Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS /// THERMOCOUPLES / INDUSTRIAL GASES

REDUCING MEASUREMENT ERROR WHEN MAKING THERMOCOUPLE TRANSMITTER CONNECTIONS

COMPANY PROFILE /// McLaughlin Furnace Group

MARCH 2019
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ALD is a subsidiary of AMG Advanced Metallurgical Group N.V.

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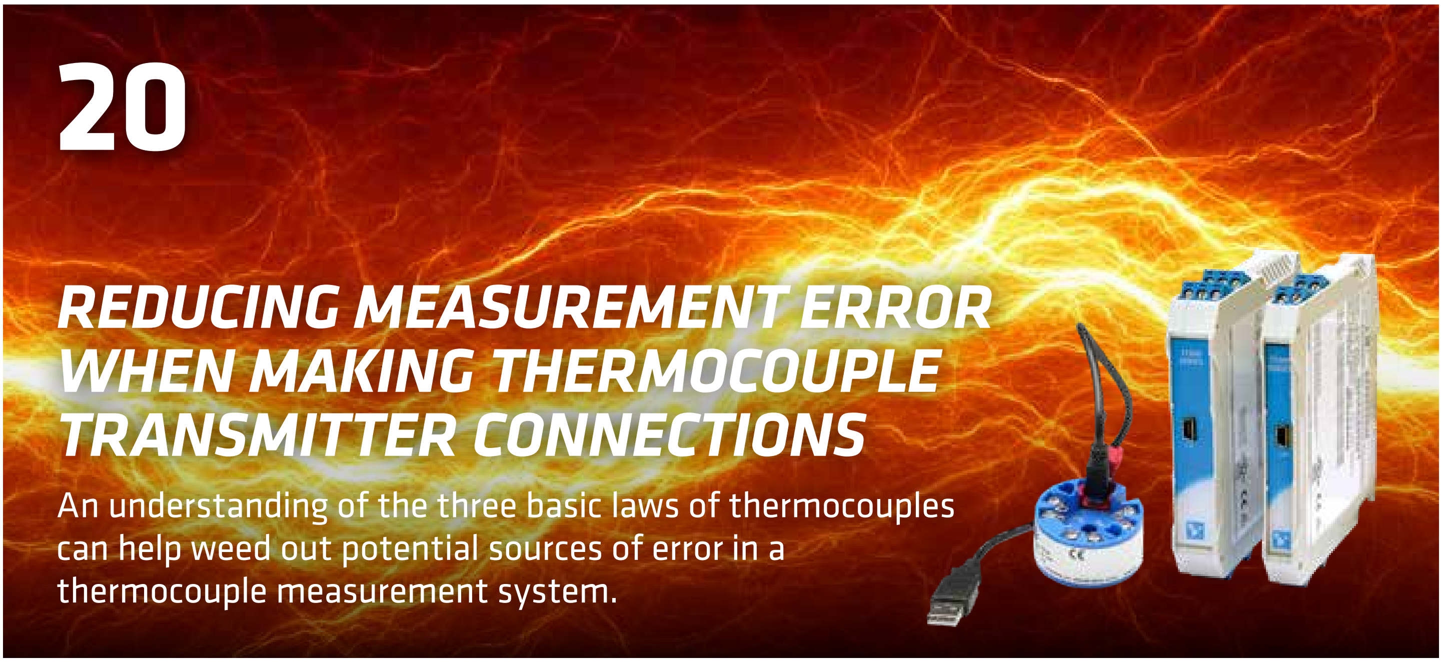

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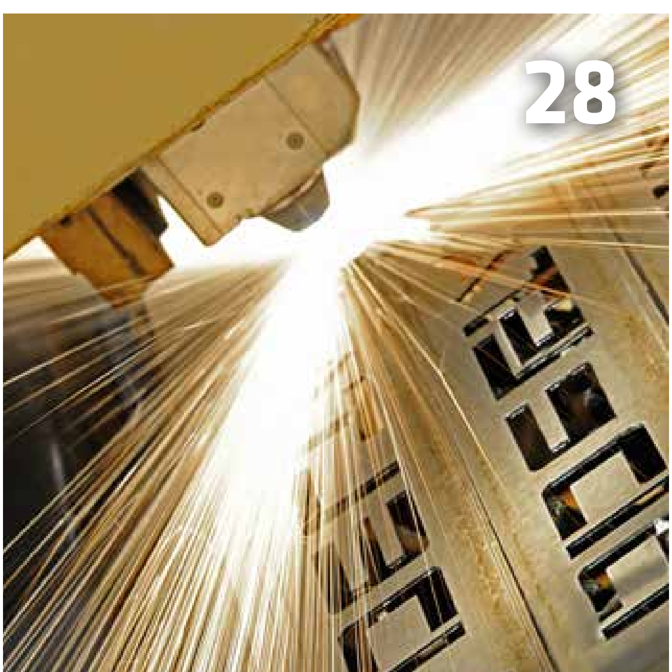
REDUCING MEASUREMENT ERROR WHEN MAKING THERMOCOUPLE TRANSMITTER CONNECTIONS

An understanding of the three basic laws of thermocouples can help weed out potential sources of error in a thermocouple measurement system.

OPTIMIZING GAS SUPPLY FOR INDUSTRIAL LASERS

Addressing the integration of production lasers with industrial gas supply systems.



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COMPANY PROFILE ///

MAKING A DIFFERENCE IN THE HEAT-TREAT INDUSTRY

Blending cutting-edge technology with more than 100 years of combined expert experience on staff, McLaughlin Furnace Group has set an industry standard for customer service and custom, go-to solutions.

COVER PHOTO: SHUTTERSTOCK

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FROM THE EDITOR ///

Here's to the unsung heroes of heat-treat

When it comes to heat-treating, the first things that usually spring to mind are big furnaces, but a lot of other puzzle pieces are necessary to be successful with thermal processing endeavors.

That's why our March issue has several articles that dive into some of these "unsung heroes" of the heat-treating world.

Beginning with thermocouples, an expert from Acromag discusses how an understanding of the three basic laws of thermocouples can help weed out potential sources of error in a thermocouple measurement system.

And on the subject of industrial gases, Air Products shares its expertise on integrating production lasers with industrial gas supply systems.

But this issue offers some other interesting tidbits as well.

In this month's Q&A, I had the privilege of speaking with Rosanne Brunello, president of Mountain Rep. In the feature, she talks about her role in the heat-treat industry and what it's like being a woman-owned business in a mostly male-dominated industry.

As usual, you'll also find plenty of useful information in our monthly columns.

In Hot Seat, Jack Titus discusses how automakers are going all in on electric and self-driving vehicles.

In Metal Urgency, Lee Rothleutner talks about the influence of small amounts of retained austenite on measuring techniques and process controls.

And, in Quality Counts, Jason Schultz shares his insights on how quality management is vital in heat-treating.

All-in-all, there's a lot to process in our March issue. I hope you find it as informative as I did.

As always, thanks for reading!

KENNETH CARTER, EDITOR
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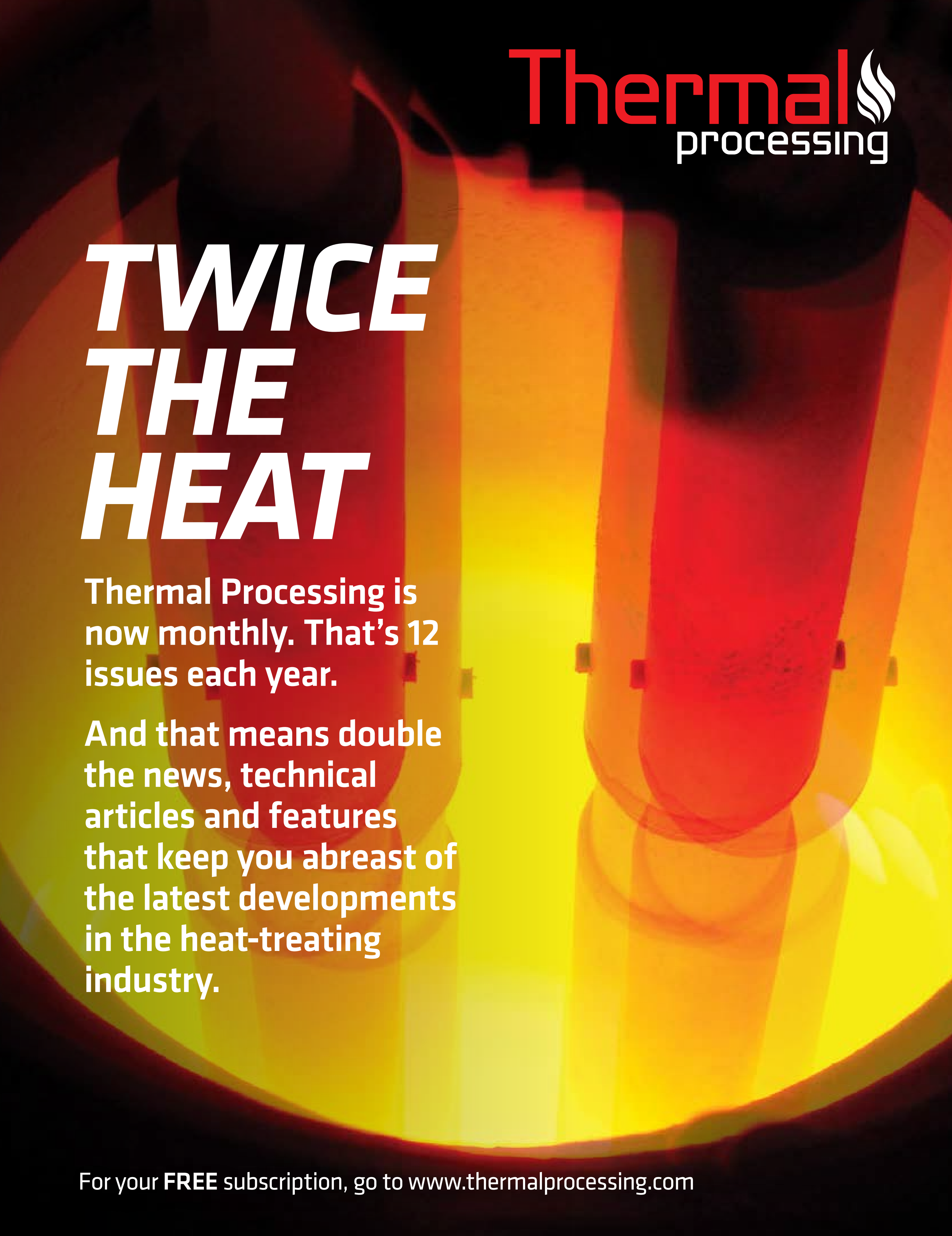

Thermal processing
TWICE THE HEAT
Thermal Processing is now monthly. That's 12 issues each year.
And that means double the news, technical articles and features that keep you abreast of the latest developments in the heat-treating industry.
For your FREE subscription, go to www.thermalprocessing.com

Advanced Heat Treat employees, government officials, local economic leaders and contractors and crews were present to for ceremonial ribbon cutting of the new AHT expansion. (Courtesy: AHT)

Advanced Heat Treat completes building expansion in Iowa

Advanced Heat Treat Corp. (AHT), a recognized leader in heat-treat services and metallurgical solutions, announced the completion of the 15,000-square foot building expansion at its corporate headquarters located in Waterloo, Iowa.

The milestone was celebrated February 7 with a ceremonial ribbon-cutting, with the AHT brand color of purple. AHT employees, government officials, local economic leaders, and the contractors and construction crew attended.

AHT President Mike Woods said, "The expansion is a knockout! A great group of people — both internally and externally — put their minds together on a mission and created a great extension of our facility. We're excited about the additional space that's going to allow us to grow, bring on new services, and enable us to better serve our customer base."

Last month, AHT announced its three new gas nitriding units with plans for a fourth before the end of the year; these units are housed in the new addition in order to separate the gas nitriding equipment from the ion (plasma) nitriding units at the corporate headquarters.

AHT has four locations: two in Waterloo, Iowa; one in Monroe, Michigan; and a fourth in Cullman, Alabama. AHT also plans to expand its Burton Avenue location in Waterloo, where traditional heat-treating services such as induction hardening and carburizing are offered.

Woods said, "This past year has been exciting. We attribute this to our amazing employees, great relationships with our customers, and our continual investment in the future. We thank everyone involved and look forward to another great year."

MORE INFO www.ahtcorp.com

Allied Mineral launches Chinese-language website

Allied Mineral Products has launched a new Chinese-language website. Alliedchina.com, targets the local business market in China.

In Northern China, Allied's manufacturing facility in Tianjin celebrated its 20th anniversary last year.

General manager Ben Ge said, "After serving the China metal industry more than 20 years, Allied Mineral Products is one of the major monolithic and precast shape refractory suppliers in China. We continually invest in human resource, manufacturing, and research in the last 20 years. This allows us to expand our business and develop new market for the company."

As with each location across the globe, Allied's Tianjin facility produces high-quality products to the same standards used at the main campus facility in Columbus, Ohio.

"Allied China has become an important part of Allied Mineral Products," said Ge. "We will continue our investment in China. This new website will help expand market influence and give us more business opportunity."

MORE INFO www.alliedchina.com

APMI International names two members 2019 Fellows

Joseph Tunick Strauss and John L. Johnson have been named 2019 Fellow Award recipients by APMI International and will be honored at Powderment2019.

APMI International's most prestigious award recognizes APMI members for their significant contributions to the goals, purpose, and mission of the organization as well as for a high level of expertise in the technol-

SEND US YOUR NEWS Companies wishing to submit materials for inclusion in Thermal Processing's Update section should contact the editor, Kenneth Carter, at editor@thermalprocessing.com. Releases accompanied by color images will be given first consideration.

ogy, practice, or business of the industry. The 2019 Fellow Award recipients will receive elevation to Fellow status at POWDERMET2019: International Conference on Powder Metallurgy & Particulate Materials during the Industry Luncheon on Tuesday, June 25.

Joseph Tunick Strauss

For more than three decades, Joseph Tunick Strauss, engineer/president, HJE Company, has strived to advance the powder metallurgy (PM) industry through engineering and ingenuity. He was the first to commercially offer turn-key small-scale high-performance gas atomizers and publish on the use of elevated temperature gas for atomization. Strauss formally introduced PM to the jewelry industry and continues to develop press-and-sinter and metal injection molding (MIM) technologies for them. He helped unite the PM and additive manufacturing (AM) communities and assisted in the formation of the AMPM conference. Strauss is a member of many professional technical societies, has served on the APMI Board of Directors, and has been on the Metal Powder Industries Federation (MPIF) Conference Committee for many years. He has received many awards including the MPIF Distinguished Service award in 2013.

