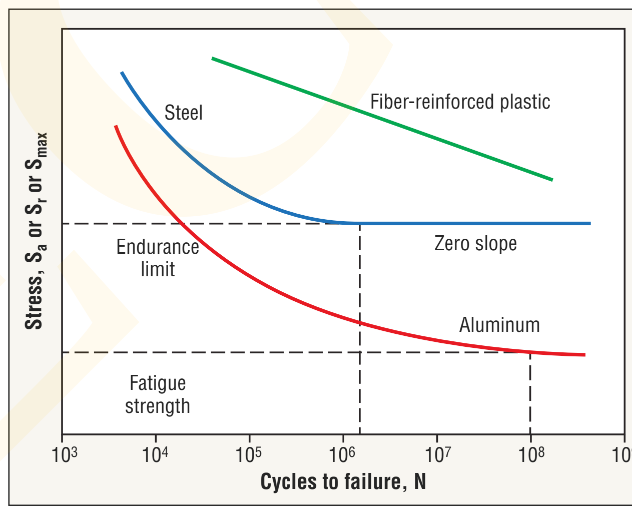


Fig. 6. S-N diagrams for steel, aluminum and fiber-reinforced plastic.

Wohler's Laws[1]

Materials can be induced to fail by many repetitions of stress, all of which are lower than the static strength. Stress amplitudes (or stress range) are decisive for the destruction of the cohesion of the material.

The maximum stress is of influence only insofar as the higher it is, the lower are the stress amplitudes (or stress ranges), which lead to failure. This translates to increasing the mean stress decreases the number of cycles to failure.

Stress-life testing is based on Wohler's work and requires multiple constant amplitude fatigue tests on identical samples to generate an S-N or Wohler diagram. Figs. 4 and 5 are diagrams of Wohler's fatigue testing machine and the S-N diagrams for the steel used in the axles, respectively.[2] Stress-life testing is the most common type of fatigue testing and is designed to determine the safe or infinite life or fatigue strength of a material or component.

The S-N or Wohler Diagram

In stress-based fatigue tests, multiple samples of identical size, shape and composition are subjected to different levels of stress amplitude (S_a) or stress range (S_r), and the number of cycles to failure (N) is measured for each. Various types of instruments and machines are used to apply cyclic loading and include rotating-bend and cantilever-bend machines (Fig. 7), servo-hydraulic or servo-electric axial push-pull testing systems (Fig. 8) and electric-motor-driven torsion fatigue testers (Fig. 9). The resulting S-N data for each identical specimen is plotted on either a log-log or semi-log graph. Regression is used to fit a curve through the points, resulting in an S-N diagram as shown in Figure 6. Depending on the type of cyclic loading, the ordinate (y-axis) will represent stress amplitude (S_a), stress range (S_r) or maximum stress (S_{max}).

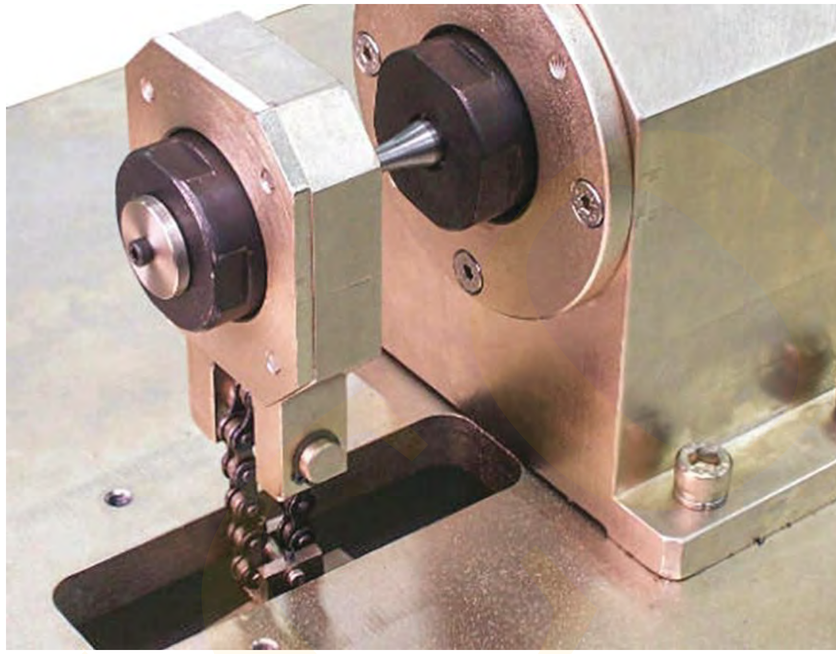


Fig. 7. Ducom Instruments rotating-bar bending fatigue-testing machine. A test piece mounted as a cantilever with single-point loading is made to rotate and thus subjected to a bending moment. Principle is similar to Wohler's machine built in the 1800s *(courtesy of Ducom Instruments)*

Fig. 8. This fatigue testing system is configured for testing dental implants according to ISO 14801 Dentistry Implants – Dynamic Fatigue Test for Endosseous Dental Implants *(courtesy ADMET)*.

development, and 24 for design and reliability analysis. A review of Chapter 3, Planning S-N and Response Tests, STP-588 Manual on Statistical Planning and Analysis for Fatigue Experiments[3] is recommended for those conducting stress-life fatigue tests.

Waveform Cycle Frequency

A fatigue test specimen is subjected to over 10 million cycles (10^7) in order to determine its endurance limit, or fatigue strength, resulting in a single test lasting days and sometimes weeks. As a result, there is an impetus to apply the stress cycle at a high frequency in order to shorten the length of each test.

Stress-life testing of metals under axial loading is governed by ASTM E466 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials. ASTM E466 recommends frequencies between 0.01 Hz to 100 Hz (10^{-2} to 10^2). However, localized yielding that occurs as a crack propagates through the test piece can cause specimen heating.

Metals are good thermal conductors, and any energy converted to heat is easily dissipated. Thus, stress-life testing of metals is generally frequency-independent. Plastics, on the other hand, are more likely to be locally heated by high rates of stress reversals due to their inability to dissipate heat. This coupled with their lower melting points can result in lower fatigue strengths at higher frequencies.

In general, 5 Hz is the recommended maximum frequency for testing plastics. Fiber-reinforced matrix composites have tailored mechanical properties that are dependent on the direction of loading relative to the fibers embedded in the composite. The direction of loading relative to the fibers and amount of resin in the matrix are important parameters when considering test frequencies.

Higher amounts of resin in the matrix produce greater hysteresis (i.e., strains within the resin), resulting in a material more

Fig. 9. A torsion fatigue testing system configured for performing fatigue tests on small components used in portable electronic equipment *(courtesy ADMET)*.

susceptible to heating at higher frequencies. Matrix composite test specifications generally limit the test frequency to 5 Hz or less. Regardless of the material, at the start of any fatigue testing regime, temperature should be monitored to ensure it does not affect the results.

