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DEPARTMENTS

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RESOURCES

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LETTER FROM THE EDITOR

Countdown to Heat Treat 2017

Things are definitely heating up as we get closer to Heat Treat 2017 in Columbus, Ohio, October 24-26. No doubt you're all excited about connecting with your colleagues in the industry.

All of the top companies and big names are expected to be there while 200 heat-treat exhibitors will crowd the floor of the Greater Columbus Convention Center.

Thermal Processing will have a booth there as well, so please drop by and introduce yourself. I'd love to meet you and discuss editorial opportunities with the magazine. I'm always looking for new and exciting ways to pass on important industry knowledge and expertise.

So, consider this issue of *Thermal Processing* a primer to get you in the mood.

We've packed the September/October issue with several articles you will definitely find of interest.

Experts from Seco/Warwick discuss the first operational system for a single-piece flow method of case hardening by low-pressure carburizing and high-pressure gas quench.

An extremely interesting article from Linde LLC addresses using sub-zero treatments to give robotic gears a helping hand to extend their performance.

And Lonny Rickman from American Steel Treating offers an analysis of atmosphere vs. vacuum carburizing and hardening.

Our company profile spotlights the achievements of Surface Combustion and how it has committed to innovative technology for more than 100 years.

To cap it all off, *Thermal Processing* is always thrilled to highlight the expertise our columnists bring to the heat-treating table. They continue to shine a light on all aspects of the industry.

I'm excited to bring you this issue, and I hope to see you at the show in October. Stop by booth #2135 and say hey, and maybe I can include you and your company in a future issue.

Thanks for reading!

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Thermal processing for Gear Solutions

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OPERATIONS

Wisconsin Oven ships sand core drying ovens to the foundry industry

Wisconsin Oven Corporation shipped two natural gas fired Enhanced Duty Walk-In Series Ovens to the foundry industry. The batch ovens will dry sand cores used in the casting process of a variety of parts.

Each of the work chamber dimensions of these sand core dryers is 10" W x 8" H x 20" L, with a maximum temperature rating of 500°F. Guaranteed temperature uniformity of ±10°F at 500°F was documented with a nine-point temperature survey. The oven bodies were constructed with tongue and groove panel assemblies featuring Wisconsin Oven's patented high-efficiency panel seams that provide 25 percent better insulating efficiency.

"These sand core dryers were designed to maximize efficiency and decrease drying time of the cores," said David Burke, sales representative for Torrid Enterprises. "The customer is able to pour and dry more cores in less time than before, resulting in an increase to their production."

Unique features of these industrial ovens include:

- Natural gas (direct) fired.
- 480 volts, 3 phase, 60 hertz.

Wisconsin Oven Corporation shipped two natural Gas Fired Enhanced Duty Walk-in Series ovens to the foundry industry. (Courtesy: Wisconsin Oven Corporation)

- 17,200 CFM @ 20 HP recirculation blower.
- Eclipse air heat burner rated at 950,000 BTU per hour.
- Combination airflow to maximize heating rates and uniformity.
- 600 CFM @ ½ HP exhaust removes 11 gallons of water per batch.
- NanoDac programmable controller/recorder.

FOR MORE INFORMATION: wisoven.com

Automotive corporation's bearing division bolsters production

A global automotive corporation's American-based bearing division placed an order with Can-Eng Furnaces International for a mesh belt furnace system for heat-treating thrust races, retainer/cages, and washers. The new, CQI-9 compliant production line features built-in flexibility that allows for both neutral hardening and carburizing. Included with the system is: An atmosphere-controlled hardening furnace, salt quench, two-stage post-quench washing system, salt reclamation unit, temper furnace salt holding tank, and Can-Eng's Level 2 SCADA system — PETTM. The electrically heated system uses unique loading combinations on its belt to meet production requirements while achieving the customer's required low residence times for the system's hardener and quench. Additionally, through the integration of Can-Eng's PET System, the automotive supplier gains access to vital tracking of products' status, detailed process data for continuous process improvements, comprehensive equipment diagnostics, cost analysis, and inventory management.

Can-Eng Furnaces International offers continuous mesh belt heat-treatment systems.

Can-Eng Furnaces' continuous mesh belt heat-treatment systems were chosen for this project not just for its proven track record, but for the custom engineering and flexibility for meeting the customer's need. Capable of treating three separate part types, multiple heat-treating processes, unique temperature operating ranges, and diverse residence times for each piece of equipment, Can-Eng provides solutions for each customer's needs.

FOR MORE INFORMATION: can-eng.com

E-Instruments offers new E8500 Plus portable emissions analyzer

The new E8500 Plus emissions analyzer is a complete portable tool for EPA compliance level emissions monitoring and testing. The E8500 Plus is ideal for regulatory and maintenance use in boiler, burner, engine, turbine, furnace, and other combustion applications.

New features:

- Upgraded software with automatic data-logging.
- New PID VOC sensor option.
- New display screen and keypad design.
- Easier filter replacement and inspection.
- Expanded internal memory (up to 2,000 tests).
- New sample conditioning system for low NOx & SO2.

Additional features:

- Electrochemical sensors – O2, CO, NO, NO2, SO2, H2S.
- NDIR sensors – CO2, CxHy, High CO.
- Low NOx and true NOx capable.
- Real-time PC software package with Bluetooth.
- Wireless remote printer.
- Internal thermoelectric chiller with automatic condensate removal.

The new E8500 Plus emissions analyzer is a complete portable tool for EPA compliance level emissions monitoring and testing. (Courtesy: E-Instruments)

FOR MORE INFORMATION: E-Inst.com

ALBA to boost aluminum smelter production by 50 percent

Aluminium Bahrain B.S.C. (Alba) is expanding its primary aluminum production capacity with the Line 6 Expansion Project. Upon the full ramp-up of Potline 6 in 2019, the company's smelter capacity will be increased by more than 50 percent, to 1.5 million tons a year. This investment will make Alba one of the largest aluminum smelters in the world.

Hertwich Engineering, a company of SMS group, has been awarded the contract for the necessary expansion of the homogenizing capacity. Alba has installed a total of six furnaces and ancillary equipment from Hertwich during the cooperation lasting more than two decades.

Now Hertwich has received an order to supply a modern batch homogenizing plant for Potline 5, which started operation in 2005, to upgrade the existing continuous homogenizing plant. This plant now on order is designed for an annual production of 60,000 tons of logs with diameters ranging from 152 to 254 millimeters, and lengths up to 8,100 millimeters. The furnace will be integrated into the material flow of the existing continuous homogenizing plant. The cooled logs will be de-stacked, separated, and tested in an ultrasonic inspection station, which is also part of Hertwich's current scope of supply. The existing saw, and equipment for transport, stacking, strapping, etc., will be used for the new batch furnace as well.

For the new primary aluminum expansion project 'Potline 6,' the continuous and batch homogenizing furnace will be installed side-by-side so the production program can be organized flexibly at this point. The main component is the continuous homogenizing plant with an annual capacity of 140,000 tons. It is designed for logs up to 9 meters in length and diameters in the range from 152 to 410 millimeters. The batch homogenizing plant (charge weight: 85 tons) with separate cooling station will be installed next to the continuous homogenizing plant, so that both plants can operate in combination using the auxiliary equipment.

For the sawing, weighing, and packaging operations, Hertwich is to deliver transport and stacking/de-stacking equipment, a linear ultrasonic testing unit, two sawing units, two strapping and weighing stations, and two briquetting presses for chips.