Joseph Tunick Strauss

Strauss reviews technical articles for several technical publications including the International Journal of Powder Metallurgy.

John L. Johnson

John L. Johnson, vice president, Elmet Technologies, has dedicated more than 20 years to research and development of processes and products for the PM industry, including pioneering rapid prototyping of metals via selective laser sintering for desktop manufacturing. He has authored or coauthored more than 100 technical papers and, as an editorial committee member, reviewed more than 200 technical articles for various technical journals including the International Journal of Powder Metallurgy. Johnson has served on many committees and association boards including the APMI Board of Directors and the MPIF Technical Board. He has been a co-chairman of the Tungsten, Refractory and Hard Materials Conference and continues to organize numerous Special Interest Programs for the annual POWDERMET conferences. While wrapping up his Ph.D. at The Pennsylvania State University, Johnson was a recipient of the 1993 CPMT/Axel Madsen Conference Grant in the early years of the program.

John L. Johnson

Established in 1998, the Fellow Award recognizes APMI members for their significant contributions to the society and high level of expertise in the technology of powder metallurgy, practice, or business of the PM industry. Fellows are elected through their professional, technical, and scientific achievements, continuing professional growth and development, mentoring/outreach, and contributions to APMI International committees.

APMI International is a non-profit professional society which promotes the advancement of powder metallurgy and particulate materials as a science. Its purpose is to disseminate and exchange information about PM and particulate materials through publications, conferences, and other activities of the society.

MORE INFO www.apmiinternational.com

Another Can-Eng Mesh Belt Furnace has been commissioned overseas. (Courtesy: Can-Eng Furnaces)

Can-Eng Furnaces commissions mesh belt furnace overseas

Can-Eng Furnaces International Ltd recently commissioned a state-of-the-art continuous mesh belt heat-treat system for the production of high-quality automotive fasteners in the Piedmont region of Italy. This Italian project was one of four installation locations for this globally recognized producer of specialty automotive fasteners that span from Europe, South America, Mexico, and the United States of America.

Can-Eng was chosen to supply its systems based on proven reliability, efficiency, and soft-part-handling features, hallmarks of Can-Eng's Mesh Belt Furnace Systems. The new, high-volume fastener system features energy efficient combustion and waste heat recovery systems, atmosphere-controlled mesh belt hardening system, oil quench, post wash system, temper furnace, soluble oil system, bi-directional conveyor discharge, and Can-Eng's Level 2 SCADA system. Can-Eng's PET™ system provides the user with access to vital Industry 4.0 data which includes product traceability, detailed process data for continuous process improvements, comprehensive equipment diagnostics, cost analysis, and inventory management.

The top-of-the-line system also integrates Can-Eng's Energy Reduction System (ERS™) which significantly reduces the energy requirements of the system. The system was commissioned Q4, 2018 and has met and exceeded the clients' performance expectations.

Through proven results, Can-Eng Furnaces' Continuous Mesh Belt Heat Treatment Systems remain an integral technology for processing high quality automotive fasteners. As the demands of the automotive industry continue to grow, Can-Eng's Mesh Belt Heat Treatment Systems repeatedly demonstrate their capability of meeting and exceeding processing standards that include AIAG CQI-9 requirements.

MORE INFO www.can-eng.com

Advanced Heat Treat Corp. announces VP of operations

Advanced Heat Treat Corp. (AHT), a recognized leader in heat-treat services and metallurgical solutions, has announced the promotion of William "Bill" Cowell to vice president of operations. He will now oversee operations for all AHT facilities.

Cowell has been at AHT since 1999 and has held a number of operational roles. Most recently, he oversaw the MidPort facility located in Waterloo, Iowa. His responsibilities have now been extended to also include the Burton Ave. plant in Waterloo; the Monroe, Michigan, location; and the Cullman, Alabama, location.

AHT President Mike Woods said, "Bill has been a vital part of our team for nearly 20 years. His understanding of our heat-treat processes, his leadership, and his operational knowledge is unparalleled. In his new role, he will help take AHT to the next level through his strategic direction and will be a great resource for our other AHT facilities."

MORE INFO www.ahtcorp.com

Gasbarre promotes Jake Verdoux to IFS manager

Gasbarre is pleased to announce the promotion of Jake Verdoux to manufacturing manager for Gasbarre Industrial Furnace Systems (IFS). IFS, formerly known as J.L. Becker, is located in Plymouth, Michigan, and falls under Gasbarre's thermal processing systems division.

Verdoux started with the IFS division of Gasbarre as a welder/fabricator in 2014. He quickly progressed and moved into the assembly department before being promoted to materials manager in 2016. His success in that role led to his promotion to manufacturing manager.

"We are excited to have Jake in this new role," said Ben Gasbarre, president of IFS. "His experience, leadership skills, and passion for the organization will lead to improved operational performance that will benefit both our organization and our customers."


Jake Verdoux

Through its Thermal Processing Systems division, Gasbarre provides top quality industrial heat-treating equipment, engineering, and service. With products ranging from batch furnaces to continuous belt furnaces, pusher furnaces, vacuum furnaces, humpback furnaces, and more.

MORE INFO www.gasbarre.com

Grieve No. 1040 is a 2200°F (1204°C), inert atmosphere pit furnace. (Courtesy: Grieve Corporation)

Grieve offers 2,200° F inert atmosphere pit furnace

No. 1040 is a 2,200° F (1,204° C), inert atmosphere pit furnace from Grieve, used for heat treating automotive parts in baskets at the customer's facility. Workspace dimensions of this furnace measure 36" wide x 36" deep x 48" high. 78 KW are installed in heavy gauge, high temperature Kanthal AF alloy wire heating elements of rod overbend design and powered through a low voltage transformer to heat the workload.

This Grieve pit furnace has 11" thick insulated walls comprising 4 " thick 2,600° F firebrick, 2 " thick 2,300° F firebrick, and 4" 1,900° F block insulation, as well as an insulated floor comprising 7" of castable refractory and 4" block insulation. Other features include a 1/4" plate steel exterior reinforced with structural steel and an air-operated, rear-hinged door. Inert atmosphere construction includes continuously welded outer shell, high temperature door gasket, sealed heater terminal boxes, inert atmosphere inlet, outlet, flow meter, and manual gas valve.

Controls on the No. 1040 include a digital indicating temperature controller, manual reset excess temperature controller with separate contactors, and an SCR power controller.

MORE INFO www.grievecorp.com

Electrical box furnace shipped to ceramics manufacturer

L&L Special Furnace Co., Inc. has shipped a floor-standing furnace to a worldwide leader of high-tech ceramics and associated components located in the Northeastern United States. The furnace will be used for glass components along with fiber optics and research and development. It will also be used to fill in on various thermal projects and development.

The work zone in the furnace is 24" wide by 16" high by 32" deep, with a temperature gradient of ±20°F at 1,100°F using two zones of temperature control with biasing to balance any temperature gradients.

The control instrument is a Eurotherm EPC3004 program control that has 10 individual programs with up to 10 segments for each program. The furnace also has overtemperature protection with manual reset and backup safety contactors. There is a NEMA12 panel and fused disconnect. Solid-state relays are used to fire the resistance coils. An audible and visual stack light is included to show current furnace status and inform the operator of any alarm conditions.

An atmosphere-sealed case allows the furnace to be operated under a protective atmosphere blanket. This option gives the operator the ability to displace the oxygen in the chamber with either nitrogen or argon to provide a virtually oxygen-free environment.

All L&L furnaces can be configured with various options and be specifically tailored to meet your thermal needs. L&L also offers furnaces equipped with pyrometry packages to meet ASM2750E and soon-to-be-certified MedAccred guidelines.

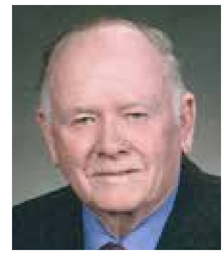
An optional three-day, all-inclusive start-up service is offered with each system within the continental US and Canada.

MORE INFO www.llfurnace.com

Thermcraft founder Morris L. Crafton passes at 93

Thermcraft Inc. lost founder Morris L. Crafton on Valentine's Day. He was 93.

After military service and a stint in the popcorn machine business, he became a partner in a business that made replacement heating elements. In 1971, Crafton and his wife, Clara, founded Thermcraft on the principal of providing the best customer service available in the thermal processing industry. Crafton took a big risk starting his own company. They secured a small warehouse in downtown Winston-Salem and began making replacement heating elements for industrial and laboratory furnace applications. Crafton handled the manufacturing duties while Clara managed the financial and administrative tasks. Thermcraft served those who were starving for top-notch customer service and a quality product. Thermcraft moved to its current facility in 1979, just a few miles south to the edge of Winston-Salem. Through new product development and various acquisitions, the Craftons began to grow Thermcraft into the company it is today.


Morris L. Crafton

Clara died from cancer in 1995. Crafton eventually turned the reigns of Thermcraft over to his son, Tom, but that didn't stop Crafton from being involved in the day-today business. He continued to drive himself to work well into his early 90s. Crafton will be remembered as a strong leader with a good sense of humor who was kind and generous to those around him.

ITW Test and Measurement names vice president

Illinois Tool Works (ITW) Test and Measurement Group president Yahya Gharagozlou has named Julien Noel vice president/general manager of the Buehler worldwide division.

Buehler is an ITW company and a premier manufacturer of scientific equipment and consumables for materials analysis used in high volume manufacturing production laboratories, universities, and research/development organizations.

Julien Noel

Noel has been at Buehler since 2015 and most recently served as the Americas Commercial Director in addition to Global Director of Strategy and Innovation.

Noel came to ITW during the acquisition of North Star Imaging in 2010. There he held several leadership roles including General Manager of Europe, Product Management and Business Development. Before that, he was business manager for Digisens and professor at the Grenoble School of Management in France.

He replaces Meredith Platt, who has been transferred to ITW's automotive segment and taking up the role of vice president/general manager for a global automotive division - seats, safety, and motion.

"I am excited to take on this crucial leadership role for Buehler. During the last few years we provided clarity in the company strategy and created innovative solutions to help manufacturers that demand excellence. We developed successful new products, streamlined online shopping and improved our customer care/service offering," Noel said.

"Together with Buehler employees, we will continue to grow, deliver customer backed innovations and uphold the values of integrity, respect, trust, shared risk and simplicity in 2019 and beyond."

Buehler manufactures value-added metallographic equipment and consumables along with the proven Wilson™ hardness testers, DiaMet™ software, ISO-certified test blocks and accessories.

In addition to its innovations, Buehler is recognized by the global materials preparation and analysis market for its laboratory solutions centers, dedicated service teams, education programs and customized processes for demanding applications.

MORE INFO www.itw.com

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

2019 annual meeting marks its 90 year

The Industrial Heating Equipment Association will celebrate its 90th anniversary at the 2019 Annual Meeting, April 29-May 1 at Lido Beach Resort in Sarasota, Florida. IHEA members will enjoy the camaraderie created by the ever-popular social events and thought-provoking presentations. The annual meeting provides plenty of opportunity to get involved with important industry-related developments while exploring new business contacts and growing relationships.

This event is filled with pertinent presentations and social activities that allow plenty of time to network with business associates while enjoying the beautiful resort, sandy beach, and sunshine.

The program will feature a dynamic presentation by Bob Sherlock, CMO of Chief Outsiders. Sherlock's presentation, "The Power of Value," will highlight why members should be paid for the value of their products and services rather than lowering prices to appease customers. Attendees also will hear from IHEA's economist Chris Kuehl with his lively update on the economy, as well as a report from Omar Nashashibi from The Franklin Partnership, who lobbies in Washington, D.C., on behalf of manufacturing trade associations. Nashashibi will offer insight to the government shutdown and latest developments on critical policies that will help companies plan for the unpredictable future.

IHEA members will gain valuable knowledge on cyber security and how to prolong the inevitability of being hacked. Chris Della Mora of HUB International Risk Services and James Moore of Goyer Management International team up to provide this critical session for anyone who uses the internet. The program also includes a presentation from IHEA member Scott Bishop with Alabama Power on the benefits of partnering with utility companies. Your business and your customers will value the process improvements and cost savings that ultimately affect the bottom line.

IHEA's committees also will meet in Sarasota as they continue to work on issues of importance to the membership and the industry at large. And, of course, the annual golf outing and beach games provide the perfect social experience to round out the meeting agenda. Review the complete program and event details online at www.ihea.org/event/AM19.

The beautiful Lido Beach Resort is on one of Florida's best beaches, featuring soft white sand that stretches for more than two miles. The resort is close to world-famous Siesta Key beach, often voted the best beach in the U.S. The resort is two minutes from the popular St. Armand's Circle filled with restaurants and shops. The resort shuttle will transport guests to St. Armand's Circle, although it is a short five-minute walk from the resort. The venue will provide members a scenic beachfront backdrop nestled on the coast of the Gulf of Mexico and surrounded with panoramic ocean views that will complement the annual meeting perfectly.

IHEA's annual meeting presentations address timely topics and thought-provoking information for all members.

IHEA 2019 Annual Meeting

APRIL 29-MAY 1

Lido Beach Resort, Sarasota, Florida

Hotel reservations at the Lido Beach Resort can be made at reservations.lidobeachresort.com, using code IHE0419.

Our group rate for junior suites is $209/night. Please book your hotel reservations now to ensure you receive our group rate.

SCHEDULE OF EVENTS

MONDAY, April 29

8 a.m.-4 p.m.	Registration Open
1-4 p.m.	IRED/Induction Meeting
5 p.m.	Blue Dot Welcome
6-7 p.m.	Welcome Reception
7 p.m.	Dinner on Your Own

TUESDAY, April 30

7:30 a.m.-5 p.m.	Registration
7:30-8 a.m.	Opening Breakfast Buffet
8-11:15 a.m.	GENERAL SESSION
8:05-9:30 a.m.	The Power of Value

Bob Sherlock, CMO-Chief Outsiders

All too often today, customers are pressuring our members for lower prices. But Bob Sherlock believes there are better alternatives than simply cutting your price. He believes in the power of "value." He wants you to be paid for what your products and services are really worth. His presentation will help you uncover strengths so you can value sell.

9:15 a.m.-2 p.m. Spouse/Guest Tour*
Selby Garden Guided Tour and Lunch at Marina Jack, $85

Set along the Sarasota Bayfront, Marie Selby Botanical Gardens is a living museum and world-class center for research & conservation. Our guided tour will include a special Gauguin's Paradise Exhibit. After visiting the gardens, we'll enjoy lunch at Marina Jack restaurant. Fee includes bus transportation, admission, tour guide, gratuities, and lunch.