A Final Note

The many variables associated with material type, sample geometry and in-service use of a part or component complicate the design and implementation of an appropriate fatigue testing regime. Like all fatigue tests, the results are suitable for application to design only when the specimen test conditions realistically simulate service conditions. This article presents the basics to stress-life fatigue testing. For those new to fatigue testing and planning to conduct their own tests, the author recommends reviewing the ASTM test specifications and references listed here.

Strain-life and fracture mechanics crack growth testing are two alternative types of fatigue tests in wide use today. Each of the three methods are employed for different design reasons. Stress-life testing is used for determining the safe infinite life of a component. Strain-life testing is used for determining safe finite life and fracture mechanics to measure the damage tolerance of a part.

Partial list of ASTM Stress-Life-Based Fatigue Testing Specifications

- ASTM D3479 Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composites
- ASTM D7774 Standard Test Method for Flexural Fatigue Properties of Plastics
- ASTM D7791 Standard Test Method for Uniaxial Fatigue Properties of Plastics
- ASTM E466 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
- ASTM E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
- ASTM E468 Standard Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials
- ASTM E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (-N) Fatigue Data
- ASTM E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
- ASTM E1823 Terminology Relating to Fatigue and Fracture Testing.

For more information: Richard Gedney is the president and founder of ADMET Inc. (Norwood, MA). For more information, call (800) 667-3220, email info@admet.com, or visit www.admet.com.

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Reader-Rated Melting/Forming/Joining Articles

Reed Miller – Editor

Once again, our readers weigh in on the best articles in 2018. This time it is in the melting/forming/joining category. Interested in what they have to say? Check out the list that follows.

One of our regular topics is "Melting/Forming/Joining." This month, we take a look at seven articles in this category that readers most preferred in 2018 based on online statistics.

Aluminum Scrap Recycling with Twin-Chamber Melting Furnace

Far and away, this article by Tenova from February 2017 is the most-read article in this category for 2018. The interest in recycling likely drove some readers to this article.

Scrap recycling with the twin-chamber melting furnace (TCF®) has become state-of-the-art worldwide. Nearly any type of scrap can be treated in the TCF. The latest installations show that the TCF fulfills the complex requirements of scrap processing regarding environment, safety and metal yield. Find out why so many readers were interested in this article by using this link: www.industrialheating.com/TCFscrap.

Combustion Technologies Improve Melting-Furnace Productivity

A June 2018 Air Products article comes in at number two for our readers. Find out what interested so many by using the following link: www.industrialheating.com/meltcomb.

New combustion technologies offer metals producers the ability to adjust the energy distribution profile and customize heat release to the requirements of a given melting operation. This article discusses how the unique capabilities of two new burners helped SDI La Farga (SDILF) increase productivity, decrease specific fuel consumption and significantly reduce burner maintenance time in its secondary copper-melting furnace.

Interestingly, as with the first article, recycling might be driving some traffic because SDILF is a recycling operation that refines all types of processed copper. To address burner challenges and achieve aggressive productivity targets, SDILF evaluated and implemented unique combustion technologies capable of adapting to the diverse needs of the operation.

Playing with Fire: Blacksmithing a Hot Topic

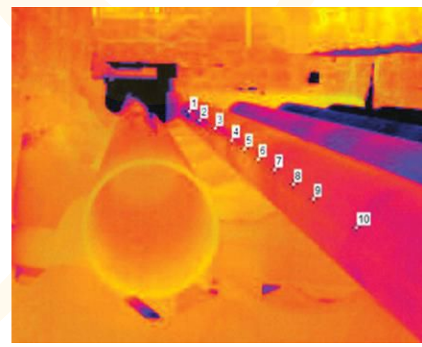
An April 2018 feature written by *Industrial Heating* staff in cooperation with Carnegie Mellon University has found favor with readers this year. We have noticed an uptick in the number of blacksmithing stories over the past few years. Because of this general interest, we try to highlight some of these in our magEzine newsletters.

Almost weekly, we run across another interesting blacksmithing story about someone who seems an unlikely blacksmith or who is making wonderful creations from lumps of metal or common items. In this article, we highlight the story of a Carnegie Mellon graduate student, but we also talk about the general phenomenon. To read it for yourself, go to www.industrialheating.com/smith.

Process Thermal Imaging in the Modern Hot-Rolling Mill

A March 2018 article by AMETEK Land has also piqued reader interest this year. This article discusses the application of single-point radiation thermometers, also referred to as infrared pyrometers, in steel hot-rolling mills. Infrared pyrometers have been widely used in steel hot-rolling mills for more than 60 years. They offer many advantages compared to contact sensors such as thermocouples.

Single-point radiation thermometers are installed at a distance, and they view the infrared radiation that is emitted by the target object. Their noncontact nature allows them to operate out of harm's way, consequently outlasting contact sensors. Because they don't touch the surface, they can accurately measure moving objects, whereas thermocouples suffer from a frictional effect, which generates heat and erodes the thermocouple. Pyrometers also feature extremely fast response speeds of a few milliseconds. This makes them very useful for measuring fast-moving strip or rod. You can find this article at www.industrialheating.com/irpyro.



Using Induction Brazing in Manufacturing Operations

This article was actually run in two parts in 2016, and both are still popular with readers in 2018. It does a good job of discussing induction and its application to the joining technology of brazing. Induction is an excellent way to quickly heat up a localized area of a large assembly in order to permanently join them together. The induction-brazing process is examined to see what it is and how it can be effectively used by brazing shops to meet some of their production needs.

Induction brazing is a wonderful tool that many shops may wish to use for certain parts that need to be brazed quickly, are too large to fit inside a brazing furnace or perhaps have areas that cannot tolerate high heat since damage might result to those areas if heated to brazing temperature. It is safe, fast and very reliable when proper procedures are followed.

Start with part 1 at www.industrialheating.com/kaybraze1 and then move to part 2 by navigating to www.industrialheating.com/kaybraze.

Torch Brazing by Hand

Clearly, brazing is of interest to readers because a February 2018 article also by Dan Kay is next on our favorites list. Brazing is one of three joining techniques in our manufacturing world that uses heat and a molten filler metal to create complex assemblies from simple starting pieces. The other two processes are welding and soldering.

When brazing, the base material being joined is not melted. Only the brazing filler metal (BFM) that is

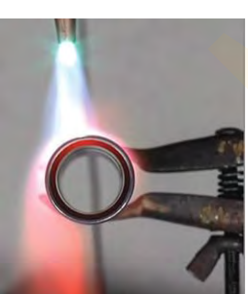
added to the joint is melted, and this molten BFM is then drawn into the joint by capillary action. Effective brazing requires heat, cleanliness of the parts being joined and, in the case of torch brazing by hand, special operator skills are needed. You can find this reader favorite at www.industrialheating.com/handbrz.