FOR MORE INFORMATION: hertwich.com

Bodycote launches game-changing Powdermet® technologies

Courtesy: Bodycote

Bodycote, a provider of heat treatment and specialist thermal processing services, introduces Bodycote Powdermet® technologies, a group of additive manufacturing processes used in the production of complex components using powder metallurgy.

Bodycote has decades of experience creating complex, high-integrity components from powdered metal. Bodycote Powdermet® technologies now incorporate new, patent-pending techniques that combine 3D printing with well-established net shape and near net-shape techniques. This new technology dramatically reduces the manufacturing time and production cost of a part compared to producing the same part using 3D printing alone.

Powdermet® technologies ensure complete powder consolidation, achieve structural homogeneity, and eliminate internal porosity and unconsolidated powder flaws. The process can produce components with varying surface features and thicknesses, with higher structural integrity than alternative production techniques. The need for brazing or welding parts together to form larger structures is eliminated. Instead, the finished article can be produced as one seamless component and largely avoid the size limitations imposed by the constraints of 3D printing. Different parts of a component can be formed from different alloys, presenting the ideal and most cost-efficient solution. Component design can be tailored to the actual requirements for performance and not limited by subsequent machining operations.

"The recent breakthroughs are truly game-changing technologies for component design and manufacturing," said Stephen Harris, group chief executive. "Industry applications are wide-ranging with early adoption expected in aerospace, oil and gas, power generation, and mining."

Bodycote continues to invest in resources and capital for development in additive manufacturing technology to create significant value for customers and meet the future growth demands. As well as its Powdermet® technologies, Bodycote provides a full range of heat treatment, hot isostatic pressing (HIP), and electrical discharge machining (EDM) services across North America and Europe tailored specifically to support the needs of companies manufacturing metal components using 3D printing.

FOR MORE INFORMATION: bodycote.com

Transor Filter expands facility in China

To meet the customer demands of an expanding Asian market, Transor Filter USA has announced expansion of its facility in Kunshan, China. Initially established in 2008, the expanded Kunshan facility now occupies 29,000 square feet and has grown to 23 employees.

This staff includes sales, engineering, assembly, and service personnel. Jonathan Guo, a 16-year veteran of Transor Filter, continues on as managing director and guides Transor's important Pacific Rim operations.

"The sustained business growth, coupled with new opportunities in Korea, Taiwan, Thailand, and Singapore, has enabled us to expand our existing facility and staff," said Transor President Irv Kaage. "Now, we're able to better meet our customers' growing demands for Transor's One Micron Filtration System (OMF)."

FOR MORE INFORMATION: transorfilter.com

850°F gas-heated cabinet oven from Grieve

Grieve's 850°F (454°C), gas-heated cabinet oven is used for curing paint on steel and aluminum test coupons at the customer's facility. Workspace dimensions of this oven measure 20" W x 20" D x 20" H. 100,000 BTU/HR are installed in a modulating gas burner, while a 600 CFM, ½-HP recirculating blower provides horizontal airflow to the workload.

This Grieve oven has 6" insulated walls, an aluminized steel exterior and Type 430 stainless steel interior. The oven features a 12" wide x 8" high door installed in the main door. Additional safety features include those required by IRI, FM, and National Fire Protection Association Standard 86 for gas-heated equipment, including a 325 CFM, ½-HP-powered forced exhauster. Controls on the No. 843 include a digital indicating temperature controller.

FOR MORE INFORMATION: grievecorp.com

The new Grieve 850 degrees Fahrenheit gas-heated cabinet oven, currently used for curing paint on steel and aluminum test coupons at the customer's facility.

The Esco Hog Tie boiler tube weld alignment clamp is offered in eleven sizes. (Courtesy: Esco)

Esco pipe alignment tool sets up quickly, easily for welding

Esco Tool of Holliston, Massachusetts, has introduced a new welding joint-alignment fixture that is easier to use than a welding vise to align pipe or tube for tack welding, and create high-integrity welds.

The Esco Hog Tie® boiler tube weld alignment clamp consists of one side with two through-holes, and a matching side with threaded inserts which accept two bolts that draw them together. Easy to set up and use, this clamp aligns the pipe or tube perfectly and exposes the ends for tack welding before removal in order to complete the entire joint weld.

The Esco Hog Tie boiler tube weld alignment clamp is offered in eleven sizes for pipe and tube from 1.125" to 3.25" O.D. It is made of precision-machined, high-strength steel. This pipe alignment tool is available by itself or as a kit with an impact wrench and socket, four 0.5" bolts, two spare through-hole inserts, two spare threaded inserts, and a metal carrying case.

FOR MORE INFORMATION: escotool.com

Thermal Product Solutions ships Gruenberg conveyor oven to firearms maker

Thermal Product Solutions, a global manufacturer of thermal-processing equipment, announced the shipment of a Gruenberg conveyor oven to an ammunition manufacturer. This conveyor oven will be used for annealing and stress-relieving brass castings.

The maximum temperature rating of this heat treat oven is 850 degrees Fahrenheit, and the work chamber dimensions are

24” W x 105.5” D x 16” H. A variable speed conveyor system provides the operator with precise process control. The equipment design consists of one oven module, constructed from a structural steel frame that supports the chamber liner and the exterior sheet metal. All interconnecting struts are non-continuous to keep the exterior cool.

The conveyor oven has plug-style circulation and heating equipment. There are three identical plugs on the unit. This design allows the replacement of heaters away from the unit by removal of the plug as well as quick interchange if an extra plug is available.

“It was important for our customer to minimize equipment downtime. Gruenberg designed the unit to have swappable heater and circulation blower plugs, as well as supplied an extra plug with this system. If a heater needs to be replaced, or if one of the air circulation blowers fails, the plug can quickly be replaced,” said Blake Lawson, applications engineer

Unique features of this Gruenberg conveyor oven include:

- Set of adjustable leveling feet.
- Variable-speed conveyor system.
- Vertical up airflow design to maximize heating rates and uniformity.
- Yokogawa UP55A programmable controller.
- Plug-style heaters and recirculation equipment.
- Cooling section.
- Bearing cooling blowers.

Features of the Gruenberg conveyor oven include a set of adjustable leveling feet, variable speed conveyor system, and vertical up airflow design to maximize heating rates and uniformity. (Courtesy: Gruenberg)

FOR MORE INFORMATION: ThermalProductSolutions.com

Ipsen invests $1 million in heat treatment industry with purchase credits

Ipsen believes that one of the most valuable things a company can do is invest in others. Ipsen is also committed to advancing the heat-treating industry with the latest innovations and updated equipment. As part of that commitment, the company is investing $1 million in the industry this year.

Companies can take advantage of Ipsen’s investment by trading in its old furnace to receive a $50,000 credit toward the purchase of a new Titan® vacuum furnace (applies to the 2017 list price of any Titan model). Ipsen will accept a trade-in of any brand heat-treating furnace (vacuum or atmosphere) in any condition. To receive this credit, transactions must take place by October 31, and the new Titan furnace must ship from Ipsen’s facility by December 31, 2017.

Ipsen is offering incentives for companies that trade in their old furnace and buy a new Titan vacuum furnace. (Courtesy: Ipsen)

The Titan vacuum furnace comes complete with PdMetrics®, an advanced predictive maintenance software platform, and it incorporates years of customer feedback to deliver user-friendly features, all while maintaining a global platform, small footprint, and short delivery times. Available in several sizes and horizontal or vertical configurations, the Titan provides powerful performance for both experienced and first-time heat treaters.