9:30-10:30 a.m. The Washington Effect

Omar Nashashibi, The Franklin Partnership

What can we possibly say about what's been going on in Washington? We're all perplexed. Omar S. Nashashibi of The Franklin Partnership returns to try and help us make sense of the craziness that is Washington, D.C., today. Omar lobbies the White House and U.S. Congress on behalf of manufacturing trade associations and other clients seeking a voice before policymakers. He will share insights into the government shutdown & the latest developments on critical policy and share what he believes it means for your business. His presentation will attempt to help you plan for the unpredictable future.

10:30-11:15 a.m. Utility Partnership Opportunities

Scott Bishop, Alabama Power

Companies are constantly looking for ways to improve their processes and bottom line. Learning about ways you can partner with your utility, for both your operations and your customers can lead to process improvements and saving money. Learn about the opportunities available to you through this presentation.

11:15 a.m. GENERAL SESSION Break

11:30 a.m.-12:15 p.m. IHEA Committee Meetings (Safety, Government Relations, Education, Marketing Communications & Membership)

12:15-1 p.m. LUNCH

1-2:15 p.m. IHEA Committee Meetings Continue

2:30-5 p.m. Committee Reports – JIFMA Report – CECOF Report

6:30-10 p.m. Lido Beach BBQ Dinner

WEDNESDAY, May 1

7:30-11 a.m. Registration Open

7:30-8 a.m. Continental Breakfast

8-11 a.m. IHEA General Session

8-9:15 a.m. Economic Update

Chris Kuehl, Armada Corporate Intelligence

The roller coaster ride that has been the story of the economy recently will be reviewed by IHEA's economist Chris Kuehl. It's hard to know what information Chris may have to share by April but it's sure to be both informative and entertaining. Chris is continuously rated one of IHEA's best speakers!

9:15-9:30 a.m. Break

9:30-10:45 a.m. Cyber Security – We're All at Risk

Chris Della Mora, HUB International Risk Services and James Moore, Goyer Management International

It's inevitable. You're going to get hacked. Your information is already available to hackers. Find out what you can do to delay the unavoidable. We'll share "true stories" and provide you with ways to make your information less valuable to hackers and the immediate steps you need to take if you find yourself hacked.

11:15 a.m. Depart for Golf Tournament

Noon Golf Tournament*

1:30-3:30 p.m. Beach Games*

7-7:30 p.m. President's Reception

7:30-10 p.m. President's Reception & 90th Anniversary Gala Banquet

10 p.m. Annual Meeting Concludes

*Additional fee applies for optional activities.

REGISTER NOW: www.ihea.org (click on the annual meeting button on the right).

GENERAL INFORMATION

Hotel Information

Room rate: $209 – single/double plus tax; all rooms are Junior Suites

Resort Fee: WAIVED Parking: WAIVED

Registration Fees

Member Fee: $995 Non-Member Fee: $1,500

Includes: Welcome reception, all meetings and presentations, Tuesday buffet breakfast, Tuesday lunch, Tuesday beach BBQ dinner, Wednesday continental breakfast, President's 90th Anniversary Reception & Gala, all refreshment breaks, all entertainment.

Committee Meetings Only Fee: $495

Includes: Welcome reception, all meetings and presentations on Tuesday, Tuesday buffet breakfast, Tuesday lunch & refreshment breaks, Tuesday beach BBQ dinner.

Spouse/Guest Fee: $499

Includes: Welcome reception, Tuesday buffet breakfast, Tuesday beach BBQ dinner, President's 90th Anniversary Reception & Gala

Annual Meeting Attire

Attire for the Annual Meeting is resort casual, including the 90th Anniversary Gala.

TO REGISTER

Go to www.ihea.org. You *must* log in to receive the member rate. You may also use two member vouchers for one Annual Meeting Registration. Contact Leslie Muck at leslie@goyermgt.com for information on using the vouchers included with your membership.

You will be able to make your hotel reservations through the link provided on the registration confirmation page.

Questions: Call Leslie Muck at 1-859-356-1575.

MORE INFORMATION

For more information about the IHEA 2019 Annual Meeting, including details about social activities and costs, go to www.ihea.org.

LEE ROTHLEUTNER
PRINCIPAL DEVELOPMENT ENGINEER /// THE TIMKEN COMPANY

Even small amounts of RA may be influential if correct measurement techniques and process controls are applied.

Retained austenite significant for strength, toughness

The role of retained austenite (RA) and the magnitude of its influence on the performance of steel components are continually debated. Depending on the application and service environment, literature shows that the presence of RA can confer both positive and negative attributes. As a result, RA continues to be an important research topic for both industry and academia. The following discussion introduces the fundamentals of RA and highlights select instances where RA is believed to be a significant factor in attributes such as product strength, impact toughness, and fatigue resistance. Due to the breadth of this topic, the discussion will be limited to medium- and high-carbon steels with additional alloying content <5 wt. %.

FUNDAMENTALS

Most industrial steel heat-treatment processes engage in an austenitization step prior to achieving the final microstructure of the component intended for service. Upon cooling to room temperature, a portion of austenite can be retained in the microstructure depending on the temperature at which the transformation occurred. In an industrial setting, steels are typically either continuously cooled or isothermally held to produce the desired microstructure. To generate measurable amounts of RA, the cooling from austenitization is typically rapid enough to avoid diffusional transformations such as ferrite and pearlite. The temperature and cooling rate required for the pearlite transformation nearly always results in complete transformation of the parent austenite, leaving no residual RA. However, lower-temperature transformations such as bainite and martensite can result in appreciable amounts of RA.

Although the specific mechanism that determines RA can be alloying- and processing-dependent, the dominating mechanism is thermodynamic stabilization of austenite by way of carbon enrichment. As bainite and martensite form, carbon migrates to regions of austenite. This locally increases the stability of the austenite and reduces bainite transformation kinetics, as well as lowering the temperature at which martensite forms.

Figure 1 shows the martensite start (M_S) and approximate finish (M_F) temperatures for plain carbon steels over a large range of carbon compositions. The M_S temperature decreases steadily with increasing carbon content, while the M_F temperature decreases more rapidly — dropping below room temperature at a relatively low carbon content of approximately 0.40 wt. %. The M_F temperature has more uncertainty due to two primary reasons:

1. The accuracy of the techniques used to identify and measure austenite in steel decreases significantly with decreasing amounts of austenite.

2. As RA fractions become small, the morphology makes measurement difficult (e.g., thin RA films between martensite plates [2]).

Some common methods for measuring RA are:

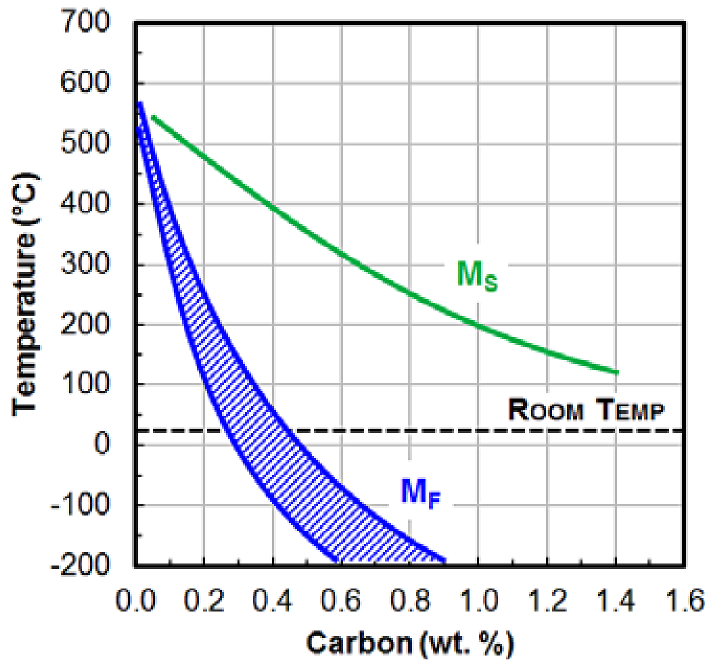


Figure 1: Martensite start (M_S) and finish (M_F) temperatures as a function of carbon content for plain carbon steels. Figure adapted from Verhoeven [1].

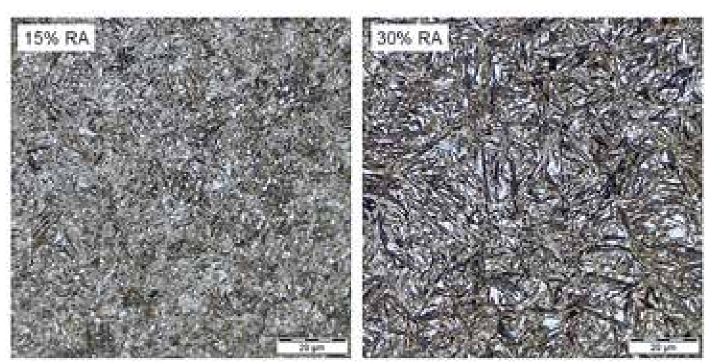


Figure 2: Optical micrographs of quenched and tempered 100CrMnSi6-6 steel with approximately (a) 15 percent and (b) 30 percent RA. Images taken at 1,000x and etched with 4 percent Nital.

1. Visually: This can be performed with light optical or scanning electron microscopy (SEM) to quantify the austenite fraction using contrast from etching behavior and/or morphology. The low cost of the light optical technique makes it the most common; however, RA measurements below approximately 10 percent are unreliable due to resolution limitations.

2. Electron backscatter diffraction (EBSD): This technique allows both the microstructural and crystallographic attributes of a crystal-

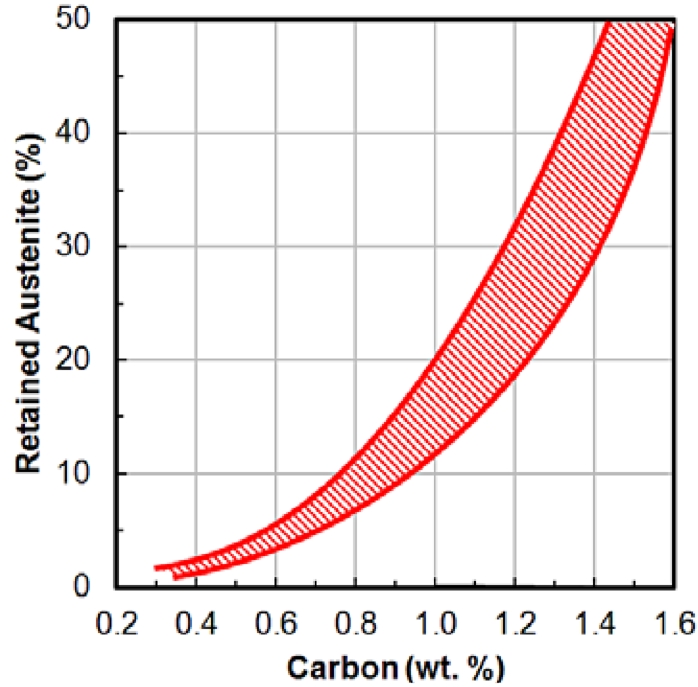


Figure 3: Retained austenite as a function of carbon content for plain carbon steels quenched to room temperature. Figure adapted from Verhoeven [1].

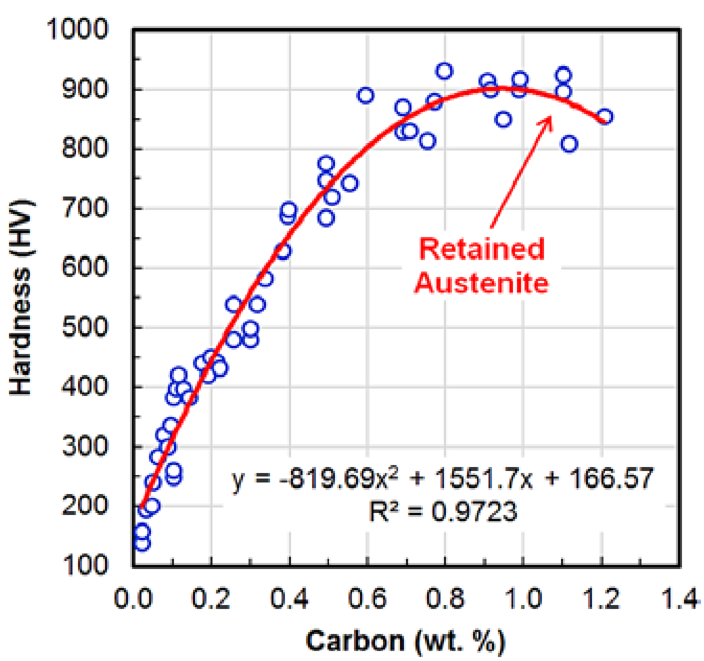


Figure 4: Hardness of martensite as a function of carbon content for plain carbon steels. Data from Krauss [4].

line material to be characterized. Unfortunately, in the context of RA quantification, accuracy and repeatability are very sensitive to sample preparation. Sample preparation challenges coupled with high equipment costs typically limit the use of this technique to industrial R&D or academic research.

3. X-ray diffraction: This technique is in common practice because it samples a much larger region than visual techniques and EBSD while being less labor-intensive in sample preparation and analysis. However, conventional X-rays only penetrate steel approximately 10μm, and therefore repeatability can be challenging [2]. This is particularly true in higher-alloy steels that may have an inhomogeneous distribution of RA.

Although the specific mechanism that determines RA can be alloying- and processing-dependent, the dominating mechanism is thermodynamic stabilization of austenite by way of carbon enrichment.

4. Magnetic induction: A fast, simple technique that provides quantitative to semi-quantitative RA data, depending on the RA content. The instrument measures the amount of ferromagnetic microstructure (i.e., non-austenitic constituents) in the steel sample. The instrument is commonly used to quantify ferrite fraction in stainless steel welds, but has been implemented as a process verification tool for RA fractions [3]. Instruments have the added benefit of being inexpensive and portable.

Figure 2 shows representative light optical micrographs of a quenched and tempered high-carbon low-alloy steel with two different austenitizing histories. The microstructure exhibiting approximately 15 percent RA (Figure 2a) also contains small carbides, both of which are observed as white regions in the image. Carbides are typically distinguished from RA by their spherical morphology. The microstructure exhibiting approximately 30 percent RA (Figure 2b) contains few or no carbides, and the RA is very pronounced as the white regions between the plate martensite.

The micrographs provided in Figure 2 emphasize an important concept regarding the aforementioned mechanism for retaining austenite in steel at room temperature. Carbon that is tied up as cementite or other alloy carbides is not available to migrate to austenite during the bainite and martensite transformations. As a result, variations in the microstructure before austenitizing — as well as the austenitizing time and temperature — result in significant changes in RA for a given quenching process. Figure 3 shows an RA range determined from data collated by Verhoeven for plain carbon steels quenched to room temperature. As carbon content increases, so does the range of RA fractions that is observed for a given carbon content.