Vacuum Diffusion Bonding for Joining Titanium Alloys

The final article on our favorites list ties in nicely with this month's aerospace focus, and it's also focused on joining. The technology of joining materials is vital to the growth of various industries where particularly demanding requirements and sophisticated materials are involved. These industries include aerospace, automotive, shipbuilding, oil, petrochemical and process engineering.

Demanding joining applications have led to increased attention being paid to diffusion bonding. This method is widely used for production of thin-metal components and parts with very complex shapes. Joints made by diffusion bonding meet the requirements for most critical structures in terms of strength, toughness, tightness and resistance to heat and corrosion. Since the process is conducted under a vacuum, a diffusion-bonded joint has minimal impurity content, even in the case of highly reactive metals. This is the reason diffusion bonding has found significant application for the fabrication of complex titanium-alloy components.

You can read this September 2017 TAV Vacuum Furnaces article at www.industrialheating.com/diffbond.



We trust you will enjoy these articles as much as other readers have in 2018. You can further mine the depths of melting, forming or joining website by going to www.industrialheating.com/mfj or using the QR Code provided.

SCAN ME

Fig. 1. Continuously working furnace for heat treatment of springs at a working temperature of up to 500°C

Continuous Tempering Furnaces to Comply with Nadcap/CQI-9

Roland von Bargen – Nabertherm GmbH; Lilienthal, GERMANY

The primary applications for our furnaces are advanced materials (ceramics), glass, laboratory applications including dental laboratories and especially thermal-processing technology.

The demand for improved temperature uniformity in combination with increased productivity as well as stable and reliable processing equipment is increasing significantly. Hence, compliance with specifications like AMS 2750E and CQI-9 is more frequently requested by our customers. Living up to these requirements is more challenging for continuous furnaces than for batch furnaces.

At first, a suitable measuring setup must be determined for the specific process. Looking at the heat treatment or tempering of springs as a bulk good, this needs to be done within the charged furnace and appropriate test pieces holding the thermocouples.

In terms of the process itself, a fast and homogeneous heat-up without any overshoots due to overheating, for example, is required as a first step. Afterward, the springs need to dwell for a certain time with a stable and homogeneous temperature uniformity across the charged area in accordance with the requirements of CQI-9. In order to comply with these requirements, an improved furnace technology is required.

Continuous Furnace with Jet Heating

The technical solution to meet the defined challenges is a continuous furnace with jet heating in the heat-up zone and conventional forced convection in the following dwell zones. Figure 1 shows one of these furnaces for the heat treatment of springs at a working temperature of up to 500°C (932°F) with a throughput of 300 kg/hour. Its heated length is approximately 3,600 mm (12 feet), and the useful band width is 1,100 mm (43 inches). Other realized furnace models are able to heat treat 400 kg/hour, and the largest ones even up to 600 kg/hour with a heated length of less than 6,000 mm and the same process cycle time and productivity.

Within the first zone, the springs are rapidly heated to the required setpoint without overheating to ensure a homogeneous quality of spring properties. A specially designed air-guidance frame is the technological feature that realizes this huge benefit. The heated air hits the bulked springs from the top with a very high velocity and volume flow rate down to the conveying belt level (Fig. 2).

After hitting the belt, the air is recycled and heated up to repeat the process. With this technology, Nabertherm realizes short and very homogeneous heat-up times at a high productivity without overshoots due to over-temperature, which are not allowed by CQI 9. For springs, typical bulking heights of 50 mm for small springs with a high bulk density can be heated up quickly.

In the second and third heating zones of the furnace, the springs dwell at set temperature for the required amount of time to achieve the customer-requested properties. Within these heating zones, a conventional forced-convection air-guidance frame (including baffles) is used to optimize the airflow onto the charge and achieve the required temperature uniformity over the belt width (Fig. 2).

In other words, an optimal temperature uniformity over the belt width can be obtained to meet the strict regulations of automotive market suppliers. The furnaces can be optionally designed to fulfill Nadcap or CQI-9 norms. For example, the furnace shown in figure 1 achieves a temperature uniformity of better than +/-10˚C in loaded condition according to CQI-9.

The measurement setup is shown in figure 3 and a typical measurement report in figure 4. For the measurement, five specimens of springs welded in the shape of typical bulking formations with tubes to fix the thermocouples are set into the bulked goods. The specimens are evenly distributed over the workspace (useful band width), and the measurement is conducted during continuous operation of the furnace with the designated charge throughput.

Conveying System and Automation

The conveying system is a stainless steel mesh belt driven by chain wheels (Fig. 5). The huge benefit of using stainless steel is that the system can be run lubrication-free. This is beneficial for many reasons. For example:

- Reduction of maintenance cost
- No contamination of the final product with lubricants or burnt residues
- No evaporation/fumes are released into the working environment due to decomposing or burning lubricants

Fig. 2. Furnace interior with different air-guidance systems depending on the different heating zones

The furnaces can be adapted to different modes and requirements for loading and unloading. From completely manual loading and unloading for larger springs to fully automized loading and unloading, nearly everything is possible. The belt width can also be divided by separators along the movement direction in order to treat different springs or different tolerance levels of one spring at the same time. The customer can choose between the following solutions:

- Manual loading and unloading of large springs
- Manual loading of large springs and passive unloading by a slide into a carrier box or onto a cooling track
- Automatic loading by a slide from a pre-process and

Fig. 3. Measurement setup for temperature uniformity survey with bulked load separated in three lanes

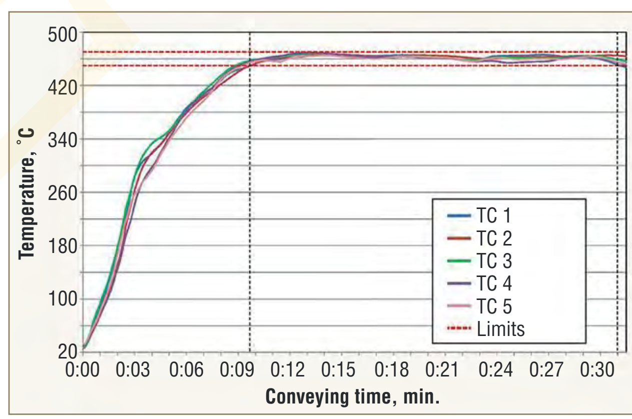


Fig. 4. Measurement curve for temperature uniformity survey with bulked load separated in three lanes

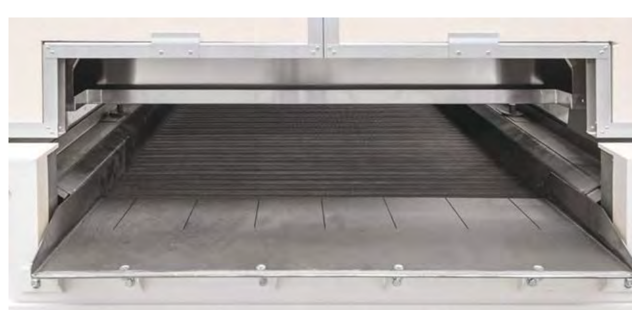


Fig. 5. Stainless steel mesh belt with chain wheel drive

unloading onto a slide into a box or onto a cooling track

- Belt width divided into three lanes – one wide central lane and two smaller ones to the left and right side of the belt. During the pre-process, the coiling machine automatically measures the springs and separates them into three tolerance levels (too short, OK, too long), which are directly transported into the furnace in separate lanes. All springs are treated identically in the process, and the tolerance level of the shorter and longer springs can be corrected by consecutive milling. Figure 1 shows this setup with the required handling devices in front and behind the furnace.