FOR MORE INFORMATION: IpsenUSA.com

Lindberg/MPH ships cyclone box furnace

Lindberg/MPH announced the shipment of a gas-fired cyclone box furnace to the heat-treat industry. The box furnace will be used for heat treating steel parts, and is the second Lindberg/MPH furnace that has been purchased by this customer.

The work chamber of this heat treat furnace is designed to accept a basket with dimensions of 48" W x 84" D x 48" H, and has a maximum temperature rating of 1,250°F. The heating/combustion system consists of one nozzle mix gas burner firing downward into a combustion chamber before entering the re-circulation airflow. The combustion chamber is at the rear of the furnace, adjacent to the recirculating fan chamber for extended service life of the recirculation fan and gas burner. The furnace hearth consists of eight alloy rollers positioned across the furnace chamber floor, suitable for the load support and manual movement.

The box furnace was designed using the customer's current Lindberg/MPH equipment as a reference. It was manufactured with additions such as variable frequency drive control of re-circulating fan motor and paperless recorder to monitor chamber temperature.

"Lindberg/MPH has a reputation in the heat-treating industry for manufacturing dependable, high quality furnaces," said Bill St. Thomas, business development manager. "Because they are confident in our quality and durability, many of our customers have multiple units in their facility."

In addition to unique features already mentioned, this Lindberg/MPH box furnace also includes:

- Durable brick lining.
- Pneumatic furnace door.
- Over temperature protection.
- Custom paint color.

FOR MORE INFORMATION:
lindbergmph.com

Lindberg/MPH gas fired cyclone box furnace. (Courtesy: Lindberg/MPH)

Atmosphere and vacuum heat treating will require specific equipment-operating and performance options

By Jack Titus

VACUUM CARBURIZING OR LPC, NEUTRAL hardening, oil or HPGQ (high pressure gas quench), vacuum pumps, graphite insulation, radiation shields or ceramic insulation, graphite or moly heating elements — these are some of the processes and equipment options OEMs and heat treaters have to evaluate to determine the cost benefit for a specific component or heat-treating system if vacuum is being considered.

Likewise, if atmosphere hardening and carburizing are in the picture, additional choices must be made. Does production demand a continuous or batch furnace, brick refractory or ceramic modules, endo generator or nitrogen/methanol, electric heat or gas-fired radiant tubes? If gas, should you pick straight SER (single ended radiant) or "U" tubes? Should tube material be heat-resisting alloy or SiC (silicon carbide) ceramic? Finally, is fuel-saving recuperation cost effective?

To enlighten the reader, and hopefully assist those charged with making the choices noted above, I'll provide an examination on how each item can affect the overall process outcome.

CARBURIZING

Carburizing has been around in various forms for centuries. The primary reason it has survived as the most applied heat-treating process is its ability to improve the strength and wear resistance of the widest range of, and the least expensive, steels.

Vacuum furnaces likely began as bell jars enclosing a small, toaster-sized, electrically insulated box. Experimentation soon exposed the increased arcing potential, as the pressure was reduced, i.e. greater vacuum. Early light bulbs no doubt contributed to the science. Today, 60 volts is considered the maximum heating element voltage for metallic and graphite heating elements. In LPC, or where a partial pressure of hydrocarbon gas such as acetylene can produce soot, voltages as low as 24 are common. Today, vacuum furnaces have heating element power supplies ranging from 80 to 900 KW; the low voltage produces huge current or ampere levels necessitating large cross-section secondary copper conductors. If the current becomes so high, creating impractically large secondary cables, the cables can be water cooled to reduce their cross section.

Commercial heat-treating vacuum furnaces were first designed with tungsten or moly rod heating elements, with some changing to flat ribbon for easier fabrication. Insulation consisted of two types: metallic radiation shields composed of two thin moly sheets backed up by three stainless-steel sheets, or a thin moly sheet backed with two to four inches of ceramic blanket.

Each insulation configuration was primarily directed to a specific industry. Radiation shields produced a very clean but inefficient (high heat loss) atmosphere, and found application in brazing where no contamination could be tolerated. Ceramic-insulated (more efficient) chambers found their way into the heat-treating arena for tool hardening and for less critical brazing applications.

VACUUM PUMPS

Vacuum pumps in the early days employed a mechanical roughing pump (generally the sliding piston type) and an oil-diffusion pump. Since scientific research propelled vacuum-furnace development, it likely provided the concept for the heat-treating segment — thus the perceived need for the diffusion pump. In addition, since graphite had not yet been used as an insulation material or heating element, diffusion pumps provided the lower oxygen concentrations needed for scientific research. As pumping systems matured, the "roots" booster replaced the diffusion pump in heat-treat applications. As graphite insulation and heating elements became accepted in the 1970s, the booster became even more popular. Since graphite was a much more effective getter for oxygen than moly or tungsten, very low vacuum pressures were no longer needed to keep steel bright during heat treatment. Evacuation times also were drastically reduced since the higher-capacity booster could be introduced at much higher mechanical pump pressures.

OIL DIFFUSION PUMPS

Oil diffusion pumps are actually traps. They operate at vacuum levels where the mean-free path of air molecules is so long, only by happenstance do they bounce into and are captured in the pump inlet, reducing the pressure. Therefore, to function properly, their inlet must be as large as possible. If the potential for back-streaming diffusion-pump oil into the furnace poses a problem, the only option is the turbo-molecular vacuum pump. These pumps operate like a jet engine's turbine blades but rotate at extremely high RPM — 20,000 to 50,000 is not unusual. By shear forced convection even at low air density, they reduce the pressure after the roughing pump has lowered the pressure in the vacuum chamber. They are expensive and costly to maintain. If extremely low water vapor is required in the vacuum system, the cryo-pump is the solution: It functions as the third stage of either the roughing plus booster, or diffusion-pump combination. As the name implies, cryo-pumps are a cold trap using liquid nitrogen at -321 degrees Fahrenheit (-196 degrees Celsius) in which water vapor molecules condense onto a substrate and reduce the pressure.

Oil diffusion pumps had another problem: They can catch fire if operated incorrectly. That issue was solved with the development of synthetic-based silicone oils.

VACUUM FURNACES

In general, today's vacuum furnaces are the batch type — one load at a time into one hot zone. In the late 1980s and '90s, multi-chamber vacuum furnaces tried to increase production, but the complexity and maintenance cost drove them from the industry. Smaller semi-continuous versions can be found, but they do not have the capacity of the atmosphere pusher or mesh belt furnaces. And they are complex.

LPC (low pressure carburizing) and outgrowth of vacuum carburizing is the result of carbon reduction of a high concentration at the steel surface. Once the surface carbon target is assumed to be reached by calculated algorithm, diffusion reduces it again to a calculated target. Only after the process is complete can you determine if the process was successful. Therefore, trial and error is the only method that can be used to produce confidence that a recipe has worked.

The most effective and by far the greatest portion of heat-treating processes enjoyed by vacuum furnaces is neutral processing, especially for brazing and hardening high-carbon tool and die steels. But there, too, some caution is warranted: At low vacuum pressures, pure elements can be vaporized from the material surface; the most common is chromium. In some cases, decarburization has been detected when the surface of steel or stainless steel is being pre-treated prior to brazing or plasma nitriding. This can occur when a partial pressure of hydrogen is introduced at elevated temperature to "clean" the material surface.