APPLICATIONS

A few select attributes stand out as being critically important to the majority of component design: strength, impact toughness, and fatigue resistance. The ways in which RA influences each are discussed in this section.

Strength

Although strength is an important mechanical property, if not the most important, data are not easily obtained in an industrial setting. As an alternative, hardness is typically measured and correlated to the specific microstructure and alloy for a given heat-treatment process. Since hardness most directly correlates with tensile strength rather than yield strength, it is important to validate any correlation.

Figure 4 shows the hardness of martensite as a function of carbon content. It is well accepted that the reduction in hardness at the higher carbon contents is due to the presence of RA [4]. Figure 5 shows stress-strain data from tensile tests of 41100 steel at three different RA fractions: 13 percent, 22 percent, and 35 percent. These data indicate a nearly 50 percent reduction in yield strength when the RA fraction increases from 13 percent to 35 percent. Unfortunately, Alley and Neu did not explicitly indicate whether the samples were tempered or tested in the as-quenched condition. These data indicate

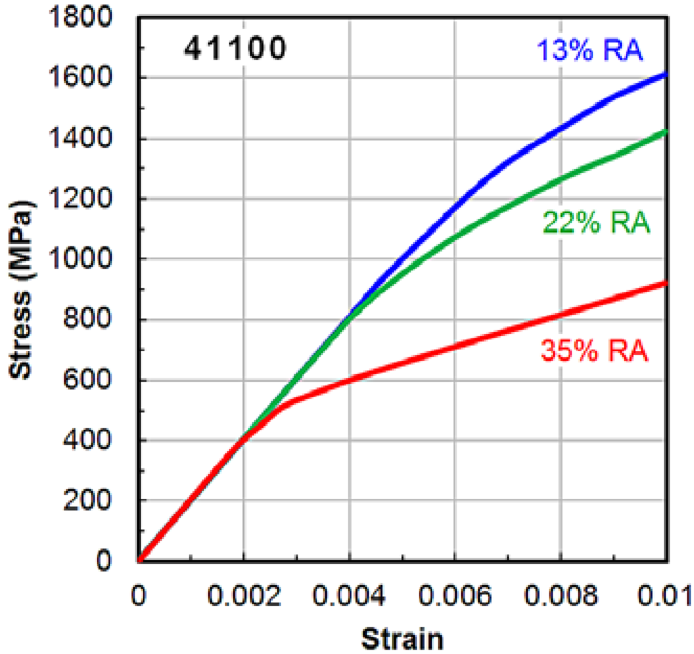


Figure 5: Tensile stress-strain curve for samples of 41100 steel with 13 percent, 22 percent, and 35 percent RA. Data from Alley and Neu [5].

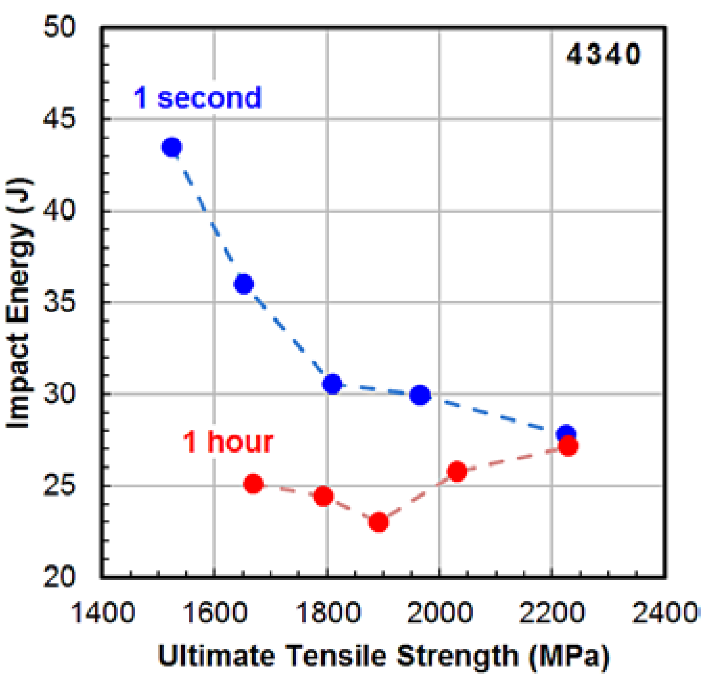


Figure 6: Impact energy from room-temperature Charpy V-notch impact testing versus ultimate tensile strength for a 4340 steel quenched and tempered for either 1 second or 1 hour in the tempered martensite embrittlement (TME) range. Data from Judge et al. [6].

controls need to be implemented to ensure small changes in RA are accounted for in design calculations as safety factors are minimized.

Impact Toughness

Medium-carbon quenched and tempered steels are often selected for very challenging applications due to their high strength and high toughness. To fine-tune a heat-treatment process to deliver the required properties, a specific tempering temperature range (200°–400°C) is typically avoided due to the increased potential for tempered martensite embrittlement (TME) [4]. As tempering temperature increases, so does its toughness, but within the TME temperature range, a low-ductility trough can be observed. Figure 6 shows data indicating that one potential method for addressing this ductility trough is through the use of a rapid temper process (e.g., induction) in lieu of conventional furnace tempering. Judge et al. suggest that the increased RA observed in the rapidly tempered specimens (1 percent–2 percent on average) is the reason for the improved impact toughness [6].

Fatigue Resistance

The resistance of a given material to high-cycle fatigue directly correlates with its ultimate tensile strength [7], which scales directly with the hardness of the material. This relationship suggests that RA fractions high enough to result in a decrease in hardness would decrease fatigue life; however, RA has been shown to improve resistance to fatigue in specific instances. In carburized steels, increasing RA fractions has been shown to improve bending fatigue [8].

In all cases, RA improves fatigue resistance via crack blunting and increased plane strain fracture toughness (K_{1c}) due to RA transforming to martensite during deformation. This mechanism is also known as transformation-induced toughening [9].

SUMMARY

Retained austenite plays a significant role in the performance of heat-treated steel components. Data indicates even very small amounts of RA may be influential. As a result, appropriate measurement techniques and process controls need to be implemented to deliver targeted performance.

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JACK TITUS
DIRECTOR OF PROCESS AND DEVELOPMENT ENGINEER /// AFC-HOLCROFT

Automakers are going all in on electric and self-driving vehicles, and that has big implications for heat-treaters.

The big gamble: Electric vehicles or bust

There's a big gamble going on in Detroit, and I don't mean at Greektown Casino; it's at the big three automakers. All have, in one way or another, put their money on EVs (electric or hybrid vehicles) but primarily on pure electric. Ford has announced that it will eliminate most of its sedans and continue development of EV and SUVs (sport utility vehicles), crossovers, and light trucks. GM has closed several plants including the one producing the Chevy Volt hybrid to focus more resources on pure electric development such as the all-electric Chevy Bolt. Apparently, they're all diverting resources and putting a major focus on the autonomous or self-driving vehicle market, where a combo internal combustion engine is a disadvantage.

With the massive changeover required to produce the quantity of vehicles their prognosticators forecast, will the consumer pay the price when the government eliminates the subsidy incentive for EVs? As I've discussed in previous columns, the success of EVs will ultimately depend on how they will compete with the gasoline engine's ability to travel about 300 miles on one fill-up even with the smallest gas tanks. Today's internal combustion four-cylinder turbo-charged engines married to a six-speed automatic gear box can easily travel more than 600 highway miles on 18.5 gallons of regular or mid-range octane fuel in a full-size five-passenger car weighing 4,200 pounds. In my opinion, if EVs are ever to lure consumers away from this 8-year-old technology, automakers have to get much more creative than they are now.

Less obvious, but still critical decisions must be made concerning heat-treating required for the new materials and more specifically where it will be done — in-house or outsourced. Therein lies the dilemma: Where will the heat-treating market put its chips — vacuum, atmosphere, batch, continuous, mesh belt, and the myriad of other furnace systems?

Automotive heat-treating, primarily case hardening, has always been about the drivetrain, gears, shafts, etc. EVs, either all electric or hybrid, will require a totally different and much more flexible heat-treating approach. In addition to case hardening for vehicle drivetrains, specialized materials for DC and AC motors also will be required. As the demand for reduced weight increases to improved mileage and emissions, vehicle structural changes will be needed to accommodate newer, more efficient, and lighter batteries that can be positioned more creatively throughout the chassis.

As I've opined in previous columns, continuous furnaces in the past provided the necessary production required for the millions of drivetrain parts. In more recent times, LPC/HPGQ batch equipment has been the choice for GM, Ford, and Fiat Chrysler, among others, for passenger vehicles for distortion control with light and heavy trucks retaining traditional atmosphere case and press quench hardening, primarily due to their more massive cross sections. In addition to hardening drivetrain components, hybrid or pure EV electric motors, either AC or DC, require heat-treating for motor laminations, copper windings, bearings, shafts, and the like. Nonferrous components like these require heat-treating processes that mirror annealing, stress relieving, and aging, to name a few. These processes do not require quenching except for some aluminum alloys.

Although LPC/HPGQ enjoyed a major portion of the multi-speed transmission case-hardening process for passenger cars, the majority of that equipment resided in the OEM organization due to its high cost. There are a few exceptions where the process was outsourced to very large commercial heat-treating companies. Outsourcing heat treating where EV and hybrids are concerned may change that status quo. Although both DC and AC electric motors are being used in EVs, the designs of these power trains are proprietary to differing degrees. The design cost of multi-speed transmissions, six-speed and above, by comparison, due in part to its complexity, was shared by competitors with each OEM making specific modifications in their final designs. That dynamic may change where EV technology is concerned due to the diversity of thought on how the motors and batteries can be integrated into the drivetrain and chassis.

Where will the heat-treating market put its chips — vacuum, atmosphere, batch, continuous, mesh belt, and the myriad of other furnace systems?

Except for drivetrains, the majority of subassemblies that go into cars are subcontracted to either siblings of the parent company or altogether separate entities, and that's where the quality focus will likely be concentrated. Whether heat-treating is done in-house or outsourced is a function of that quality. If autonomous or self-driving cars reach the numbers hoped for, the infrastructure and maintenance required to keep all of them running will be a challenge. I believe the initial foray into mass production of ASDV (autonomous or self-driving vehicles) will be fleets such as delivery vans, rental cars, online delivery services, and car-sharing organizations, and probably uses no one has envisioned yet.

I also believe the end result will be commercial heat-treaters that have the majority of batch heat-treating equipment in the U. S. and likely Europe. The process flexibility these batch systems must provide will lead to a new generation of equipment.

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JASON SCHULZE
METALLURGICAL ENGINEER /// CONRAD KACSIK

Operators must consider production demands, equipment maintenance, and equipment operation in pursuit of quality.

Quality management is vital in heat-treating

Quality management in the thermal-processing industry is essential to not only conformance, but also as a check-and-balance to both systems and operations. Quality at any thermal processor can be thought of as both an advocate for the company and for the purchaser. Being that all employees are responsible for quality, I would like to examine this from an operator's point of view.

THE STANDARD

In general, operators are trained in how to prepare hardware (when necessary) for thermal processing, how to load and operate equipment, and how to perform any necessary inspections. This may be split between departments or this may be performed by a single operator. Training typically consists of on-the-job (OJT) training followed by some type of test (written and/or practical) that approves them as a qualified operator. During this process both procedures and work instructions are typically used.

For operators, there are many variables within their job that should be considered, including production demands, equipment maintenance, and equipment operation. Some operators are responsible for multiple furnaces at once, making their focus even more spread out.

The standard would be that the operators are able to give the attention necessary to each variable they are responsible for, including the quality of the product. Included in this (possibly imaginary) standard would, of course, be quality oversight to ensure quality is maintained throughout each variable.

THE PRACTICAL SIDE

I was once told by one of my early mentors that "if an operator makes a mistake, it's your fault as an engineer. What could you have done to prevent the operator from making the mistake? Maliciousness is the only exception." This has stayed with me throughout my career. This is also why operator error is not an acceptable root cause in any setting. In management and engineering, we should be looking at what tools we can give operators to mitigate errors.

A common tool is training. Throughout my consulting, I've seen many versions of operator training from industry and prime specification requirements and testing, to using ARP1962. While these may be useful in select settings, your operator should also be trained on the company heat-treat procedures and/or work instructions. Consider the basic flow-down process with regard to heat-treat; 1) the purchase order and/or print contain heat-treat requirements (including Nadcap), 2) these requirements are flowed down to internal procedures and/or work instructions. This means that, most of the time, testing and qualification of operators should not include industry or prime specification requirements. These requirements would have been included within the company procedures by the engineer or quality organization. This is also true regarding Nadcap checklist requirements. In the end, as long as the requirements flowed down from the purchaser are documented within a company's internal procedures and/or work instructions, operator training needs to include only company policies, procedures, forms, and work instructions. Of course, practical and classroom testing should be incorporated.

Also, whenever procedures and/or work instructions as well as forms are modified, confirming the changes made with the operators is a good practice, as they are exposed to the process all day. The operator may well turn out to be a great source of knowledge for both the engineering and quality group.

In defense of heat-treat operators, it would be difficult to keep quality in mind in each process they perform, as much as we would expect them to. Including quality steps within procedures is a good remedy to this issue, especially if they are trained to their specific company procedures. Another way to remind heat-treat operators is to include them in quality meetings to ensure they understand the goals and requirements that affect them.

SUMMARY

So often the industry focuses on management, engineering, and quality management. It's important to be reminded that we build and organize our procedures to ensure our heat-treat operators produce quality product that conforms to the industry and/or prime specifications. Focusing on operator training can be the strongest ally for quality.

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Jason Schulze is the director of technical services at Conrad Kacsik Instrument Systems, Inc. As a metallurgical engineer with 20-plus years in aerospace, he assists potential and existing Nadcap suppliers in conformance as well as metallurgical consulting. He is contracted by eQualearn to teach multiple PRI courses, including pyrometry, RCCA, and Checklists Review for heat-treat. Contact him at jschulze@kacsik.com.

ISSUE FOCUS ///

THERMOCOUPLES / INDUSTRIAL GASES

REDUCING MEASUREMENT ERROR WHEN MAKING THERMOCOUPLE TRANSMITTER CONNECTIONS

An understanding of the three basic laws of thermocouples can help weed out potential sources of error in a thermocouple measurement system.

By BRUCE CYBURT

The thermocouple (TC) is a thermo-electric device used to measure temperature and nearly two-thirds of U.S. temperature measurement makes use of thermocouples. Most industrial applications use a TC to remotely sense temperature and then transmit its signal some distance using TC transmitters to monitor and control a process. The TC transmitter amplifies, isolates, and converts the low-level signals to another signal suitable for monitoring and retransmission. Unfortunately, the interface between the TC and mating instruments is widely misunderstood, which often leads to measurement error. The focus of this paper is on the connectivity aspects of thermocouples and TC transmitters to reduce error that can be extended to include connection to any thermocouple instruments.