The aforementioned examples affirm that fully automized lines are possible and can easiliy be realized.

Summary and Outlook

Nabertherm continuous furnaces allow a highly productive in-line tempering process for springs as bulk goods or as single pieces. With this technology, a faster heat-up is achieved without using over-temperatures that might influence the final properties or result in overshooting, which is not allowed by CQI-9.

Due to the faster heat-up phase, the dwell cycle under homogeneous temperature distribution can either be extended without changing floor space or the floor space can be reduced with a shorter furnace length. By the semi-modular furnace design with one or more heating zones and the following dwell zones, the furnaces can be easily adapted to different throughput requirements by extending or decreasing the overall length.

Choosing the right furnace provides productivity gains at a high quality level as a competitive edge not only for springs, as reported in this article, but also for other bulk goods. IH

For more information: Contact Roland von Bargen, project manager, Nabertherm GmbH, Bahnhofstr. 20, 28865 Lilienthal / Bremen (Germany); tel.: +49 (4298) 922-165, fax: +49 (4298) 922-129; e-mail: Roland.vonBargen@nabertherm.de; web: http://www.nabertherm.de. Nabertherm is a Germany-based company offering furnaces since 1947, with industrial furnaces covering nearly all heat-treatment needs.

17th Annual Materials Characterization & Testing Buyers Guide

The following companies are suppliers of testing and material characterization equipment. Easily find the piece of equipment you're looking for and see the corresponding companies that offer it. More information about each company can be found online at www.industrialheating.com/materialstesting

Suppliers listed in this Buyers Guide responded to a special mailing by *Industrial Heating* and do not necessarily represent the entire materials characterization and testing industry. To be included as a supplier in this Buyers Guide, please contact Breanne Rozek at 248-244-6259 or rozekb@bnpmedia.com.

Company	Adhesion- / Bond-Strength Testers	Bend Testers (See Universal Testing Machines)	Borescopes, Other Visual Inspection Equipment / Systems	Chemical / Surface Analysis Equipment - Spectrometers, Emission	Chemical / Surface Analysis Equipment - Spectrometers, Mass	Chemical / Surface Analysis Equipment - Spot Test Kits, Metal / Alloy	Compression Testers (See Universal Testing Machines)	Corrosion Testing Equipment	Creep Testers	Dilatometers	Eddy Current Testers / Accessories	Electromagnetic Testers	Extensometers	Fastener Testers	Fatigue Testers	Film Thickness Meters	Flexural Testers (See Universal Testing Machines)	Fracture Toughness Testing Equipment	Furnaces / Environmental Chambers (Laboratory)	Gas Analyzers
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Aerohoff Inspection Services Inc. P.O. Box 5801, Oceanside, CA 92052-5801 (760) 806-2782 sales@aerohoff.com; www.aerohoff.com											●									
Aerospace Testing and Pyrometry 4371 Saratoga Dr., Bethlehem, PA 18020 (844) 828-7225 sales@atp-cal.com; www.atp-cal.com																			●	
AFFRI Inc. 850 Dillon Dr., Wood Dale, IL 60191 (224) 374-0931; Fax: (630) 350-7958 usa@affri.com; www.affri.com		●																		
AIC Supplies LLC 27555 Homestead Rd., Laguna Niguel, CA 92677 (949) 877-1920 info@aicsupplies.com; www.aicsupplies.com																				●
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AMWEI Thermistor Sensor Co. 11-502, Songpingshan, Langshan Rd., North Area, Shenzhen High-tech Industrial Park., Nanshan, Guangdong, China 518057 86-755-26570111; sales@amwei.com; www.amwei.com																				
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Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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Fischer Technology 750 Marshall Phelps Rd., Windsor, CT 06095 (800) 243-8417; Fax: (860) 298-6090 info@fischer-technology.com; www.fischer-technology.com								●	●		●				●	●		●		

Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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17th Annual Materials Characterization & Testing Buyers Guide

Company	Adhesion- / Bond-Strength Testers	Bend Testers (See Universal Testing Machines)	Borescopes, Other Visual Inspection Equipment / Systems	Chemical / Surface Analysis Equipment - Spectrometers, Emission	Chemical / Surface Analysis Equipment - Spectrometers, Mass	Chemical / Surface Analysis Equipment - Spot Test Kits, Metal / Alloy	Compression Testers (See Universal Testing Machines)	Corrosion Testing Equipment	Creep Testers	Dilatometers	Eddy Current Testers / Accessories	Electromagnetic Testers	Extensometers	Fastener Testers	Fatigue Testers	Film Thickness Meters	Flexural Testers (See Universal Testing Machines)	Fracture Toughness Testing Equipment	Furnaces / Environmental Chambers (Laboratory)	Gas Analyzers
Forward Technology LLC 260 Jenks Ave., S.W., Cokato, MN 55321 (320) 286-2578; Fax: (320) 286-2467 info@forwardtech.com; www.forwardtech.com	●																			
Gilmore Diamond Tools Inc. 1231 County St., Attleboro, MA 02703 (508) 226-0053; Fax: (508) 226-0072 info@gilmorediamond.com; www.gilmorediamond.com																		●		
Hitachi High-Tech Analytical Science 2 Technology Park Dr., 2nd Fl., Westford, MA 01886 (978) 850-5580 contact@hitachi-hightech-as.com				●	●			●			●									
ibg NDT Systems Corp. 20793 Farmington Rd., Ste. 8, Farmington Hills, MI 48336-5182 (248) 478-9490; Fax: (248) 478-9491 sales@ibgndt.com; www.ibgndt.com											●									
Imada Inc. 3100 Dundee Rd., Ste. 707, Northbrook, IL 60062 (847) 562-0834; Fax: (847) 562-0839 imada@imada.com; www.imada.com														●						
Impact Scientfic 32158 Camino Capistrano #A429, San Juan Capistrano, CA 92675 (949) 533-9100 dhenriks@impactscientific.com; www.impactscientific.com																				
KARL STORZ Industrial Group 2151 E. Grand Ave., El Segundo, CA 90245 (800) 329-9618; Fax: (805) 968-0933 industrialsales@karlstorzindustrial.com; www.karlstorzindustrial.com			●																	
Kiltel Systems Inc. 2809 96th Ave. N.E., Clyde Hill, WA 98004-1710 (425) 451-7689 paul@kiltel.com; www.kiltel.com																				
King Tester Corp. 308 Schell Ln., Phoenixville, PA 19460 (610) 279-6010 king@kingtester.com; www.kingtester.com																				
LECO Corp. 3000 Lakeview Ave., St. Joseph, MI 49085 (269) 985-5496; Fax: (269) 982-8977 info@leco.com; www.leco.com				●	●															
Mager Scientific Inc. 1100 Baker Rd., P.O. Box 160, Dexter, MI 48130-0160 (734) 426-3885; Fax: (734) 426-3987 sales@magersci.com; www.magersci.com																				

Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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17th Annual Materials Characterization & Testing Buyers Guide

Company	Adhesion- / Bond-Strength Testers	Bend Testers (See Universal Testing Machines)	Borescopes, Other Visual Inspection Equipment / Systems	Chemical / Surface Analysis Equipment - Spectrometers, Emission	Chemical / Surface Analysis Equipment - Spectrometers, Mass	Chemical / Surface Analysis Equipment - Spot Test Kits, Metal / Alloy	Compression Testers (See Universal Testing Machines)	Corrosion Testing Equipment	Creep Testers	Dilatometers	Eddy Current Testers / Accessories	Electromagnetic Testers	Extensometers	Fastener Testers	Fatigue Testers	Film Thickness Meters	Flexural Testers (See Universal Testing Machines)	Fracture Toughness Testing Equipment	Furnaces / Environmental Chambers (Laboratory)	Gas Analyzers
Mahr Inc. 1144 Eddy St., Providence, RI 02905 (800) 343-2050; Fax: (401) 784-3246 orders@mahr.com; www.mahr.com																				
Massachusetts Materials Research Inc. P.O. Box 810, 1500 Century Dr., West Boylston, MA 01583 (508) 835-6262; Fax: (508) 835-9025 kpelletier@massmaterials.com; www.massmaterials.com	●				●										●					
MB Dynamics 25865 Richmond Rd., Cleveland, OH 44146 (216) 292-5850 sales@mbdynamics.com; www.mbdynamics.com															●					
Mecmesin Corp. 45921 Maries Rd., Ste. 120, Sterling, VA 20166 (703) 433-9247; Fax: (703) 444-9860 info@mecmesin.com; www.mecmesin.com	●	●					●						●	●			●			
Metlab Corp. 4011 Hyde Park Blvd., P.O. Box 1075, Niagara Falls, NY 14302-1075 (800) 828-6866; Fax: (716) 282-6971 sales@metlabcorp.com; www.metlabcorp.com			●																	
Milwaukee Technologies Inc. 7620 W. Clarke St., Milwaukee, WI 53213 (414) 453-8111 fpmti58@gmail.com; www.brinellhardnesstesters.net																				
MKS Instruments Inc. 2 Tech Dr., Ste. 201, Andover, MA 01810 (800) 227-8766; Fax: (978) 557-5100 mks@mksinst.com; www.mksinst.com					●															●
North Star Imaging - An ITW Co. 19875 S. Diamond Lake Rd., Rogers, MN 55374 (800) 635-8392; Fax: (763) 463-5651 sales@4nsi.com; www.4nsi.com																				
NSL Analytical Services Inc. 4450 Cranwood Pkwy., Cleveland, OH 44128 (877) 560-3992; Fax: (216) 438-5050 techsales@nslanalytical.com; www.nslanalytical.com		●			●	●								●	●		●		●	
Odyssey Technical Solutions 2000 Steam Way, Round Rock, TX 78665 (512) 989-7007 sales@odysseyrf.com; www.odysseyrf.com											●									
OXY-GON Industries Inc. P.O. Box 40, Epson, NH 03234 (603) 736-8422; Fax: (603) 736-8734 sales@oxy-gon.com; www.oxy-gon.com																			●	

Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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17th Annual Materials Characterization & Testing Buyers Guide

Company	Adhesion- / Bond-Strength Testers	Bend Testers (See Universal Testing Machines)	Borescopes, Other Visual Inspection Equipment / Systems	Chemical / Surface Analysis Equipment - Spectrometers, Emission	Chemical / Surface Analysis Equipment - Spectrometers, Mass	Chemical / Surface Analysis Equipment - Spot Test Kits, Metal / Alloy	Compression Testers (See Universal Testing Machines)	Corrosion Testing Equipment	Creep Testers	Dilatometers	Eddy Current Testers / Accessories	Electromagnetic Testers	Extensometers	Fastener Testers	Fatigue Testers	Film Thickness Meters	Flexural Testers (See Universal Testing Machines)	Fracture Toughness Testing Equipment	Furnaces / Environmental Chambers (Laboratory)	Gas Analyzers
Parker Research Corp. P.O. Box 1406, Dunedin, FL 34697-1406 (800) 525-3935; Fax: (727) 797-3941 sales@parkerndt.com; www.parkerndt.com																				
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Phase II Machine & Tool Inc. 21 Industrial Ave., Upper Saddle River, NJ 07458 (800) 526-9087; Fax: (201) 963-8353 info@phase2plus.com; www.phase2plus.com			●													●				
PolyScience 6600 W. Touhy Ave., Niles, IL 60714 (800) 229-7569; Fax: (847) 647-1155 sales@polyscience.com; www.polyscience.com					●															●
Power n Sun Burlington Tower, Business Bay, Ste. 2305, Dubai United Arab Emirates 971 4 3686393 info@powernsun.com; https://powernsun.com																				
Proceq USA Inc. 117 Corporation Dr., Aliquippa, PA 15001 (724) 512-0330; Fax: (724) 512-0331 info-usa@proceq.com; www.proceq.com	●																			
Ross Engineering Corp. 540 Westchester Dr., Campbell, CA 95008 (408) 377-4621; Fax: (408) 377-5182 info@rossengineeringcorp.com; www.rossengineeringcorp.com																				
Russell NDE Systems Inc. 4909 - 75 Ave., Edmonton, Canada T6B 2S3 (780) 468-6800; Fax: (780) 462-9378 info@russelltech.com; www.russelltech.com			●								●	●								
Shimadzu Scientific Instruments 7102 Riverwood Dr., Columbia, MD 21046 (410) 381-1227; Fax: (410) 381-1222 webmaster@shimadzu.com; www.ssi.shimadzu.com	●			●	●								●							
SIUI (Shantou Institute of Ultrasonic Instruments Co. Ltd.) #77 Jinsha Rd., Guangdong, Shantou, China 515041 86-754-88250150; Fax: 86-754-88251499 siui@siui.com; www.siui.com								●												
Sonatest 12775 Cogburn, San Antonio, TX 78249 (210) 697-0335 sales@sonatestinc.com; www.sonatest.com								●								●				

Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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17th Annual Materials Characterization & Testing Buyers Guide