ENDO CARBURIZING FURNACES

Two segments comprise atmosphere or endo carburizing furnaces: batch and continuous. Each of those two segments can have either brick or ceramic fiber refractory insulation. As such, the practical high-end temperature limit of the endo carburizer is 2,100°F (1,149°C). Obviously, there are brick refractories that can operate up to and above 3,000°F (1,648°C) but for carburizing, 2,000°F to 2,100°F (1,093°C to 1,149°C) is the practical limit for fiber and brick. Which material is chosen depends on one's personal preference, however, brick will generally last about 10 years while ceramic lasts five to seven. Very high carbon potential will always require brick lining. Ceramic fiber has the advantage of less heat storage, making short cycles with plunge cooling between loads more cost effective in time and energy consumed.

In the U.S., with the wide availability of natural gas and its lower cost due to fracking, it is the first choice of heat treaters for heating. Likewise, electricity produced with natural gas has also benefited. As for longevity of heating systems, gas or electric (both if

> "Carburizing has been around in various forms for centuries. The primary reason it has survived as the most applied heat-treating process is its ability to improve the strength and wear resistance of the widest range of, and the least expensive, steels."

using heat-resisting alloy radiant tubes) can expect similar life when exposed to similar atmospheres. Electric does have the maintenance advantage of clean tube interiors, whereas gas can produce soot that can carburize the tube ID if the burners are not tuned properly, shortening its life.

RADIANT TUBES

There's another decision regarding the style of radiant tube when gas heating: the "U" tube or the straight SER (single ended radiant) tube. There are two competing schools of thought regarding the tubes. SERs consist of two parts — the combustion inner tube and the outer tube. Combustion takes place through the ID of the inner tube with the effluent traveling back to the burner between the inner tube OD and outer tube ID over the recuperated burner assembly. The "U" tube, as the name implies, produces a flame that travels down one leg and up the other leg of the U. These tubes have the advantage of twice the exposed radiation area compared to the SER tube. To produce the same energy output, the SER tube must produce twice the energy density as the U tube, thus it must be made from more expensive heat-resistant SiC material — especially on the inner tube. Another advantage of the U tube is it requires half the number of tubes. Even though the SER can produce very high heat output per tube, in order to provide uniform radiation, more SER tubes are still required, so a "striping" heat distribution can be avoided when SER tubes are spaced farther apart. In some circumstances where one desires to take advantage of the higher output of the SER tube and reduce the number of tubes, a SiC muffle is installed in the furnace hot zone to shield the parts from the tubes and reduce the striping effect.

LOW PRESSURE CARBURIZING

LPC is a carburize/diffuse process that obtains the final surface carbon by high concentration and reduction. Conversely, the endo gas mix of 20 percent CO, 0.2 percent CO_2, 40 percent H_2 and 40 percent nitrogen creates a near equilibrium composition between the CP of the atmosphere and the steel surface. The CP of endo gas can be controlled by several approaches and the most recent is the oxygen probe. Before the probe, infrared analysis of CO_2 and dew point sensors were also employed. Dew point is still a preferred method for controlling the endo generator gas mix. Since residual oxygen is always present in endo gas, the oxygen probe provides a repeatable accurate sensor that corresponds to the CO_2 and dew point reactions. Its repeatability and accuracy are derived from its calibration to the consistent oxygen content of air.

Endo gas is generated by passing a 2.5/1 ration of air to natural gas through a 1,950°F (1,066°C) nickel catalyst. Fine-tuning can produce dew points of +25°F (-3.8°C) to +50°F (10°C) with the typical target of +35°F (1.7°C). A 35°F dew point and 0.2 percent CO_2 will produce about 0.4 percent CP at 1,700°F (925°C) in an empty furnace.

QUENCHING

Finally, quenching is the process that produces the strength and hardness resulting from carburizing or straight neutral hardening. For atmosphere furnaces, oil has been the overwhelming favorite simply due to the wide operating temperature range. For decades — possibly centuries — salt has hardened tools and small dies. Then, austempering salts became popular for producing the tough ductile bainite structure for fasteners and cutting blades. Water has been used but primarily where one part at a time is processed, such as induction hardening. Polymer is a water-thickening agent designed to make water quenching more controllable and uniform.

With the continued development of vacuum carburizing LPC, HPGQ became popular with automotive gear carburizing and where distortion control was critical.

HPGQ arrived in steps over time in single-chamber vacuum furnaces employing nitrogen at six-bar pressure, 87 psia; then, 10-bar nitrogen, followed by 20-bar helium that produced hardness similar to quenching in low agitation cold oil. Helium replaced nitrogen for two reasons: It results in faster heat transfer, and used much less fan horsepower. Since helium is expensive, it had to be recycled, and that required additional high-pressure storage tanks and a multi-stage compressor. Recycling helium via all of the piping and transferring from the vacuum vessel inevitably resulted in small concentrations of air mixing with helium. Oxygen scrubbers of various types were integrated into the recycling network. Today, due to the high maintenance cost, helium is slowly going the way of multi-chamber vacuum furnaces with nitrogen again making a renascence. Nitrogen can harden steels but with slower heat transfer, necessitating lower pressure and smaller loads — and/or the steel must have higher hardenability.

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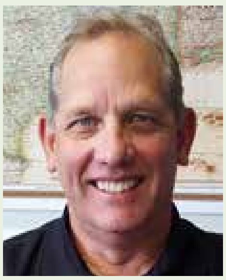
Endothermic generator controllers can help free up heat treaters to focus on other aspects of carburizing

By Bob Fincken



ONE OF THE CRITICAL ELEMENTS IN THE carburizing process is the ability to create a base atmosphere suitable for the parts placed inside a carburizing furnace. The focus of this article is the creation of gas in an endothermic generator.

Generator control systems have historically provided control of air/gas ratio and possibly a trim system, used to maintain a dew point that could be rich (too much gas) or lean (too much air). The dew point range could typically be between 30 degrees Fahrenheit and 50 degrees Fahrenheit. Flowmeters are provided to maintain a base ratio (2.7:1) for the air/gas mixture supplied to a retort filled with nickel-coated catalyst. The gas is then passed through an air cooler (some older systems used water) to freeze the reaction so the gas can be transported through a header system to furnaces. The ratio at which the gas is generated offers a dew point that can be measured. The trim control system allows for an automated adjustment of the air/gas mixture with the addition of more gas or more air. This compensates for changes that influence the dew point, such as weather conditions or spiking of the incoming gas by the gas supplier to maintain a specific BTU.