A TC is formed using a pair of different metal wires joined at one end (referred to as the hot junction). At the opposite open end of a pair of wires (its cold or reference junction), a low-level voltage proportional to the difference in temperature between the ends can be measured. Of available temperature sensors, the TC has the widest application range giving accurate measurement of extreme temperatures in harsh environments. To extract the hot end temperature from measured TC voltage related to the difference, it is necessary to measure the temperature at the open end to determine the temperature at the other end (the hot junction). Because the TC voltage is not linear with temperature, its conversion from voltage to temperature normally requires a complex polynomial specific to the thermocouple type, or optionally determined using a standard lookup table of TC voltage versus temperature. Originally, TC voltage was tabulated while holding its reference junction in an ice bath corresponding to 0°C (hence the term cold junction). Modern thermocouples still reference themselves to a cold junction of 0°C with their standard table tabulating output voltage over temperature with respect to 0.000mV at 0°C. The use of standard TC tables and a simple correction can reduce this polynomial conversion from voltage to temperature to a combination of measured and tabulated voltage (more on this later).

The nature of the TC circuit is that it is prone to produce error when mating it to a measurement device without some insight into how these thermocouples and TC components work. This paper reviews TC behavior and outlines common problems encountered when connecting to thermocouples to measure temperature to help you avoid error and get the best possible performance from your TC temperature measurement system. It is written primarily for industrial users of thermocouples and TC transmitters, but much of this information can be extended to any thermocouple instrument. For more comprehensive information about thermocouples, please refer to whitepaper 8500-911, The Basics of Temperature Measurement Using Thermocouples, available free for download from www.acromag.com.

BUILDING A THERMOCOUPLE

Thermocouples were developed from a principle first demonstrated in 1822 by German physicist Thomas Seebeck when he observed

Temperature transmitters. (Courtesy: Acromag)

that the application of temperature along a metal conductor drives charge separation in the conductor such that a small voltage is developed across it (Figure 1). Using two different metals joined at one end to create an open-circuit loop, he was able to measure this thermo-electric effect and relate the voltage seen at the open end to the temperature difference between ends. This effect is only evident for two different metals and different combinations produce different voltage levels for the same temperature difference. This was later coined as "The Seebeck Effect" and the Seebeck Coefficient of various materials remains a measure of the magnitude of this voltage generated by a temperature difference across the material. The Seebeck coefficient has units of Volts per Kelvin (V/K), or microvolts per Kelvin (uV/K), and is inversely related to the material's current carrier density, such that insulators will have a high Seebeck coefficient, and metals will have a lower coefficient due to their higher carrier concentration.

Referring to Figure 1, by applying heat to one end of a conductor, the atoms that make up the metal will vibrate rapidly and the kinetic energy of the vibrating atoms spreads along the wire and conducts heat from the hotter end to the colder end. These rapidly vibrating atoms at the hot end of the metal drives free orbiting electrons to the colder end, leaving it more positively charged. The magnitude of this charge separation or voltage difference varies only with different material types such that its length or gage has no effect on the voltage magnitude. Because different materials produce different degrees of charge separation for the same temperature difference, tying two different conductors together at one end drives a net voltage difference measured at the open end and is directly proportional to the difference in temperature between the ends. By tabulating this voltage difference for various imposed hot-end temperatures while its cold end is held at a steady reference temperature, the relationship between the thermoelectric voltage and sensed temperature can be derived.

The most important thing to remember about the TC is it that it's the temperature difference between ends that produces the charge imbalance that drives the small voltages, not the junction of the two dissimilar metals that form the thermocouple circuit. While you can form your own TC circuit with different combinations of two conductors, standard TC types using specific metals and alloys are available that produce larger, stable, and predictable output voltages relative to applied thermal gradients. These standard types have their voltage over temperature tabulated in TC type tables relative to a cold junction at 0°C and 0.000mV. These TC voltages could have been referenced to another temperature than 0°C, but 0°C was chosen because it is easily reproducible within ±0.2°C using a mixture or slurry of ice and water. By holding the cold junction at 0°C, the temperature of the other end directly corresponds to its thermoelectric voltage found by look-up in the standard TC type table.

THREE FUNDAMENTAL PRINCIPLES OF THERMOCOUPLES

To correctly apply thermocouples to temperature measurement, it's important to understand three thermoelectric principles that govern TC behavior and that give important clues for properly conditioning them.

The first basic principle is The Law of Homogeneous Materials (see Wikipedia.org): A thermoelectric current cannot be sustained in a circuit composed of a single homogeneous material by the application of heat alone, and regardless of how the material may vary in cross-section.

This tells us:

› No current flows in a conductor circuit by the application of heat alone when made of a single metal.

› Two different metals are required to form a thermocouple.

› The size or gage of wire does not affect the voltage produced.

› The voltage produced is independent of temperature variations along the TC path.

The TC produces a voltage difference between ends independent of the temperature distribution along its length allowing you to pass TC wires through hot and cold areas without affecting its measurement if the wire material is kept consistent along the wire path (i.e. using TC connection blocks & extension wires).

The second principle that governs TC behavior is The Law of Intermediate Materials (see Wikipedia.org): The algebraic sum of the thermoelectric EMFs in a circuit composed of any number of dissimilar materials is zero if all the junctions are maintained at a uniform temperature.

This tells us:

› If a different metal than the TC material is used to connect either or both TC wires, the measured voltage will not be affected if the different metal is kept at the same temperature across its transition or isothermal.

Extending this principle to the cold junction at the open end of a TC circuit where the measurement is taken (inclusive of the lead

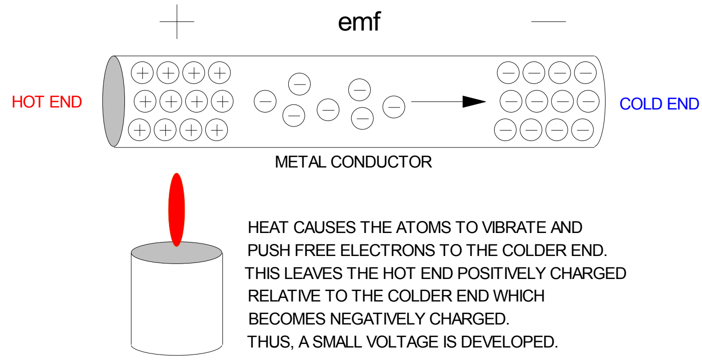

Figure 1

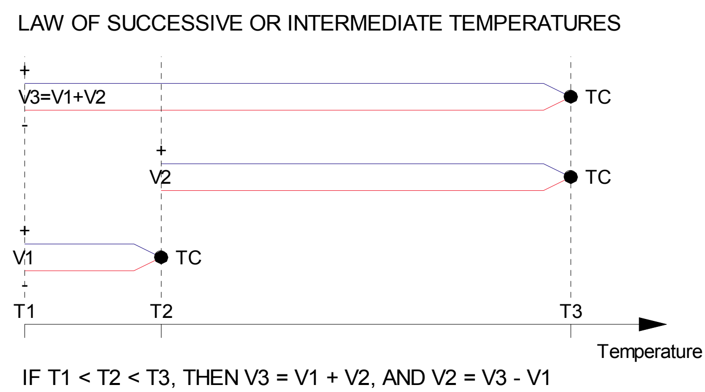

Figure 2

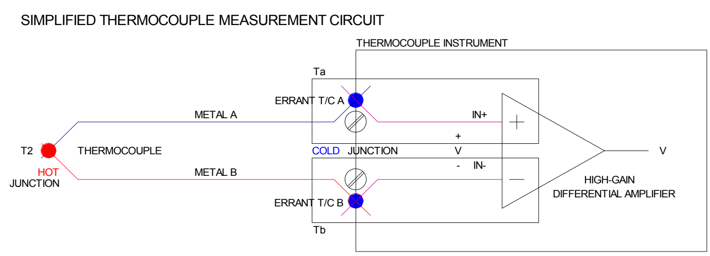

Figure 3

metal, solder, copper board traces, etc.), it may be considered isothermal when its combined temperature remains constant, usually following a period of heat exchange with its surroundings where its temperature may adjust slowly over time before finally reaching thermal equilibrium (its warm-up period).

The third principle that governs TC behavior helps us combine TC voltages mathematically using standard tabulated values taken with respect to the same reference is referred to as "The Law of Successive or Intermediate Temperatures" (see Wikipedia.org): If two dissimilar homogeneous materials produce a thermoelectric voltage V1 when its junctions are at T1 and T2, and then produce thermoelectric voltage V2 when the junctions are at T2 and T3, then the voltage produced when the junctions are at T1 and T3 will be V1 + V2, as long as T1<T2<T3.

The behavior of a TC type is normally characterized by a 5th or higher order polynomial used to calculate its voltage versus temperature in its standard table. The Law of Successive or Intermediate Temperatures allows you to instead accomplish cold junction compensation of the TC measurement by subtracting the TC voltage of the cold junction temperature from the measured voltage to get the actual voltage that corresponds to the hot end of the TC circuit. This is illustrated graphically in Figure 2.

In practice, temperature T3 is unknown and the cold junction temperature is not 0°C. You have the measured voltage V3. If you also measure the temperature at the cold junction T1 and look up its equivalent voltage V1 relative to T2=0°C in a TC type standard table. By subtracting V1 from your measured V3, you can determine V2. Then the temperature T3 can be matched to the voltage V2 by referring to the TC standard voltage versus temperature table.

THE COLD JUNCTION AND COLD JUNCTION COMPENSATION

You should be aware of how a TC instrument accomplishes cold junction compensation, the limits it imposes on your measurement, and potential conditions that can increase CJC error.

Briefly, we've shown that the open-end thermo-electric voltage measured across a thermocouple is only related to the difference in temperature between the ends. To determine the temperature at one end, we need to know the temperature of the opposite end. Cold Junction Compensation simply refers to the method we use to extract the measured temperature by determining the cold junction contribution to get the remaining portion that corresponds to our measured temperature when the cold junction temperature is not 0°C. Briefly, applying cold junction compensation to the open end helps us extract the sensed temperature at the other end (hot junction) from our measured voltage. Of course, if the connections at the open end are kept at 0°C, its contribution to the measured voltage is 0mV, allowing us to easily determine the sensed temperature via simple lookup of the voltage in the TC type standard voltage/temperature table. In practice, keeping the open end at 0°C is not easily accomplished. Instead we can measure its temperature, determine its voltage contribution in the TC type look-up table, then subtract it from the measured voltage and look up the corresponding temperature for the resulting voltage in the standard TC type table.

The Law of Intermediate Materials says that the sum of the thermoelectric voltages in a TC circuit created by any number of different metal junctions will be zero, if each of the metal-to-metal junctions can be maintained at the same temperature or isothermal through their connection. Maintaining all these metal elements at the same temperature or isothermal can be very difficult to accomplish, especially if they extend some distance, or are individually subject to other thermal influence that may unevenly affect their temperatures. Keeping inadvertent thermocouples isothermal cannot be completely avoided, but we take precautions to keep their contribution small by limiting varying temperatures influences on them. Manufacturers of TC instruments with cold junction compensation have two challenges:

› Make the CJC circuit isothermal as quickly as possible by closely coupling the TC wire connection points to keep them subject to the same temperature--any uneven temperature gradient between the point pairs will be a source of error.

› The temperature of the CJC connection points must be measured at least as accurate as the TC itself. The response time of the CJC temperature sensor is also a factor in maintaining accuracy for systems that require a fast response, as the cold-junction is often subject to unstable ambient conditions (like nearby board components that dissipate power unevenly or unstable air currents).

The performance of a TC transmitter is reflective of how well the manufacturer was able to accomplish CJC and this usually requires some compromise. For example, the transmitter may require a longer warm-up time, making it vulnerable to temporary error driven by quickly changing temperatures or power conditions near the junction. It may not measure its cold junction temperature as accurately as the thermocouple, or with equivalent resolution, increasing measurement uncertainty. But more often, poor installation practices in the use of this equipment increases CJC and measurement error making it one of the greatest sources of thermocouple measurement error.

The single best way to make cold junction connections with other metals is to minimize the distance between the metals, balance their thermal masses, and reduce the thermal resistance between them.

The Law of Intermediate Materials allows thermocouple connections using other metals without affecting the measured value if the "other metals" if their connections are kept at the same temperature or isothermal. To resolve the TC voltage measured to the hot junction, the instrument must measure the temperature of its "isothermal" cold junction circuit accurately and achieved accuracy of the measurement is only as good as the accuracy of its measured cold junction temperature.

A simplified thermocouple circuit including the cold junction is illustrated in Figure 3.

Ideally, TC instruments should have a short warm-up time with fast cold junction compensation and closely couple their CJC sensor to the cold junction terminals, or use terminals made of a compatible TC material. Because many instruments mount the CJC sensor on the circuit board with the cold junction connections outside the enclosure. Some manufacturers try to embed the CJC sensor in the bulk of the terminals (usually its plastic) or locate the sensor as close as possible to the terminals mounted to its circuit board. Both approaches limit the ability to precisely measure the real temperature of the cold junction connections and this is sometimes reflected in the specifications which may indicate increased error with CJC on, or only specify accuracy with CJC off. Some manufacturers avoid CJC error by using cold junction terminals made of the same material as the TC to push the cold junction down to the circuit board in closer contact with an on-board temperature sensor.

Unfortunately, that makes the instrument TC type-specific and the junction is still vulnerable to board heat source variations driven by other board components. The reality is that these instruments come in many sizes, shapes, and styles such that their construction often involves tradeoffs that affect their CJC relative to cost and performance. Be aware of the potential problem areas to help minimize CJC error.

The single best way to make cold junction connections with other metals is to minimize the distance between the metals, balance their thermal masses, and reduce the thermal resistance between them (i.e. we want heat to be evenly distributed across them). Anything that can drive a difference in temperature in the circuit between and including the cold junction connections will add error to the measurement.