Company	Adhesion- / Bond-Strength Testers	Bend Testers (See Universal Testing Machines)	Borescopes, Other Visual Inspection Equipment / Systems	Chemical / Surface Analysis Equipment - Spectrometers, Emission	Chemical / Surface Analysis Equipment - Spectrometers, Mass	Chemical / Surface Analysis Equipment - Spot Test Kits, Metal / Alloy	Compression Testers (See Universal Testing Machines)	Corrosion Testing Equipment	Creep Testers	Dilatometers	Eddy Current Testers / Accessories	Electromagnetic Testers	Extensometers	Fastener Testers	Fatigue Testers	Film Thickness Meters	Flexural Testers (See Universal Testing Machines)	Fracture Toughness Testing Equipment	Furnaces / Environmental Chambers (Laboratory)	Gas Analyzers
Struers Inc. 24766 Detroit Rd., Westlake, OH 44145-2525 (888) 787-8377; Fax: (440) 871-8188 info@struers.com; www.struers.com																				
Sun Electronic Systems Inc. 1845 Shepard Dr., Titusville, FL 32780 (321) 383-9400; Fax: (321) 383-9412 info@sunelectronics.com; www.sunelectronics.com																			●	
Sun-Tec Corp. **46590 Ryan Ct., Novi, MI 48377** **(248) 669-3100; Fax: (248) 669-1199** **info@sunteccorp.com; www.sunteccorp.com** See Our Ad on Page 37																				
Sun-Tec Corp., Detroit Testing Machine 46590 Ryan Ct., Novi, MI 48377 (248) 669-3100; Fax: (248) 669-1199 info@sunteccorp.com; www.sunteccorp.com																				
Technisonic Research Inc. 328 Commerce Dr., Fairfield, CT 06825 (203) 368-3600; Fax: (203) 368-1922 tonyr@technisonic.net; www.technisonicinc.com																				
Technology Design Ltd. Wharton Park House, Nat Ln., Winsford, Cheshire United Kingdom CW7 3BS; 44-0-1606-590123; Fax: 44-0-1606-591253 tdsales@technologydesign.com; www.technologydesign.com								●												
Technology for Energy Corp. (TEC) 10737 Lexington Dr., Knoxville, TN 37932 (865) 966-5856; Fax: (865) 675-1241 daniel.klawonn@tec-materialstesting.com; www.tec-materialstesting.com																				
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Thermcraft Inc. 3950 Overdale Rd., Winston Salem, NC 27107 (336) 784-4800; Fax: (336) 784-0634 info@thermcraftinc.com; www.thermcraftinc.com																			●	
Thwing-Albert Instrument Co. 14 W. Collings Ave., West Berlin, NJ 08091 (856) 767-1000; Fax: (856) 767-2615 info@thwingalbert.com; www.thwingalbert.com	●	●					●						●			●				
Tinius Olsen **1065 Easton Rd., Horsham, PA 19044** **(215) 675-7100; Fax: (215) 441-0899** **info@tiniusolsen.com; www.tiniusolsen.com** See Our Ad on Page 42	●													●						

Hardness Testers / Accessories	●		●	●							●
Image Analysis Systems (for Quantitative Metallography)	●										
Impact Testers											●
Infrared Thermography Equipment								●			
Leak Testers											
Load Cells											
Magnetic Particle Testing Equipment / Accessories											
Metallographic Specimen Preparation Equipment / Supplies	●		●	●							
Metallographs											
Microscope Accessories											
Microscopes - Electron, Scanning											
Microscopes - Electron, Transmission											
Microscopes - Light, Metallurgical											
Microscopes - Stereo											
Modulus Testers, Dynamic											
Particle / Powder Analyzers (Size, Surface Area, etc.)											
Penetrant Testing Equipment / Accessories											
Porosimeters											
Radiographic Testing Equipment / Supplies											
Recorders / Controllers - Temperature		●									
Residual Stress Analyzers / Testers							●				
Software (Mechanical Testing, Nondestructive Testing)											●
Sorters (Metals And Alloys)											
Stiffness Testers										●	
Strain Gauges										●	
Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)								●	●		
Tensile Testers (See Universal Testing Machines)				●						●	
Thermal Analyzers								●			
Thickness Gauges										●	
Torsion Testers											●
Ultrasonic Testers / Accessories					●	●					
Universal (Tension / Compression) Testing Machines / Accessories			●							●	●
Viscometers											

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Ulbrich Stainless Steels & Special Metals Inc. 153 Washington Ave., North Haven, CT 06473 (203) 239-4481; Fax: (203) 239-7479 information@ulbrich.com; www.ulbrich.com																				
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United Testing Systems Inc. 1375 S. Acacia Ave., Ste. A, Fullerton, CA 92831 (800) 765-9997 info@unitedtesting.com; www.unitedtesting.com	●	●					●		●				●	●	●		●		●	
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Vulcan Electric Co. 28 Endfield St., Porter, ME 04068 (207) 625-3231; Fax: (207) 625-8938 www.vulcanelectric.com																				
Willrich Precision Instrument Co. Inc. 80 Broadway, Cresskill, NJ 07626 (866) 945-5742; Fax: (201) 567-1411 victoria@willrich.com; https://willrich.com			●																	
YFT Leak Test 18 Flyway Dr., Newtown Square, PA 19073 (844) 938-5325 info@yamahaleaktest.com; www.yamahaleaktest.com	●																			

Hardness Testers / Accessories	Image Analysis Systems (for Quantitative Metallography)	Impact Testers	Infrared Thermography Equipment	Leak Testers	Load Cells	Magnetic Particle Testing Equipment / Accessories	Metallographic Specimen Preparation Equipment / Supplies	Metallographs	Microscope Accessories	Microscopes - Electron, Scanning	Microscopes - Electron, Transmission	Microscopes - Light, Metallurgical	Microscopes - Stereo	Modulus Testers, Dynamic	Particle / Powder Analyzers (Size, Surface Area, etc.)	Penetrant Testing Equipment / Accessories	Porosimeters	Radiographic Testing Equipment / Supplies	Recorders / Controllers - Temperature	Residual Stress Analyzers / Testers	Software (Mechanical Testing, Nondestructive Testing)	Sorters (Metals And Alloys)	Stiffness Testers	Strain Gauges	Temperature Measuring Devices (Pyrometers, Thermocouples, IR Thermometers, etc.)	Tensile Testers (See Universal Testing Machines)	Thermal Analyzers	Thickness Gauges	Torsion Testers	Ultrasonic Testers / Accessories	Universal (Tension / Compression) Testing Machines / Accessories	Viscometers
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Aftermarket/Training/Consulting Directory
Directory and buyers guide of aftermarket replacement and spare parts for industrial furnace systems and the companies that supply them.

Heat-Treating Capabilities Directory
Directory of commercial heat treaters to choose from by certifications and thermal-processing capabilities.