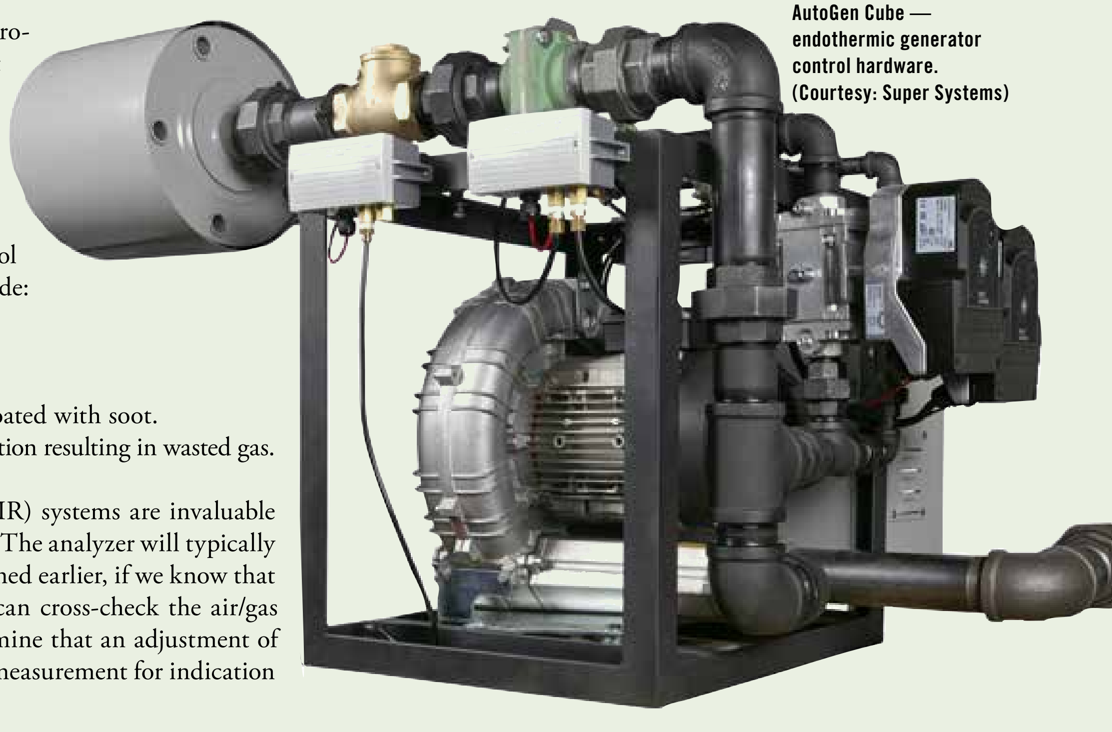
The makeup of the endothermic gas provided by a generator is typically 40 percent hydrogen, 40 percent nitrogen, and 20 percent carbon monoxide. Maintaining these percentages will result in a carburizing atmosphere that is conducive to best carburizing practices. So what can go wrong with a typical generator control trim system? Some potential issues include:

- Sticking float-type flowmeters.
- Air/gas ratio out of adjustment.
- Trim control valves not working.
- Catalyst depleted of the nickel or coated with soot.
- Unnecessary endothermic gas production resulting in wasted gas.

Nondispersive infrared analyzer (NDIR) systems are invaluable when trying to troubleshoot these issues. The analyzer will typically measure CO, CO_2, and CH_4. As mentioned earlier, if we know that 20 percent CO is being generated, we can cross-check the air/gas ratio and sticking flow meters, or determine that an adjustment of the air and/or gas ratio is required. The measurement for indication of sooted or nickel-depleted catalyst can also be achieved by using an analyzer. If the indicated measurement of CH_4 is higher than 0.05 percent, a burnout of the catalyst is required, using the manufacturer's required procedures. If, after a burnout, the CH_4 level is still high, the catalyst may need to be replaced altogether.

The endothermic generator control systems sold today take all of these items to the next level, providing a better and more automated solution. Technology advancements have led the way for the next generation of endothermic generator control. Systems are now designed to fully automate a generator using microprocessors evaluating many digital and analog inputs such as temperature, dew point, and air/gas flow. They evaluate demand for endothermic gas and will automatically turn up and turn down the amount of gas. As described previously, the gas composition of the endothermic gas can be evaluated using NDIR to further make decisions on necessary steps for control and maintenance.

Temperature control loops for single- and multi-tube generators are built into the control hardware. The temperature of the gas leaving the generator is also monitored for heat exchanger performance by placing a deviation alarm around the practical temperature (<200°F) required to cool the gas prior to delivery in the header.



AutoGen Cube — endothermic generator control hardware. (Courtesy: Super Systems)

Dew point measurement and control can be achieved using a metal oxide polymer sensor or an oxygen sensor.

Differential pressure flowmeters using coarse adjustment technology allow the systems to measure the pressure through an orifice plate, then respond quickly using a highly accurate drive motor and sophisticated control loop algorithms for incremental adjustments to the system, keeping the air/gas ratio in the desired range.

The gas trim control uses the same technology as the coarse adjustment in tandem with the dew point measurement to achieve accurate control of the dew point. The best method of control when monitoring demand requires a fast control loop with logic that ensures the multi-variables are not conflicting with each other.

Electronic feedback from the flowmeters to the control system offers real-time digital monitoring of the air, gas, and total endothermic gas flows, with the ability to trend the results for historical review.

Demand for gas in a heat-treating facility can change due to a number of factors:

- Furnaces are added to or removed from service due to maintenance, production demands, or other issues.
- If batch integral quench furnaces are in use, charging and discharging loads also create variable demand for gas.

The multi-variable control systems implemented on generators will monitor demand by placing a sensor in the supply header. This sensor feeds back real-time demand to automate the supply of gas using a variable frequency drive (VFD) tied to the integral blower in the system for air and a variable flow meter for gas. As the demand changes, the VFD adjusts the blower speed and gas flow to compensate for the demand required. Typical systems have turndown capabilities of 5:1. Recovery from such demand changes is also an essential component in any automated system. The dew point should stabilize rapidly without manual intervention.

A modern generator with the latest in process-controls technology will also allow for easier operation with a graphical interface and built-in diagnostics for troubleshooting.

All these elements come together in SSi's AutoGen system to form an easy-to-manage, automated, and adaptable system for producing endothermic gas more efficiently and accurately. AutoGen can help free up heat treaters to focus on other aspects of their processes, helping reduce downtime, increase effectiveness, and allow them to create better, more reliable products for their customers.

ABOUT THE AUTHOR: Bob Fincken is the national sales manager for Super Systems Inc., where he manages North American Sales Operations. He has over 30 years' experience in the heat treat industry providing engineered systems, customer service, and training.

Each heat-treatment process should be evaluated to determine its acceptable hardenability range to remain a capable process

By Lee Rothleutner

MANY HEAT-TREATING PROCESSES CANNOT tolerate appreciable variations in steel hardenability. For an established in-control process, deviations in chemical composition and starting microstructure may result in a variety of issues including quench cracking, out-of-spec hardness, low ductility, and excessive distortion. Consequently, a hardenability tolerance should be assessed and defined for all new processes to ensure incoming material is properly controlled without being over specified.

HARDENABILITY DEFINED

Hardenability is often used synonymously with "end-quench" or "Jominy" hardenability, a reference to a standardized test that quantifies the hardness of a steel as a function of distance from an austenitized and water-quenched surface [1, 2]. This test has both beneficial and detrimental aspects. It is beneficial in that it allows the chemical composition variation of the raw material (e.g., bar or billet) to be characterized for quality-control purposes with relative ease, but is detrimental in that it is limited in translating those results to components processed through a specific heat-treatment process. As a result, for the remainder of this discussion, hardenability will be defined generally as the suppression of ferrite/pearlite formation upon cooling from austenite [1]. This definition encompasses those additional effects that are directly dependent on a specific heat treatment process.