As an installer, protect the cold junction terminals from anything that can drive a temperature difference between them or force an uneven distribution of heat across them. This usually involves shielding them from unstable ambient conditions near the cold junction connections and across its circuit. Always consider potential sources of varying temperature and try to make the thermal conditions near the cold junction more stable. This could require added shielding, or simply rearranging the position of equipment. Look for adjacent sources of heat (power supplies, other modules, etc.), vents, and cooling fans, etc. Focus on items that operate intermittently or with variable power dissipation. While it may not be possible to eliminate items, you can take measures that minimize their influence on the cold junction. For example, you might locate the measuring instrument (or at least its cold junction terminals) outside of the air stream of a cabinet cooling fan. You can sometimes add space between instruments and adjacent heat sources. Look at the mounted position of an instrument relative to its vents—is it positioned in such a way that it cannot easily release hot internal air? Be careful in routing sensor leads to the instrument and make sure that at the point you break out the TC leads prior to a connection, that one lead is not subject to a source of heat that causes its lead to conduct heat to its cold junction connection and upset its thermal balance across the cold junction. Avoid introducing other inadvertent thermocouples to your TC loop. For example, have you selected external terminal blocks that match the TC or have you substituted less expensive isotherm blocks that require you to maintain the same temperature through them (adding one more path for inadvertent thermocouples that can negatively affect your measurement if you can't keep them isothermal)? Have you shared a terminal with one TC lead such that this adjacent wire may be heat sinking the TC lead and upsetting its thermal balance across the cold junction? Small thermal gradients across the cold junction circuit may also occur due to self-heating of nearby board components. Also consider changes to the operating state of the instrument that might drive changes in internal power dissipation which will acts on the CJC sensor sharing that space.

The cold junction connections and its sensor needs more time to reach thermal equilibrium, causing periods of increased measurement error immediately following changes in ambient conditions. Be sure to consider potential sources of error when making TC instrument connections related to the fact that cold junction ambient temperatures are tracked slowly relative to the fast response time of the TC hot junction. This lag can result from the larger thermal mass of the connectors and poor thermal coupling to the CJC sensor. While a slow responding cold junction does tend to filter out some rapid changes in cold junction ambient, it does not prevent the slow progression of an instrument to an accurate measurement after a notable shift in cold junction ambient.

Potential error related to CJC is evident by long warm-up times specified for TC instruments. Measurement accuracy generally improves as a change in cold junction ambient is absorbed by the CJC materials and its heat is more evenly distributed across its connections to the cold junction sensor. For example, if someone suddenly opens a cabinet door and hot air contained rushes out, causing a rapid shift in cold junction ambient to shift temporarily throwing off the measurement until a new thermal equilibrium can be reached. Or perhaps, a fan is operated intermittently inside the cabinet causing an ambient to shift. For thermocouple transmitter or instrument connections that include cold junction compensation, it might take from 30-60 minutes to reach a new thermal equilibrium. When assessing a temperature measurement system for the presence of these conditions, keep in mind that a shift in operating ambient can also be sourced by the circuit itself—Has its operating state changed abruptly affecting its internal power dissipation? For a loop-powered 2-wire transmitter, this would be true if the external load being driven has been reduced or shorted, or if the power supply voltage has changed or is excessive relative to what is required to drive the load.

Some instruments allow you to disable cold junction compensation and doing so can give some indication of how much error is being contributed due to "thermal gradients" acting on CJC. When

TT Series. (Courtesy: Acromag)

resolving these errors, review the module placement and position, adjacent influences, your wiring, etc. In addition to conditions that magnify CJC error, other real sources of measurement error often involve poor choices of connection materials like wire, cable, and terminals and thermocouple routing errors to the transmitter.

CONNECTION MATERIALS

The materials you select to connect a thermocouple will impact the accuracy of your system (terminal blocks, thermocouple wire and cable, and extension cable).

TERMINAL BLOCKS

Thermocouple wires are designed to be fine to help prevent their mass from affecting the temperature being sensed making them delicate and subject to breakage. While TC instrument manufacturers often provide wiring diagrams showing thermocouples wired to cold junction terminals on the instrument, this is often not the case. Industrial applications typically use TC terminal blocks separate from the instrument to mate to the TC leads with TC wire and extension cable connecting the terminals on the transmitter. These extra terminals often serve as a strain relief and facilitate easy change-out of a failed instrument or sensor. Unfortunately, offsetting TC connections from the instrument adds another potential source of error usually related to the choice of terminals. Users not familiar with the Law of Homogeneous Materials or The Law of Intermediate Metals may incorrectly choose standard terminals that subject TC leads to errant thermocouples that result from thermal differences that develop across the extra junctions. It is important to use terminal blocks designed specifically for the thermocouple type to avoid adding error and there are three main types of TC terminal blocks uses that come in many physical varieties. Most are DIN rail mounted and some may include a special socket for connecting the plug of a hand-held meter designed to monitor thermocouple voltage.

The best type of TC connector uses connection materials the same as the TC metals, or of a compatible alloy. By the Law of Homogeneous Materials, use of this in the wired path will not affect the voltage measurement because it matches or mimics the material of your TC leads. Any temperature variation through this other material has no effect on the measured TC voltage and operates transparent to the TC wire. Of course, these connectors are more expensive since they TC type specific. Any error resulting from their use is usually attributed to mismatching them to the TC type or flipping their polarity. In the U.S., the body color of a TC connector closely matches the outer insulating sheath of the TC type.

The next best TC connector is the “universal” type. Universal types do not use connection metals that match the TC leads, making them less expensive. Universal types instead try to closely couple the ingress and egress wires with little or no intermediate material contact to create an isothermal union to the TC and mimic a homogeneous connection. In this type, the input TC wire enters one end and the output TC wire exits the opposite end. The two wires overlap for some length inside the connector and make good thermal and electrical contact, usually without passing through an intermediate metal. Two clamping screws and a common pressure plate are used to secure the wires. As a result, the negative effect of using non-homogeneous material is minimized.

The least expensive universal type is designed to equalize the temperature across the union and is sometimes referred to as an “isotherm block.” This type of connector exploits the Law of Intermediate Materials to allow other metals to connect the TC circuit but not affect the measurement by attempting to keep the material isothermal or at the same temperature. For example, its wire screws are usually recessed to shield them from air drafts and its plastic housing is designed such that its input and exit paths are closely spaced. These blocks do make connection to the thermocouple using an intermediate metal, and they are less favorable because they rely on maintaining the same temperature through the material to minimize its effect on the measurement by limiting the contact length to an intermediate metal. And while they have a cost advantage and may be applied universally to any TC type, they do not form perfect isothermal unions and small voltage effects can develop, especially where the diameters of the mating wires differ, which is most often the case.

Because universal connector types may involve some intermediary contact, you should take precautions with both to ensure no difference in temperature between its wire input and output paths. Of course, for any connection type, error can be driven into the measurement due to the breakout they force between the individual TC wires from their sheath and from each other, which sometimes exposes one wire to a different temperature than the other, conducting its heat to the connection block and upset the isothermal balance across its non-homogeneous connection path. The breakout of the individual TC wires leaves a portion of the wire unshielded vulnerable to noise pickup—always keep the breakout length to a minimum. Some of these connection blocks will include screw connections for the TC cable shield which is helpful to extend the shield right to the instrument minimizing breakout exposure.

Perhaps the greatest concern of using any type of external terminal to connect the TC wires is to make sure that standard, non-thermocouple types are never used for this purpose, or have been inadvertently substituted, which drives errant thermocouple voltages into the measurement and reduces accuracy. Don’t try to justify use of cheaper standard blocks using the Law of Intermediate Metals, as these terminal use steel or a nickel-plated copper alloy for their contacts adding more errant thermocouples to your measurement. They only work if you can assure the temperature on both sides of the connection block remains the same or changes at the same rate—highly unlikely in a packed control cabinet full of warm equipment, cooling fans, or other devices that may heat or cool the interior ambient in an uneven way.

TC EXTENSION WIRE & CABLE

To extend TC wire over long distances, less costly thermocouple extension cable is often used with TC terminal blocks to lower cost. These cables often have larger diameters up to 14 AWG and can be used to reduce loop resistance too. Extension cable will use similar materials to the TC, or materials better suited for the intervening environment along its path. But for extension cables, it’s important to remember that its thermal behavior may only approximate that of the TC and its insulation may restrict the TC to use over a smaller temperature range. Be cognizant of use of the extension and its potential limitations, as it can increase error if applied improperly with respect to temperature and environment. The extension wire conductors of base metal thermocouples (J, K, N, E, and T) usually matche the composition of the TC and exhibit the same thermoelectric properties. The extension wires of noble metal thermocouples (R, S, and B) are usually a different alloy which may only approximate the noble metal properties and over a more limited range. Their conductor materials are different because the noble metals contain platinum, which is very expensive to use as an extension over a long distance. The careful use of different materials is not usually a problem, as these noble metal types are mostly used at higher temperatures with lower resolution, making their different material error contributions less significant. But in all cases, the maximum application temperature is limited by the extension wire insulation and this is an important factor in their selection.

Potential measurement errors from using extension cables often result from poor connections driving errant thermoelectric voltages into the measurement, mismatching TC types, or reversing its polarity. You must use the correct TC extension cable type for the TC and observe the proper polarity. Substitution of any other type will increase measurement error. The same rules apply to mating connection blocks. Other problems may result by using extension cable of an incompatible material type for its environment, or where the extension wire is mismatched to the sensor or environment. For example, thermocouples that use iron metal will be subject to corrosion that may impede continuity, particularly in wet environments. Extension cable that does not match the TC type exactly will have a lower operating temperature range unsuitable for use close to the hot junction.

THERMOCOUPLE SENSOR WIRING AND WIRE ROUTING

The path that you take in routing the sensor to the instrument will also impact measurement accuracy. Consider that the fine TC lead wires made from other materials than copper have a higher resistance than copper, making them more sensitive to noise pickup, especially AC-coupled noise. Additionally, because thermocouples output a low-level voltage, they have a low signal to noise ratio, higher conductor impedance, and most often connect to equipment that amplifies its signal, making long TC routes an easy pickup of errant noise signals from nearby equipment and power lines. Take measures in routing TC leads and extension cables that respect this sensitivity to noise pickup as follows:

› Route TC wires defensively and do not combine them with power wires. Operation in noisy environments or nearby electric motors may benefit from the use of screened extension cable.

› Avoid combining TC leads over long parallel paths with output or signal wires, which may inductively couple noise into the TC wires.

› Minimize the length or loop area where thermocouple cables or wires pull apart to make a connection to an instrument or TC terminal block.

› Individual wires can be twisted together to make sure both leads pick up the same signal (i.e. they reject common mode noise).

Note also that while the TC signals are small, much larger voltages may exist at the instrument due to the presence of common-mode voltages driven by inductive pickup along the sensor wire, or via multiple earth ground connections in the system. For example, inductive pickup is a common problem when using a TC to sense the temperature of a motor winding or power transformer. For some applications, multiple earth grounds may be inadvertent, perhaps when using a non-insulated or grounded TC to measure the temperature of a hot water pipe. In this instance, any poor connection to earth ground may drive a few volts of difference between the pipe and measurement instrument. These instruments often make use of high-quality, high-gain, differential instrument amplifiers that help reject noise common to both input leads as long for voltages within the common-mode input range of the amplifier, usually limited to only ±3V or ±5V by its internal DC voltage rail. This ability to reject common-mode noise is strong for signals near DC, but weaker as the frequency of the noise increases. It usually helps to twist the wires together to make sure that both leads pick up the same signal allowing any common mode noise to be rejected by the amplifier. Keep the lead length short and any loop area small where the cable wires part to make the instrument connection. For long runs, consider using screened cable with earth ground connected at the instrument end to minimize its noise pickup. There are different types of screened cable which include copper or mylar/aluminum tape, or even screened twisted pair if required. You have many options to combat noise pickup in a TC circuit and you may wish to consult with your cable vendor. The following link is a good resource for learning about other options in this regard: www.thermocables.com/faq.htm

Also consider that the junction of a TC sensor is commonly grounded and in direct contact with its surrounding case metal to give it a faster response time, but this can be troublesome for noise pickup and potential ground loop error which will significantly increase measurement error, often many times greater than the error contributed by the other influences we've reviewed. Ungrounded junction TC sensors are available where sensor isolation is required, but usually with an increase in response time. You may alternatively select an isolated TC transmitter for use with a grounded TC sensor to combat ground loop error.

A REVIEW OF BEST PRACTICES WHEN MAKING THERMOCOUPLE CONNECTIONS

Considering the TC connection carefully, CJC effects, plus the connectors and cables you use to increase your measurement accuracy:

› Are the cold junction connections exposed to open air drafts that may unevenly distribute heat across them, such as that from heating or cooling-fans?

› Is the transmitter mounted inside the enclosure in a way that helps shield its cold junction connections from quickly varying air currents caused by movement of personnel and equipment, heating/air-conditioning fans, and outdoor air currents?

› Is the transmitter adjacent to a power supply or "warm" device that may cause one junction terminal to be warmed different from the opposite terminal, upsetting its isothermal balance? Are the individual leads of the TC wire fanned out of their sheath in a way that one lead may be subject to a different temperature than the other that could conduct heat to its cold junction?

› Have you observed proper polarity in connecting your TC sensor, any extension cables, and any matching TC terminal blocks? TC types are color coded and RED denotes Negative Lead for American or ANSI TC types. Sometimes this leads to confusion because it is opposite the convention used for DC power where red typically denotes positive.

› Have you allowed the transmitter up to 60 minutes of warm-up time after applying power to reach thermal equilibrium across its cold junction circuitry necessary for accurate cold junction compensation?

› Is the transmitter mounted in a position that curbs the flow of air across or through the unit that may increase its internal ambient? Are its vents blocked by adjacent modules, circuits, cables, or other obstructions? This can result in a larger internal ambient, increasing its potential for error driven by a longer thermal warm-up and wider temperature variation acting on the CJC temperature sensor inside the unit.

› Have you positioned modules in a way that allows air space between them to minimize the negative effect of adjacent heat sources on cold junction connections that might upset its isothermal balance? Are modules spaced farther apart from more significant sources of heat, such as power supplies, cooling fans, etc.?

› Have you spread the TC wires apart with a larger than required separation gap between them before they connect to terminals? If the cold junction terminals do not match the TC material, this breakout can drive a difference in temperature between the wires, where the individual leads route differently and may be subject to different temperature influences. This difference in temperature can act on the non-homogeneous cold-junction circuit upsetting its isothermal balance. Breaking the wires out of their shield also makes them more prone to noise pickup too. Sometimes a TC sheath is pulled back to individually tag the TC wires and while this looks nice, it opens the door for another potential source of error.

› Are you using crimp-on pins or terminals on TC wire ends to protect the wires inserted into the instrument? While this is done with good intention, this material is generally not the same as the TC and will effectively extend the cold junction by displacing it from its terminal and making its mass more vulnerable to developing a temperature across it. For some pin-style crimp-on connectors, the clamp of the cold junction terminals of the instrument will make contact over a smaller area and increase its thermal resistance. In general, you get better performance by simply connecting the TC wire or cable directly to the cold junction terminals of the unit. Most terminals are a cage-clamp style that already does a good job of protecting the wire and the use of additional crimp terminals is not necessary.