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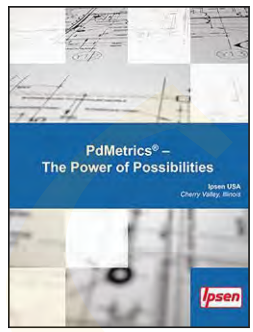

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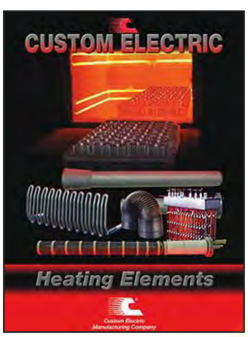

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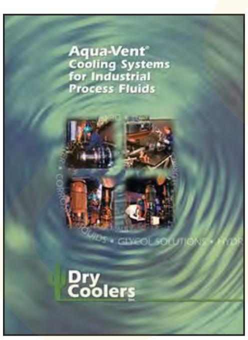

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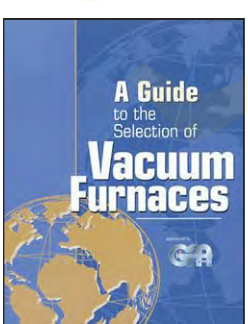

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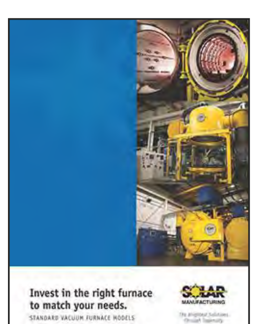

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Hardness Testing Machines

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The FH Series from Tinius Olsen offers a full range of hardness testers, including: universal, Rockwell, Vickers and Brinell models; standard and extended height frames; indenters and tables; hardness blocks; a full slate of options and accessories; and Horizon analysis and control software.
www.tiniusolsen.com

Laboratory and Industrial Furnaces

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Carbolite Gero, part of Verder Scientific, offers industrial heat-treatment solutions from 30-3000°C. With 75 years of experience Carbolite Gero has the expertise to provide an ideal, robust solution for your heat-treatment needs. Carbolite Gero also specializes in units compliant to AMS 2750E and cold-wall vacuum chamber furnaces.
www.verder-scientific.com

Thermal Processing Products

Refractory Technology

Stellar Materials LLC

Thermbond 7200 Series can substantially reduce the cost of most furnace repairs through its ability to provide consistent properties regardless of installation method. It can be mixed with water for casting or pumping; mixed with 7200 Liquid for gunning or ramming; or mixed with 7200 Accelerator for shotcreting. Only two different liquids are required for all five major installation methods, and the amount of liquid is roughly 5% by volume of the dry mix. Thermbond 7206 is a mullite-based material, and Thermbond 7206-N is non-wetting to molten aluminum. Thermbond 7229 is a mullite-based material with a 20% SiC addition, and Thermbond 7229-N is the same formulation in a version that is non-wetting to molten aluminum. www.thermbond.com

Polishing Guide for Metallography

Buehler Ltd.

"Polishing Guide" includes application and process information for metallography lab technicians. Topics include how polishing works and why picking the right consumables can be the difference between moving on to analysis and having to start over with another sample. It features a selection guide for cloths, as well as expert knowledge to help choose the best quality abrasives. The guide also includes solutions to common issues; frequently asked questions; and recommended polishing methods for aluminum, nickel, titanium, copper, composites, thermal coatings and steels. www.buehler.com

Horizontal Hardening Machine

EFD Induction

Horizontal continuous (HC) and horizontal pusher (HP) versions are now combined in the new horizontal hybrid (HH) machine. HardLine Hybrid can be used as either pusher, continuous or both to provide three different functions in one machine, reducing both cost and setup time. HardLine horizontal heat-treatment systems deliver short cycle times, reproducibility and the reliability needed when mass-producing steel bars and shafts. The machine can handle workpiece lengths from 50 to 600 mm and diameters of 5 to 50 mm. Automatic reject separation allows working without stops. HardLine Hybrid is very operator friendly with smart ergonomic design and easy-to-use control interfaces. www.efd-induction.com

Cleaning Technology

Houghton International

An advanced cleaner has been designed to replace solvents in precision cleaning applications. Houghto-Rinse RTD is a water-based, non-flammable, ready-to-use cleaner that delivers outstanding process performance and surface appearance in a wide range of surface finishing applications. It is a direct replacement for highly volatile solvents in applications where flammability, health, safety and environmental factors are concerns. It Houghto-Rinse RTD is safe for use on all surfaces, including aluminum, steel and magnesium. www.houghtonintl.com

Temperature Profiler for Vacuum Brazing Furnaces

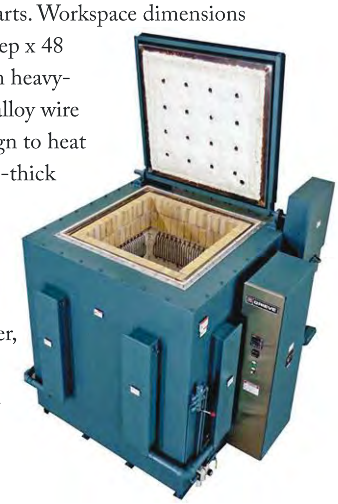
Fluke Process Instruments

The Datapaq Furnace Tracker automatically generates CQI-9 and AMS 2750E reports for aluminum vacuum brazing furnaces. The data logger traces product temperature profiles via 10 thermocouples throughout all process phases. Thermal protection is provided by a phase-change heat sink and a thermal barrier consisting of nine stainless steel and aluminum reflective plates with a ceramic outer coating. The Datapaq VB1150 vacuum barrier protects the logger for 3.5 hours at 1112°F (600°C), and the maximum operating temperature is 1292°F (700°C). After only 45 minutes of cooling down, the system is ready to be reused. www.flukeprocessinstruments.com

Atmosphere Pit Furnace

Grieve

No. 1040 is a 2200°F (1204°C) inert-atmosphere pit furnace that can be used for heat treating automotive parts. Workspace dimensions measure 36 inches wide x 36 inches deep x 48 inches high, and 78 kW are installed in heavy-gauge, high-temperature Kanthal AF alloy wire heating elements of rod overbend design to heat the workload. The furnace has 11-inch-thick insulated walls comprised of 4.5-inch-thick 2600°F firebrick, 2.5-inch-thick 2300°F firebrick and 4-inch 1900°F block insulation. Controls include a digital indicating temperature controller, manual reset excess temperature controller with separate contactors and an SCR power controller. www.grievecorp.com



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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.

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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.

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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.

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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

SALT BATH TRANSFORMER

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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.