CHEMICAL AND MICROSTRUCTURAL INFLUENCES

Chemical effects on hardenability are typically calculated using chemical ideal diameter (DI) — which is defined as the diameter in which the center of a round bar contains 50 percent martensite when quenched from austenite [3]. Grossmann used brine for his quenchant, but ideal diameter typically assumes an "ideal" quench rate, which is infinite [3]. Figure 1 shows the effect of different alloying elements on hardenability through multiplying factors used to calculate DI. The danger with this multiplying factor comparison is that the data represent only one austenite grain size (ASTM grain size 7) and does not take into consideration effects related to the form of the alloying elements in the steel.

In plain carbon steels, a smaller austenite grain size has been shown to markedly, and negatively, influence hardenability [3]. The generally accepted mechanism for this observation is that increasing grain size decreases the grain boundary surface area and, therefore, the number of inhomogeneous nucleation sites for ferrite and pearlite [1]. However, this grain-size effect can be confounding in both low alloy and microalloyed steels. In these steels, the amount of alloying still in precipitate form can be significant at common austenitizing temperatures. In general, having the alloying in solid-solution yields the greatest influence on diffusional transformations, increasing hardenability.

Figure 2 shows the solubility of chromium carbide ($Cr_{23}C_6$) in austenite. The nominal compositions for three commonly heat-treated alloys containing chromium (Cr) are indicated: AISI 4140, 5160, and 52100. The dashed line for each alloy represents the precipitation path for $Cr_{23}C_6$ in austenite, assuming all Cr has precipitated as $Cr_{23}C_6$.

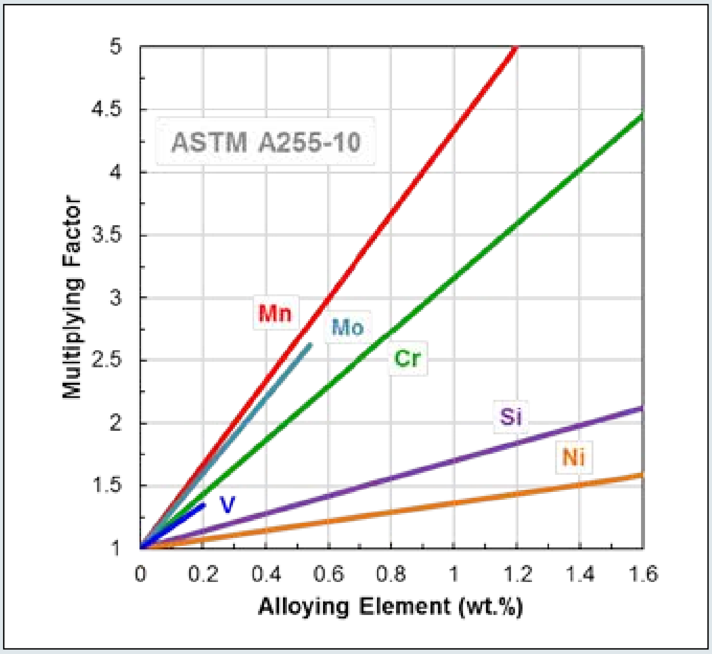


Figure 1. Multiplying factors for most common alloying elements (other than carbon) used to determine ideal diameter in steel. Data plotted from equation provided in ASTM A255-10 [2].

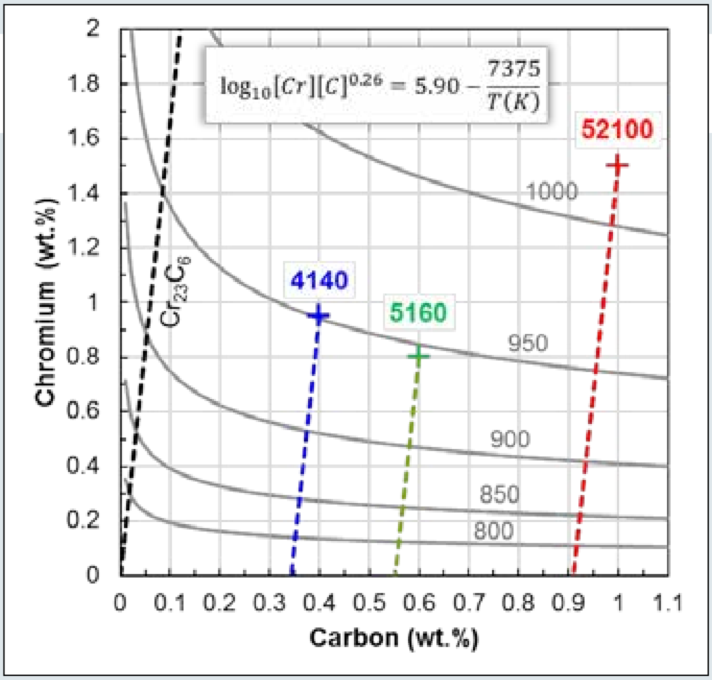


Figure 2. Solubility of chromium carbide ($Cr_{23}C_6$) in austenite with nominal chemical compositions for AISI 4140, 5160, and 52100 indicated. Solubility product data from Ashby and Easterling [4].

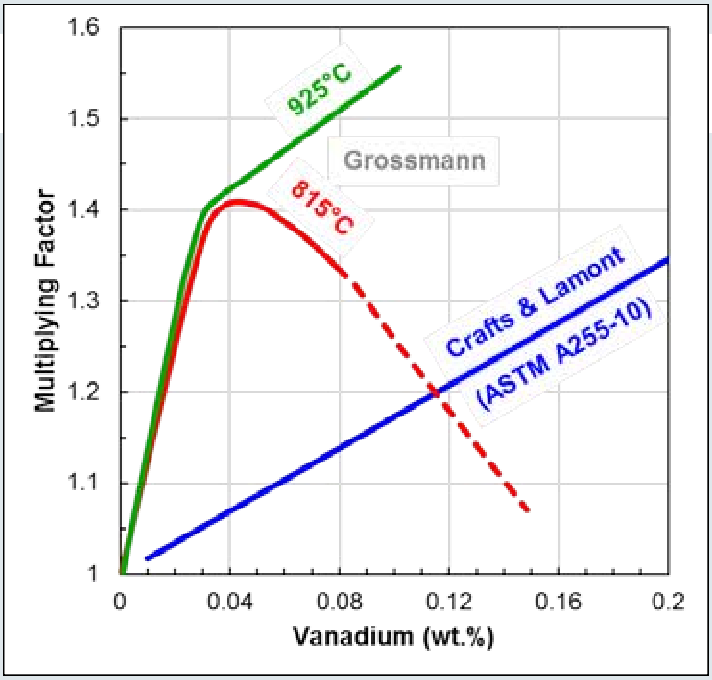


Figure 3. Multiplying factors for calculating the effect of vanadium on the hardenability of steel. Data from ASTM A255-10 [2] and Grossman [3].

This assumption is not likely accurate, but it provides a worst-case scenario for discussion purposes. This data shows that a significant amount of Cr may still be in precipitate form in all three alloys unless austenitized at high temperature, where grain growth will occur. Steels that are hardened from a pearlite or spheroidized-starting microstructure will have substantially different hardening behavior depending on the carbide size and the austenitizing temperature. This emphasizes the importance of having good quality-control checks and purchase specifications in place to ensure issues do not occur.

Figure 3 shows the influence of vanadium (V), a common microalloying element in steel, on hardenability as a function of austenitizing temperature (from Grossmann [3]) as well as data currently used in ASTM A255 for determining the hardenability of steels [2]. Although the current ASTM standard indicates austenitizing temperature has no dependence, Grossmann showed a clear effect. At V levels typical of modern medium carbon microalloyed steels (approx. 0.08 wt.%), the influence of austenitizing temperature may be significant. Since Grossman's work, the influence of microalloying elements such as V and niobium (Nb) has been investigated in great detail, and the mechanisms found to be relatively complex [5-9]. Therefore, their influence on hardenability is mentioned briefly for awareness only.