› Is one lead of the TC sharing a connection with another wire in the same terminal? The presence of this other wire can heat-sink the TC lead, driving a temperature difference across the cold junction that contributes error. Its negative effect is magnified if the adjacent lead is of a larger diameter than the TC wire causing it to act as a heat-sink ability and increasing the thermal resistance of the TC wire to junction contact. For example, some transmitter models may require that a TC break jumper be installed by sharing a terminal with one

ST Series with cable. (Courtesy: Acromag)

of the TC leads—keep this jump wire short and of a gage no greater than the TC wire to avoid increased error.

› Has a fault or other condition at the transmitter caused its circuit to increase or change its nominal power dissipation, affecting the heat distribution across the cold junction connections? For example, a two-wire temperature transmitter will dissipate more heat internally if its load resistance is reduced or shorted, or if its power supply is excessive relative to the level needed to drive the load.

› Make sure that any terminal block used in your TC circuit is not a standard type which will drive errant TC voltage into your measurement. TC connections should only use TC terminal blocks, or isotherm (universal) terminal blocks designed specifically for thermocouple connection.

› For multiple adjacent mounted instruments, but arranged from bottom to top (i.e. perhaps on a vertical DIN rail), consider the chimney effect of rising heat that will cause the units on top to be naturally heated by the units on the bottom, potentially affecting their accuracy, as this heat will be unevenly distributed across the cold junction connection circuitry? TC transmitters are typically designed with their input terminals positioned at the bottom and power terminals at the top when mounted on a horizontal DIN rail to help reduce chimney effect error and you should respect this arrangement when field-mounting the unit.

› Have you taken care to reduce undue strain imposed on the TC wires? Watch for wires damaged or broken by pulling and routing, rough handling, frequent vibration, or other stress. Note that TC wires are made fine to help prevent the wire mass from affecting the sensed temperature at the hot junction but this makes them more delicate and subject to breakage.

› Make sure that your TC circuit only uses TC wire or extension wire of the same type. In some instances, an uninformed service technician may inadvertently substitute standard cable or cable of a different TC type, which will drive error voltage into your system.

› Keep the sensitive TC wires away from other current-carrying conductors, electric motors, switching solenoids, and sources of RF noise to avoid pick up. For long runs in noisy environments, you are probably better off converting the TC signal locally to 4-20mA for transmission of the signal over the longer distance.

› Watch the loop resistance of your TC circuit and try to keep it below 100Ω. This is important because most TC instruments include lead break detection, which involves running a small current through the sensor to detect a lead break. This small current passing through the higher resistance TC wire and can generate voltage error for excessive resistance. Increased sensor resistance also makes the sensor more susceptible to errant voltage drops resulting from coupled noise currents. When calculating resistance, remember the total wire length doubles because of its return path. By the Law of Homogeneous Materials, you can safely extend the TC wire with extension cable of a larger gage, which will have a lower resistance than that of the finer TC wire.

IMPORTANT PRINCIPLES TO KEEP IN MIND

By the Law of Homogeneous Materials, the TC voltage is NOT affected by temperature change along the wire path (only at the ends) if the wire metals are homogeneous (or nearly homogeneous like some extension wire). This means that you can insert metal junctions of the same wire material without affecting the measured voltage, useful for splicing and extending the TC.

By the Law of Intermediate Materials, if a different metal is inserted into either or both leads, it will have no effect on the TC voltage if the junctions into and out of the other metal are kept at the same temperature. This allows you to connect your instrument to the TC without affecting its measurement if you can ensure a constant temperature through the chain of extra metals added into the circuit.

By the Law of Successive or Intermediate Temperatures, the nonlinear TC sensor which normally requires a complicated polynomial to resolve its voltage versus temperature relationship can alternately be reduced to a simple mathematical combination of our measured TC voltage and tabulated voltage found in a standard voltage versus temperature table for the TC type. This allows the measurement to cold junction compensated by simply adding or subtracting voltage values using the measured voltage, the measured cold-junction temperature, and the standard TC table to resolve associated TC temperature. Simply stated, this law allows a TC calibrated at one reference temperature to be used at any other reference temperature via a simple algebraic correction.

CONCLUSION

A keen understanding of the three basic laws of thermocouples: Homogeneous Materials, Intermediate Metals, and Successive or Intermediate Temperatures, can be helpful in weeding out potential sources of error in thermocouple measurement systems. It's also valuable in properly selecting and applying the components commonly used to connect thermocouples to instruments. This coupled with an awareness of how cold junction compensation works and the limitations it imposes on our measurement and wiring practice, will go a long way toward improving thermocouple measurement accuracy.

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OPTIMIZING GAS SUPPLY FOR INDUSTRIAL LASERS

Addressing the integration of production lasers with industrial gas supply systems.

By DON BOWE

Laser cutting of metals and other materials has grown rapidly due to developments in laser power, advancements in CNC automation, and decreasing costs. The industrial gas requirements for lasers have been quite dynamic as well.

Depending on the material to be cut, the process or assist gas can be air, oxygen, or an inert gas (nitrogen or argon). Each gas provides different production results. Lasers operating with O_2 combine the energy of the laser with the exothermic energy from the reaction of O_2 with the metal to make the cut. The cut surface with O_2 is not as clean as one made with an inert gas. When an inert gas is used as the assist gas, the laser provides all the energy to melt the metal. The role of N_2 or argon is to clear away the molten material from the area of the cut. These gases also inert the cut area and facilitate cooling of the surface until it is at a low enough temperature to avoid oxidation. The result is a clean, oxide-free surface.

OEM SCOPE

There are many manufacturers of lasers and laser cutting systems. The optimum system requirements depend on many factors including: dimensional accuracy, surface finish, cut-edge quality, type of material, thickness, post-processing needs, overall cutting time, and the amount of material to be cut. Based on all of these inputs, the OEM will design a laser cutting system that will typically have an industrial gas requirement (O_2, N_2, or argon). The OEM will also define the required purity, flow rate, and pressure of the gases consumed in the laser. The focus of this article is to provide information on the supply systems and gases that support laser cutting.

PURITY

Many laser OEMs refer to overall purity of the gases used and typically require grade 5, or five 9's, purity. The purity table shows the purity of various grades.

Often times it is more meaningful to evaluate the impurity levels rather than overall purity. The main impurities of concern are those that can oxidize the material being cut, such as the PPM O_2 level and the dew point (moisture) level. Most industrial liquid N_2 grades meet the five 9's purity level. The dew point of gaseous N_2 from a liquid N_2 supply is typically less than minus 90°F (< about 3 PPMV).

The impact of N_2 purity on cleanliness of the laser cut is shown on various metal pieces in Figures 1 and 2. A bright, clean surface is achieved only with a purity of 99.995 percent or greater.

1000 PPM = 0.1% Impurity = 99.9% N_2	Three 9's purity
100 PPM = 0.01% Impurity = 99.99% N_2	Four 9's purity
10 PPM = 0.001% Impurity = 99.999% N_2	Five 9's purity

Purity table.

PIPING

The houseline piping needs to be properly selected to handle the maximum pressure and peak flow rate. Since the required flow rate to the laser varies with the thicknesses and type of material being cut, it is extremely important to understand the range of thickness to be cut. With high flows and high initial supply pressures, line size is extremely important due to the concern for potential pressure drops, especially when growth is not factored into the initial piping design.

For lasers using O_2, there is an additional requirement for piping and flow components; they need to be "oxygen cleaned and oxygen compatible." Equipment used in oxygen service must be cleaned according to strict industry guidelines. The most commonly used specifications in the industry are CGA G-4.1, NFPA 99, and ASTM G93. "Oxygen cleaning" or "cleaned for oxygen service" means that all particulates and organic residue have been removed from the surface of the piping and the components. Oxygen combines readily with many elements to form compounds called "oxides." One example is iron oxide, or rust, that forms on iron in the presence of oxygen and moisture.

Figure 1: Comparison of identical metals cut with 99.9% and 99.999% pure nitrogen.

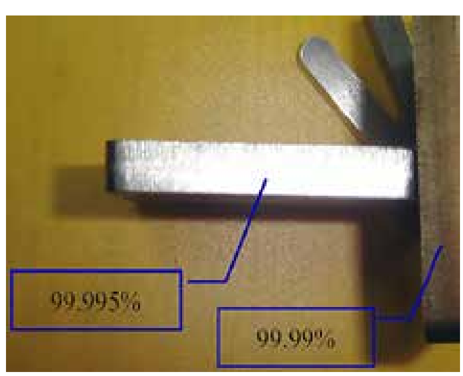


Figure 2: Comparison of identical metals cut with 99.99% and 99.995% pure nitrogen.

FLOW CAPACITY

The houseline piping needs to be designed to provide the required flow rate at the required pressure.

If the piping system does not have the required flow capacity, excessive pressure drops will occur. A supply system will have a certain initial maximum pressure and flow rate capacity. Once gas starts flowing down the houseline, its pressure can only decrease. The goal of a properly designed houseline is to minimize the pressure drop along the houseline and provide the required flow of gas at the minimum required pressure.

The laser OEM specifies a certain minimum gas pressure at the inlet to the laser under peak flow conditions. When there are multiple lasers on a common houseline, the laser at the furthest point from the supply system is the most easily starved for pressure and flow. Pressure drops can be caused by inadequate pipe diameter, excessive pipe length, circuitous piping (e.g. elbows, T's, pipe diameter reduction, etc.), and/or components with low-flow capacity (isolation valves). The correct flow component selection is an important part of a properly designed houseline network.

Table 1 illustrates the impact of pipe sizing on pressure drop for three different sized pipes at flow rates from 1,000 SCFH to 6,000 SCFH. In this evaluation, the gas is N_2 with an initial pressure of 450 PSIG and a pipe length of 250'. The pressure drop is the difference between the inlet pressure and the pressure as the gas exits the pipe. A 0.5" diameter pipe with a flow rate of 6,000 SCFH N_2 has a pressure drop of 40.44 PSI. This means that the pressure at the end of the 250' pipe run will be (450 - 40.44) = 409.56 PSIG.

If, instead, the houseline was 1.5", the pressure drop would only be 0.207 PSI with a resultant downstream pressure of (450 – 0.207) = 449.8 PSIG.

Although oxygen itself is nonflammable, combustible materials burn more strongly in oxygen. The higher the oxygen percentage and the higher the pressure, the stronger the combustion and the lower the required ignition temperature.

Materials that do not normally ignite in atmospheric air will burn and may explode in an oxygen-rich environment.

Pipe ID, inches	Flow Rate, SCFH					
	1,000	2,000	3,000	4,000	5,000	6,000
0.5	1.159	4.453	9.941	17.663	27.766	40.44
1	0.067	0.249	0.541	0.944	1.456	2.079
1.5	0.007	0.026	0.056	0.096	0.146	0.207

Basis: Nitrogen gas flowing through 250 ft long pipe, inlet pressure = 450 PSI

Table 1: Pressure Drop (PSI) in Schedule 80 Pipe.

	Annealed	Drawn**
Nominal Size, in	S = 6,000 PSI	S = 10,300 PSI
¼	1074	1850
⅜	1130	1946
½	891	1534
⅝	736	1266
¾	852	1466
1	655	1126
1¼	532	914
1½	494	850
2	435	747
2½	398	684
3	385	662
3½	366	628
4	360	618
5	345	592
6	346	595
8	369	634
10	369	634
12	370	635

*Based on maximum allowable stress (S) in tension (PSI) for 100°F

**When brazing or welding is used to join drawn tube, the corresponding annealed rating must be used

Source: Copper Tube Handbook

Table 2: Rated Internal Working Pressure (PSI)* for Copper Tube (Type K) at 100° F.

PRESSURE RATING

The houseline piping must be designed to handle the expected pressure. Tables 2 and 3 show the rated working pressures for Type K copper tubing and welded stainless steel pipe, respectively. There is tremendous variation in pressure rating depending on the diameter and material, especially for the larger-diameter copper tubing. If a new houseline is being installed, it usually makes sense to oversize the pipe with regard to both flow capacity and pressure rating to account for future production growth.

PRODUCT MIX

The amount of N_2 for assist gas for cutting stainless steel can vary from several hundred SCFH for relatively thin material (< 0.1") to several thousand SCFH for > 0.5". Therefore, it is important to understand how much cutting time will be associated with each grade and thickness. After this has been determined, the monthly gas consumption can be calculated by multiplying the flow rate for each material and thickness times the amount of monthly cutting hours. This monthly consumption can be used to optimally size the industrial gas supply system.

Figure 3 illustrates typical gas flow rates for various materials and thicknesses, using a 4 kW laser. This data stresses the importance of understanding the product mix when sizing a system since the assist gas flow rate can vary significantly based on material thickness.

Pressure ratings for standard seamless A312-TP316/316L stainless steel pipes

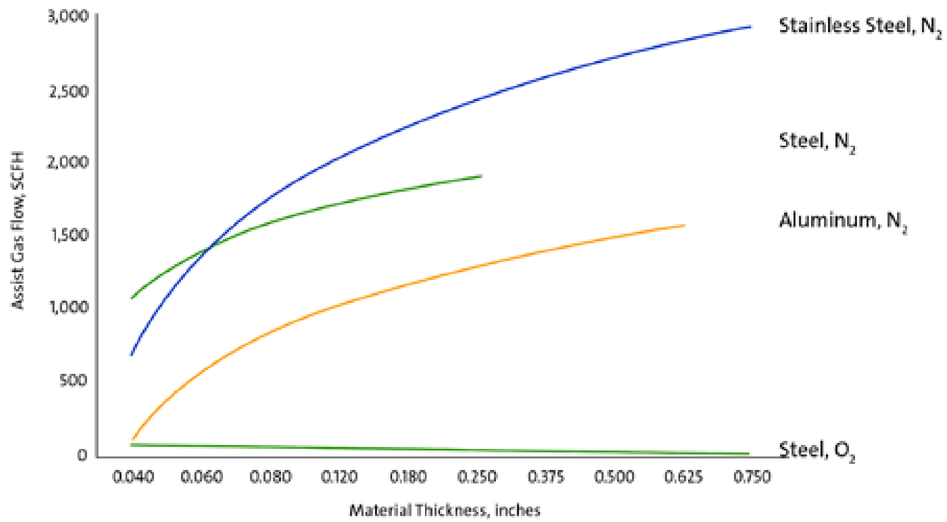
	Pressure Rating (PSIG)	
Pipe Size, in	Pipe Schedule	Temperature 100°F
1"	40	3048
	80	4213
	160	6140
1½"	40	2257
	80	3182
	160	4619
2"	40	1902
	80	2747
	160	4499

Source: Engineeringtoolbox.com

Table 3: Stainless Steel Pipe Pressure Ratings.

INDUSTRIAL GAS SUPPLY MODES

There are many different gas supply modes available. The one that



Source: Trumpf TruLaser 2030 as cited in "Trumpf MASTERCutSheetFIBER.pdf

Figure 3: Typical assist gas flow rates vs. thickness for various materials and gases; 4 kW Laser.