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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" × 36" × 18"	Hevi Duty	Elec 2000°F
18" x 36" x 18"	Lindberg (Fan)	Elec 1850°F
20" × 48" × 12"	Hoskins	Elec 2000°F
24" × 36"× 20"	L&L Up/Down	Elec 2000°F
24" × 48"× 20"	Lindberg	Elec 2200°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 x 60"D	Procedyne Fluid Bed	Elec 1850°F
28" Dia x 48"D	Lindberg	Elec 1250°F
72" Dia x 72"D	Flynn + Dreffein (2) (Atmos.)	Elec 1400°F
60" Dia x 52"H	"Bell" Nitrider (Retort)	Elec 1200°F

VACUUM FURNACES

24" x 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

BELT FURNACES/OVENS

10" × 6' x 7"	Abbott (Brazing) "Like New"	Elec 2150°F
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
72" × 25' × 12"	Wisconsin	Gas 500°F
72" × 40' × 12"	EFCO Roller Hearth (Atmos)	Gas 1700°F

MISCELLANEOUS

Combustion Air Blowers (All sizes)		
24" x 36"	Lindberg Charge Car (Manual)	
30" x 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 (Just Added)	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
20" × 18" × 20"	Blue-M	Elec 1300°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" × 36"	Surface (Atmos)	Elec 1400°F
30" × 48" × 30"	Surface	Elec 1250°F
36" × 36" × 36"	Grieve	Elec 350°F
36" × 36" × 36"	Blue M Enviroment Chamber (-18°C to +93°C) (Just Added)	
36" × 30" × 36"	Trent	Elec 1400°F
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
38" × 20" × 26"	Grieve	Elec 500°F
42" × 72" × 36"	Despatch	Elec 1350°F
48" × 24" × 36"	Blue-M (2)	Elec 600°F
48" × 48" × 20"	Lindberg (Hyd. Press)	Elec 1250°F
48" × 34" × 52"	Heat Mach. (2)	Elec 500°F
48" × 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 72"	Despatch	Elec 650°F
54" × 72" × 72"	Grieve	Elec 1050°F (Just Added)
48" × 72" × 36"	Lindberg - Car Bottom	Elec 1600°F
55" × 30" × 60"	Precision Quincy	Elec 350°F
68" × 72" × 72"	Gruenberg	Elec 450°F
72" × 120" × 72"	Grieve	Elec 1050°F (Just Added)
72" × 120" × 78"	Grieve	Gas 500°F
72" × 252" × 60"	Precision Quincy "Car Oven"	Gas 500°F
108" × 96" × 65"	Eisenmann (4)	Gas 1200°F

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Batch

C0052 Surface Combustion Temper Furnace (30"W x 48"L x 30"H, 1200°F, gas-fired)
C0068 Despatch Aluminum Aging Box Furnace (60"W x 72"D x 66"H, 395°F, electric)
U3624 Lindberg Nitrogen Temper Furnace (24"W x 36"D x 18"H, 1350°F, gas-fired)
U3644 BeaverMatic Batch Temper Furnace (42"W x 60"D x 48"H, 1500°F, gas-fired)
U3651 JL Becker Batch Temper Furnace (36"W x 48"D x 36"H, 1350°F, gas-fired)
V1010 Dow Batch Temper Furnace (30"W x 48"L x 20"H, 1250°F, gas-fired)
V1024 PIFCO Batch Temper Furnace, Skid Hearth (36"W x 48"L x 30"H, 1200°F, electric)
V1068 Surface Combustion Oil Quench Furnace (30"W x 30"D x 48"H, 1950°F, gas-fired)
V1081 Lindberg Batch Temper Furnace (20"W x 24"D x 18"H, 1250°F, electric)
V1095 Surface Combustion Temper Furnace (30"W x 48"D x 30"H, 1250°F, gas-fired)
V1096 Surface Combustion Temper Furnace (30"W x 48"D x 30"H, 1400°F, gas-fired)
V1106 Dow Batch Normalizer Furnace (45"W x 84"D x 32"H, 1800°F, gas-fired)

Batch High-Temp Furnaces

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

Batch Oil Quench Furnaces

C0086 Huber Car Bottom Furnace (10'4"W x 12'8"D x 8'H, 1800°F, gas-fired)

Drop Bottom Furnaces

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

Internal Quench Furnaces

C0064 Lucifer IQ Furnace (18"W x 24"D x 18"H, 1900°F, electric)
U3569 Surface Combustion IQ Furnace (24"W x 36"D x 18"H, 1750°F, gas-fired)
U3606 Dow/AFC IQ Furnace (30"W x 48"L x 24"H, 1850°F, gas-fired)
V1046 Surface Combustion IQ Furnace (87"W x 87"L x 36"H, 1850°F, gas-fired)
V1082 Holcroft IQ Furnace with Top Cool (36"W x 48"D x 30"H, 1850°F, gas-fired)
V1093 Surface Combustion Allcase IQ Furnace (30"W x 48"L x 30"H, 1850°F, gas-fired)
V1111 Surface Combustion IQ Furnace (30"W x 48"D x 30"H, 1850°F, gas-fired)

Mesh Belt Brazing Furnaces

C0103 JL Becker MB Brazing Furnace w/Exo & Dryer (30"W x 24'5"heated L x 10"H, 2050°F, electric)
U3529 CI Hayes Mesh Belt Brazing Furnace (18"W x 6"H x 8' heating, 2100°F, electric)
U3592 JL Becker Mesh Belt Brazing Furnace (12"W x 6"H, 2100°F, electric)
V1035 Seco Warwick Mesh Belt Brazing Furnace (18"W x 12"H x 8'heated, 2100°F, electric)

Mesh Belt Tempering Furnaces

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

Pit Furnaces

V1088 Leeds & Northrup Pit Furnace (24"ID x 30"D, 750°F, electric)

Pusher Furnaces

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

Roller Hearth & Rotary Furnaces

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

Salt Pot Furnaces

C0136 Park Thermal Salt Pot Furnace (16" dia x 30" deep, 1650°F-1750°F, elect)

Steam Tempering Furnace

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

Tip Up Furnaces

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

Vacuum Furnaces

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

Endothermic Gas Generators

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

Exothermic Gas Generators

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

Material Handling - Conveyors

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

Ovens - Cabinet

U020 Blue-M Oven/Ref (20"W x 20"H x 18"D), (-4°F/400°F)
U3625 Lindberg Atmosphere Oven (38"W x 38"D x 38"H, 850°F, electric)
U3629 Cabinet Oven (30"W x 30"D x 36"H, 750°F, electric)
U3642 Blue-M Oven/Ref, 20"W x 18"D x 20"H, (-4°F/400°F)

Ovens - Walk-In

C0039 Gehnrich Walk-In Oven (72"W x 96"L x 72"H, 400°F, electric)
C0108 Park Thermal Walk-In Oven (90"W x 144"D x 72"H, 850°F, gas-fired)

Freezers

V1129 Webber Freezer (-120°F, electric)

Blowers

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

Charge Cars

U3621 Dow Charge Car, DEDP (66"W x 60"D x 54"H)
V1085 Holcroft Charge Car (DE/DP, 36"W x 48"D)
V1112 Surface Combustion Charge Car (SE, 30"W x 48"L)

Scissors Lifts & Holding Tables

V1086 Holcroft Scissors Lift & (2) Holding Tables

Heat Exchanger Systems

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

Holding & Cooling Stations

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

Water Cooling Systems

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

Washers

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

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Extensive inventory of heat treat baskets and boxes Heat Treat Lines

Heat Treat Lines

V1137 T-6 Annealing & Aging Furnace Line

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