CONCLUSION

Fraction of alloy carbides dissolved upon austenitizing may have a significant influence on hardenability, thus requiring careful monitoring of the starting microstructure as well as the chemistry. Each heat-treatment process should be evaluated to determine its acceptable hardenability range to remain a capable process. Influence of both variation in microstructure and chemical composition should be examined independently, if possible.

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The heating system and burners play an essential role in upholding part quality and maximizing furnace operation

By Nate Sroka

THE BACKBONE OF ANY ATMOSPHERE FURNACE is the heating system. The heating system plays an essential role in keeping the furnace operating at peak performance and ensuring part quality. In efficient batch atmosphere furnaces (such as Ipsen's ATLAS atmosphere heat-treating system), a temperature uniformity of at least ±13 degrees Fahrenheit (±7 degrees Celsius) is maintained in the heat chamber.

To satisfy those needs, Ipsen developed the Recon® burner, which is coupled with a safe, reliable fuel delivery and burner management system (Figure 1). These differ from other burners in that they have more uniform heating down the length of the tube. This is accomplished with a high-velocity flame that pushes the heat down the tube farther and more uniformly.

WHY TUNING MATTERS

To maintain temperature uniformity throughout the heating system, the burners must all be tuned together within a tight temperature range. This ensures they are emitting or radiating the same output, and it contributes to uniform heating and uniform processing of parts. Finally, it prevents the burners from running too rich (i.e., using too much gas and not enough air), which can cause the tubes to wear prematurely and add unnecessary maintenance costs.

STEPS FOR TUNING BURNERS

When it is time to tune the burners on your atmosphere furnace, there are a few simple steps you should follow. These include:

1. Set the burners to high fire with the furnace at room temperature.
2. Identify the air header (blue pipe on ATLAS) and open the valve.
3. Identify the gas header (yellow pipe on ATLAS) and open the valve.
4. Repeat steps 2 and 3 (i.e., opening each valve) for the remaining number of burners. (ATLAS has eight burners.)
5. Wait for the furnace to reach 1,400° F (760° C) or above (1,650° F [899 °C] is recommended).
6. Check the exhaust oxygen levels with a gas analyzer. (A value between 2.5 and 4 percent is acceptable; an ideal level would be between 2.5 and 3 percent.)

If the exhaust oxygen levels are within the desired range, then the furnace should be ready for production. Overall, the Recon burner system has been shown to provide good repeatability and is able to consistently hold a value between 2.5 and 3 percent.

However, if your levels are not between at least 2.5 and 4 percent, then the natural gas flow should be increased or decreased to achieve the desired value. Increasing the amount of gas will lower the excess oxygen level, and decreasing the gas will increase the excess oxygen level. Making an adjustment at 1,400° F (760° C), though, may not provide the best results. This is because as the furnace temperature increases, the air density decreases. Instead, adjustments should be made at 1,650° F (899° C), which will ensure the best overall air-to-gas ratio for normal operation.

Figure 1: Recon® burner system, which features single-ended, self-recuperative radiant tube (SERT) style burners.

Since the air density changes at higher temperatures (has less air), the excess air level can drop as well. Typically, burners that have an excess oxygen level of 3.5 percent at 1,400° F will have an excess level of 2.5 percent at 1,650° F. In a system with poor repeatability, this small difference can be a significant issue. This is why we recommend putting the final settings in place at higher temperatures.

NOTE: It is important to be aware that the Recon system also reacts differently at higher temperatures.

THE PROPER AIR-TO-GAS RATIO

What you might not realize, though, is that the best air-to-gas ratio for normal operation is not necessarily the perfect ratio. Stoichiometric combustion (i.e., perfect combustion) is achieved when the proper air-to-gas ratio of 10:1 is maintained. Yet as you can see in Figure 2, when we achieve stoichiometric combustion, we do not achieve the highest efficiency – and is why we run at a slight excess air setting of 2.5 to 3 percent (ideal) or 2.5 to 4 percent (acceptable).

As part of these efforts to maintain the ideal air-to-gas ratio, there are individual metering controls at each burner that allow the flow of gas and air to be adjusted. However, once the furnace manufacturer sets the air flow, it should never be readjusted except to return it to the factory setting. This is because the air setting is what determines the firing rate of the burner. In all, once the air and gas metering valves are set, the burners should continue to function efficiently.

BURNER MAINTENANCE: WHAT AND HOW OFTEN?

To ensure the best ratio is maintained, it is important to check it with a combustion analyzer every six months. You should also maintain a clean air filter on the regenerative blower as any blockage can significantly reduce efficiency of the burner. The frequency at which you need to replace the filter depends on the surrounding environment, but you should check it at least once a month.

In the end, how often you tune your burners depends on their performance and overall efficiency. If you look inside your atmosphere furnace and can see that one or more burners are glowing a different color, this indicates that they are not operating uniformly and need to be tuned. Hearing a loud ‘pop’ when heating the furnace up from any state is also an indication that the burners are not correctly tuned.

Overall, the heating system and burners play an essential role in maintaining part quality and maximizing furnace operation. By tuning the burners as needed, one can better ensure the furnace is operating as intended.