If a pressure regulator is needed on the houseline, it is important to select one that has adequate flow capacity. An improperly sized pressure regulator can potentially limit the downstream flow.

fits a specific requirement is determined by the supply system's capability for maximum pressure, flow rate, and storage capacity. Over the years, the flow rate and pressure requirements for the assist gas in laser cutting have increased.

This has made the selection of the proper N_2 supply system even more critical because not all N_2 supply systems have the same pressure and flow capabilities. All aspects of an industrial gas supply system must be designed properly so that safety, efficiency, and performance of the laser can be assured. The following is a summary of the main supply options:

Cylinders: These are the smallest, simplest mode of supply. The gas is at high pressure, but the amount of stored gas is minimal. A typical cylinder contains about 275 SCF at 2,200 PSIG. Cylinders can be manifolded together to supply more volume.

Microbulk: This supply mode provides gaseous N_2, O_2, or argon from a relatively small cryogenic liquid tank. These tanks range in size from 230 liters (5,658 SCF) to 5,000 liters (123,000 SCF). These supply systems have a wide range of pressure capabilities. Some are as high as 500 PSIG MAWP and are able to supply a houseline with a pressure of 450 PSIG. These supply systems can have a limited flow capacity; therefore, the peak process flow requirement must be compared with the systems flow capacity. In some cases, it makes sense to use two or more microbulk tanks for increased capacity. The use of more than one tank can facilitate a continuous supply of process gas during the filling of the tanks. One tank is online while the other is being filled.

Bulk Tanks: These are the traditional industrial gas tanks. They range in size from 1,500 gallons (140,000 SCF N_2) to greater than 11,000 gallons (1,024,210 SCF N_2). Most of these tanks have a 250 PSIG MAWP, so the maximum houseline pressure is about 200 PSIG. Since this pressure is too low for most lasers, additional equipment must be added to enable a higher supply pressure. There are commercially available gas supply systems that take liquid from the supply tank and then pressurize it for the process. Such systems have high flow and pressure capability. Houseline pressures as high as 550 PSIG are available for N_2.

Another alternative is to use the bulk tank to supply a cryogenic pump, a high-pressure vaporizer, and gaseous hydril tubes to provide a high-pressure supply system.

High-Pressure Bulk Tanks: There are also other supply systems that can produce high pressure and high flow rates. These include high-pressure bulk tanks. They can operate as high as 600 PSIG MAWP. Sometimes these tanks have a cryogenic ground pump so they can be filled from the supply trailer without depressurizing (venting) the tank and interrupting the supply to the use point. The ground pump enables the delivery tanker truck to overcome the tank's operating pressure, thus allowing an uninterrupted supply of high gas pressure to the laser.

The best choice of a supply system depends on the amount of usage (SCF/month), the peak combined flow rate (SCFH), the production schedule (hours/month of cutting), and the minimum houseline pressure. The anticipated growth of the gas requirement should also be considered in this evaluation.

It is important to take into account how the tanks are filled and whether the tank needs to be depressurized in order to fill the tank. This can result in a loss of gas supply during the fill procedure. The venting of gas during tank depressurization also has an economic cost since the vented gas is lost. Venting also occurs during the switching between liquid containers during normal operation of the gas supply system.

The last factor in determining the best mode of supply is whether there needs to be a continuous supply.

Some supply modes require the tank to be depressurized while being filled.

PRESSURE REGULATION

If a pressure regulator is needed on the houseline, it is important to select one that has adequate flow capacity. An improperly sized pressure regulator can potentially limit the downstream flow. Many standard cylinder pressure regulators can handle the pressure but can only provide a limited flow capacity and should not be used. An improperly chosen pressure regulator can become a flow restriction.

SUMMARY

There are many factors that must be considered when designing the industrial gas supply system. The supply system must be engineered along with the houseline piping and associated components to ensure that it operates safely, properly, and efficiently to meet the demanding laser requirements.

ABOUT THE AUTHOR

Don Bowe is a senior applications engineer at Air Products. Please contact Air Products for assistance in specifying the right oxygen, nitrogen, or argon supply system for your laser operation at 800-654-4567.

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COMPANY PROFILE ///

McLAUGHLIN FURNACE GROUP

MAKING A DIFFERENCE IN THE HEAT-TREAT INDUSTRY

A furnace before a rebuild (inset) and after McLaughlin Furnace Group rebuilt it. (Photos courtesy: McLaughlin Furnace Group)

Blending cutting-edge technology with more than 100 years of combined expert experience on staff, McLaughlin Furnace Group has set an industry standard for customer service and custom, go-to solutions.

By KENNETH CARTER, Thermal Processing editor

A Tru-Mix^{TM} Endothermic Gas Generator.

Jeff McLaughlin doesn't want his customers to consider McLaughlin Furnace Group as an average service company. The company's ultimate goal is to give its customers a product they want.

"I'm a hands-on guy; I'm a field guy," said McLaughlin, the company founder and president. "I understand the equipment inside and out. When they deal with McLaughlin Furnace Group, they're not only dealing with my highly-skilled staff, but a lot of times I'm involved in the process from the beginning."

McLaughlin brings his unique bag of skill-sets to the services and products McLaughlin Furnace Group offers the heat-treat industry.

REBUILDS

McLaughlin Furnace Group rebuilds all types of furnaces. Most furnaces are rebuilt at McLaughlin's facility in Avilla, Indiana. The furnaces are stripped down to the shell and sandblasted down to the bare metal. Warped metal is straightened or replaced, and cracks are repaired and reinforced. The lining is re-bricked including proprietary hearth and door lintel designs. The combustion system is upgraded with fuel-efficient burners and state-of-the-art controls. Door and elevator mechanicals are upgraded with rugged, yet easy-to-maintain systems.

McLaughlin Furnace Group also repairs and rebuilds vacuum pumps including mechanical and diffusion pumps to reduce vacuum processing systems' downtime.

TRU-MIX™ ENDOTHERMIC GAS GENERATOR

In trying to better meet customers' needs, McLaughlin has developed the Tru-Mix^{TM} endothermic gas generator, which has been engineered to consistently produce the highest quality gas.

"The Tru-Mix generator is one of the most innovative units that we've done," he said. "We designed and tested it against other OEMs, and it's 33 percent more efficient. Nobody has that on the market. It's very robust, very consistent, and has little margin for error."

The Tru-Mix generator is efficient and its design allows it to be installed in areas with low ceilings, according to McLaughlin.

"We clam-shelled it," he said. "You can open it from the side. It's very, very maintenance- and operator-friendly."

VARIABLE TEMPERATURES

McLaughlin Furnace Group also offers tempering furnaces that have a variable temperature range.

"We run a really robust temper furnace that ranges from 250 degrees to 1,450 degrees within plus-or-minus 10 degrees to meet all the Nadcap specs," he said. "A lot of people struggle with getting the low ends, and we can take it to 200 degrees — if we would like to — all the way up to 1,550 degrees with a gas-fired furnace. That's unique to some of the processes because when you're selling the commercial and captive heat treats, they want to be able to have that lateral movement of temperature range."

CUSTOMER APPROACH

McLaughlin Furnace Group's wide range of services and products are a needed part of the industry, but McLaughlin said his company's excellent customer approach often takes it to the next level.

"I listen to the customer," he said. "I can communicate with the CEOs, the plant engineers, production managers, maintenance managers, purchasing managers. I can touch on all those levels because I've been in those positions — all of them — and I'm still a field guy. I view things from a maintenance side, and I view things from an engineering side."

McLaughlin said he explains to the customer what products he uses, as well as how the customer can benefit from the company's manufacturing processes.

"My biggest thing is efficiency," he said. "We want to make equipment more efficient and more effective. That's what I think we give our customers that sets us apart from other OEMs. The big thing we offer is a different philosophy than just putting a product out there."

A McLaughlin-Vesco Vacuum Pump. The company is scaling out its business in order to cover the vacuum side.

"As technology grows across the world in many other industries, heat-treat is always going to follow it – or lead it. I see the heat-treating industry leading some of the technology that we have moving forward with electric cars, semiconductors, and everything else."

EXCEEDING EXPECTATIONS

McLaughlin Furnace Group's ability to go that extra mile for its customers is evident in a recent furnace rebuild.

"We came in with a different view of we're going to build you a new shell and cut this one out," he said. "We're going to pull it out like a bad tooth. We're going to put a new set of dentures on this furnace, so to speak, right? We're going to give you a better product. That's exactly what we did, and it was up and running in two-and-a-half weeks. The customer couldn't believe it."

The bottom line for the customer added up to only $50,000 more, but the new shell was built off-site, allowing the customer to continuously run product until cutting out and marrying the new shell into the line, according to McLaughlin.

"That saved them money," he said. "Now they've got a furnace that they never shut down. They've got a brand-new shell, a brand-new design, and it's 30 percent more efficient."

NITRIDING

Another area of the heat-treat industry that McLaughlin Furnace Group is diving into is nitriding.

"We've designed our Tru-Tride system for horizontal nitriding," he said. "It's a nitriding furnace that holds a very tight uniformity nitriding process, very robust. It has internal dual cooling. Nobody else is doing that."

MULTI-FACETED COMPANY

McLaughlin started McLaughlin Services in 2007, and in 2017, he bought Vesco, a vacuum service company in East Windsor, Connecticut, and created McLaughlin Furnace Group.

McLaughlin Furnace Group covers the company's OEM side, supplying furnaces, generators, car bottom furnaces, and heat-treat equipment.

A McLaughlin Temper Furnace.

A McLaughlin Nitriding Furnace.

McLaughlin Services operates underneath that, as well as Vesco-McLaughlin, which specializes in vacuum engineering.

"We're scaling out a little bit to be able to cover the vacuum side of the business — pump repairs, full service maintenance on the vacuum systems, installations, removals, rebuilds, and hot zone rebuilds," he said. "We do service; we do installations, and we're kind of 'umbrella-ing' all of the heat-treat industry as a whole."

Being able to service customers quickly and efficiently is part of what keeps McLaughlin Furnace Group busy. Often, that means completing a job faster than the lead times offered by their competitors.

"I want to be able to have faster delivery and service," he said. "I want to be able to build a robust product that customers can rely on and which helps minimize their need for service and makes them money."

TECHNOLOGY GROWTH, COMPANY GROWTH

McLaughlin said that he expects the heat-treat industry to grow as advances in technology increase.

"As technology grows across the world in many other industries, heat-treat is always going to follow it — or lead it. I see the heat-treating industry leading some of the technology that we have moving forward with electric cars, semiconductors, and everything else."

Along with that growing technology, McLaughlin sees McLaughlin Furnace Group growing with it.

"My vision is to change the furnace industry as people know it," he said. "That's my goal. That's why I went into it."

MORE INFO www.mclaughlinsvc.com

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ROSEANNE BRUNELLO /// PRESIDENT AND OWNER /// MOUNTAIN REP

"If somebody comes to me with a need, I'm on it – whatever I can do to help make their problem go away."

What do you and Mountain Rep do for the heat-treat industry?

Mountain Rep is a manufacturing rep firm that has been in business for 35 years; however, we've only been in the heat-treatment world for about three years. I moved back to Cleveland, and this is kind of the way that my company wound up going into the heat-treat business. I currently sell nitriders for RUBIG. I sell gas and plasma nitriders, plasma-coating systems. I work with a rebuilder of vacuum pumps, a rebuilder of hot zones, and 3D-temperature uniformity surveys that take the data off the SSI data logger, and they make a 3D image from it, which is pretty cool because it helps with predictive maintenance and the furnaces. That relates to AMS 2750, and that spec keeps getting tighter and tighter, and now RUBIG, I think is going to be requesting everybody be computerized. They're getting away from the paper that those machines used to use. It's a good time for that. That's the VVS, which is software created by Pete Husheck from Phoenix Heat Treat. He came up with this software where it takes data and it turns it into a 3D image of the inside of the hot zone of the furnace.

I'm very involved with ASM. I'm going to be the chairperson this coming year for the Cleveland chapter. Right now, I'm the vice chair. I'm a member of the Heat Treat Society. I reach out to the students at Cleveland State University and Case Western Reserve to get them interested in careers in engineering. I'm just a nice girl from Cleveland, Ohio.

What made you decide to add heat-treat to your company's offerings?

When I moved back to Cleveland, I had a business for 30 years that dealt with the machining and the processing of aerospace components and sub-assemblies. I did that for 30 years, and I loved it. I did great. I repped lines like a CNC machine shop and an investment casting house — which I did really well with — and hardening ground gears, and all the aerospace-type commodities, but then I moved home.

When I moved home, everything kind of got scrambled, and HC Stark called me and offered me a regional manager job, and I learned all about moly and molybdenum. The all-metal hot zone is made out of molybdenum. When Stark hired me for a year, I learned all about moly. They put me in charge of the heat-treat furnace customers. That worked out great, and then and I decided to start Mountain Rep again, which was perfect because I had already been in business for 35 years.

What's a typical day like for you at Mountain Rep?

I start answering emails, and then I start calling customers. It's very hard to get a hold of people today. It is very hard to get people to reply to your emails and to your phone calls, and it's a very fine line not being a pain about trying to call too much or being overly aggressive, so I'm on LinkedIn a lot. I connect with people there. I try to get them to let me come see them or send them an email. You kind of have to feel each thing out by itself. Every call is different.

The heat-treat industry is kind of a male-dominated world. Has that been a challenge for you being a woman-owned business?

I started off in 1983 selling CNC machine tools when CNC came out to replace NC, and these guys would've never bought a furnace from me, because I was a girl, so I've dealt with that my whole career. This one is little tougher; you're right. The good old boys are still around and God bless them, I hope they live forever, but when they do go, you know, I'm going to be right there behind them.

Actually, a lot of people are very, very nice to me. My whole thing about meeting with people is to see how I can help them. I like them to teach me. One thing I've always done in my 35 years, is I get them to teach me something. In fact, right now since I'm into nitriding now, my question is: Teach me something about nitriding. If I could get every single person that I meet to teach me one little thing, just one little thing, I'll remember it forever. I'm like a little sponge trying to learn about it.

How do you approach customers when they come to you with a need?

I pride myself on my customer service. If somebody comes to me with a need, I'm on it — whatever I can do to help make their problem go away. I follow up; I'm thankful; I'm eager; I'm enthusiastic. I *am* a girl, so now I can play my girl card. I could wish you Happy Valentine's Day. I could bring you a little tray of cookies.

Where do you see the heat-treat industry in the next five to 10 years and Mountain Rep's place in that?

My five-year plan is to have local sub-reps in all four states. I already have one in Michigan. He's great; his name is John Young, and he joined me in January. And I would hope that maybe they want to keep it going after I'm done.

I'm not saying I'm going to retire in five years. Maybe, that's the 10-year plan.

MORE INFO www.mtnrep.net