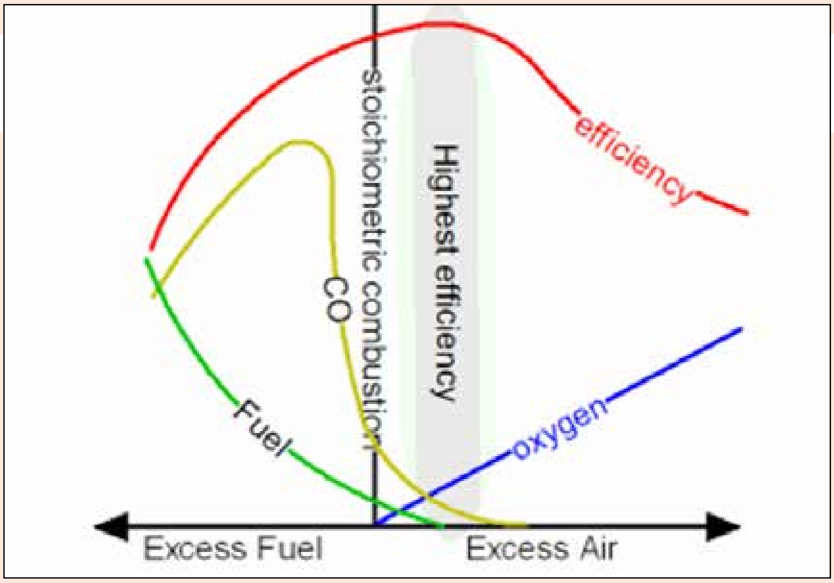
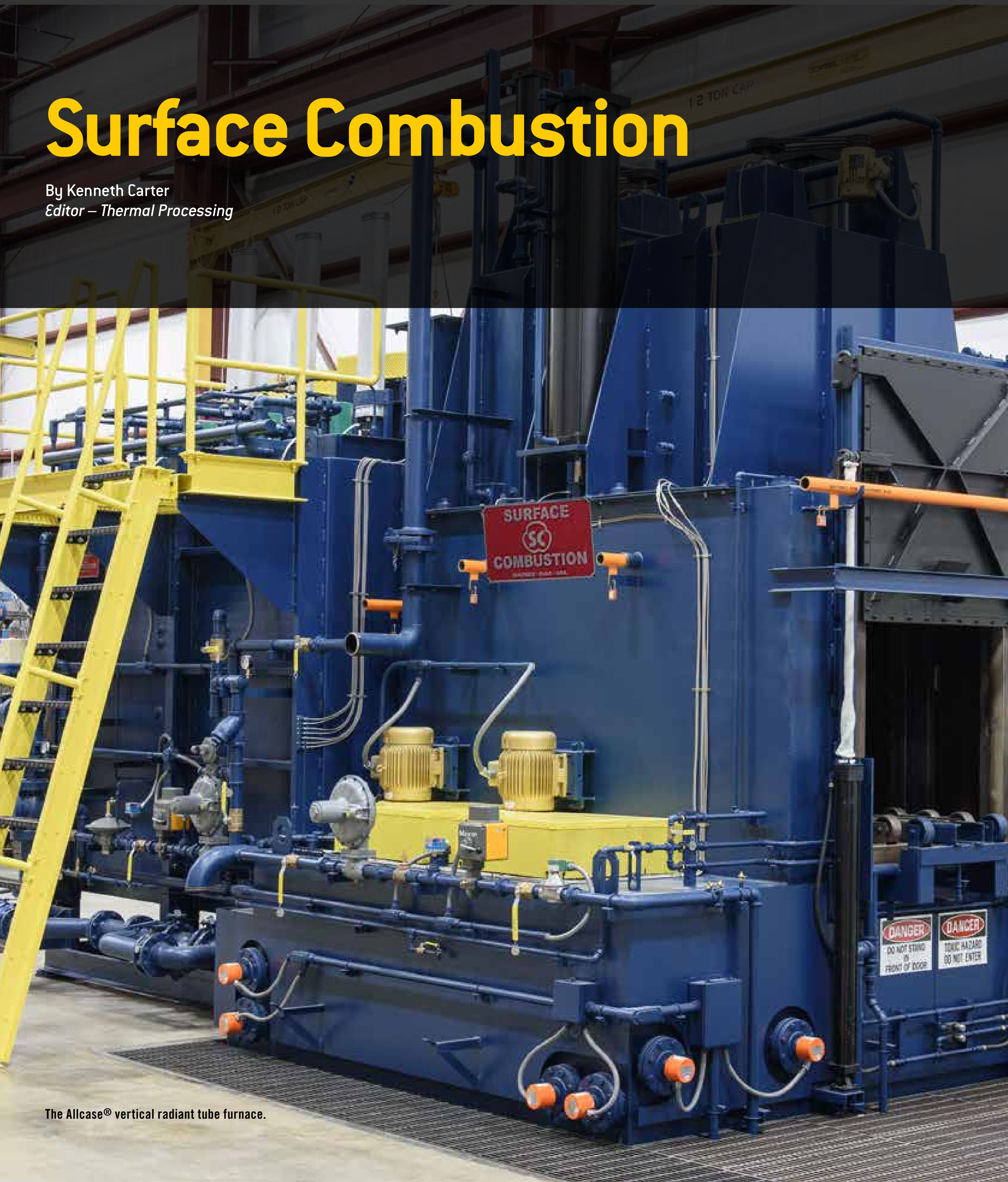


Figure 2: Illustration of expected combustion gas levels.

ABOUT THE AUTHOR: As a mechanical design engineer with Ipsen, Nate Sroka focuses on the mechanical design of atmosphere heat-treating systems. Before joining Ipsen in 2014, he received his Bachelor of Science in Mechanical Engineering from Northern Illinois University. Sroka also brings with him a significant amount of knowledge and training on combustion safety, NFPA 86, furnace maintenance, and heat-treatment evaluations.

Surface Combustion

By Kenneth Carter
Editor – Thermal Processing



The Allcase® vertical radiant tube furnace.

For more than a century, Surface Combustion has shown a constant commitment to develop innovative technology, while nurturing long-standing relationships with heat treaters who trust its equipment.

SURFACE COMBUSTION CONSIDERS ITSELF MORE THAN JUST a company that was founded on a patented heating concept, although it certainly is that.

The employees who make up the private U.S.-based company take a long view.

Surface Combustion President B.J. Bernard explains:

"Continuous improvement is in our culture," he said. "We want to foster a culture of creative thinking, imagination, ingenuity, and teamwork. Surface will devote resources to all markets (both domestic and international) to provide best-in-class support to our customers no matter where they conduct business around the globe."

With that philosophy at the forefront of everything it does, Surface Combustion has continued to redefine its performance limits while introducing a variety of advancements in thermal-processing equipment.

"From our initial product lines of small oven furnaces, pot-hardening furnaces, aluminum-melting furnaces, rivet heaters, and small forge furnaces, to the first continuous billet heating furnace, to the development of the industry standard Allcase® batch integral quench furnace, to the metal parts furnace designed for the destruction of chemical weapons, Surface showcases our continuous commitment to innovation and technology as a means of meeting the needs of our customers," B.J. Bernard said.

That dedication shines through with Surface Combustion's 675 U.S. patents and more than 75 industry-recognized trademarks.

"By our 100th anniversary in 2015, there were over 250,000 Surface thermal systems installed worldwide, many having been in operation for over 40 years," said Ben Bernard, vice president of Global Sales and Marketing.

SERVING DIVERSE INDUSTRIES

And those thousands of systems can be found in a myriad of industries that include automotive, off road, gears, mining, oil exploration, solar, tool and die, electronics, aerospace, commercial heat treating, government ordnance, incineration/thermal destruction, hand tools, defense, wind, natural gas, agricultural, and bearings.

"At Surface Combustion, we develop long-standing relationships with heat treaters who trust our equipment," Ben Bernard said. "They know that a quality Surface furnace, generator, or accessory will afford them lower, predictable operational expenses, and that our aftermarket services will work to ensure less down-time and longer product life."

In order to make that happen, Surface Combustion has a customer service department to back up those claims, according to Alex Kominek, business unit manager, Standard Products.

"The customer service staff can provide immediate answers and quickly schedule on-site support," he said. "Feedback from our customers has often resulted in the development of new items of maintenance-friendly features resulting in a better product. Our customers know that they are not just purchasing a piece of equipment but entering into a partnership."

TECHNICAL EXPERTISE

And as an engineering company, Surface Combustion places a high value on the technical expertise of its people, said John Gottschalk, business unit manager, Engineered Products.

"Extensive technical and engineering education, combined with a mature professional staff, make our employees highly effective in serving our customers," he said. "At Surface Combustion, we keep informed of the latest developments and techniques in technical fields. We add new engineering graduates to our staff every year. Recent graduates contribute their technical abilities while working with senior engineers, building new relationships, and adding value to the service we provide to our customers. Our engineers and designers are dedicated to expanding capabilities and developing better thermal-processing systems and equipment."

And the equipment that Surface Combustion offers is extensive:

Standard equipment: A variety of batch furnace designs and atmosphere generators that perform a range of heat-treating processes make up Surface's standard offerings.

Allcase® batch integral quench furnace: The Allcase has been the industry standard for more than 65 years, according to Kominek, with more than 3,000 units installed worldwide. Continued product improvements and ease-of-maintenance enhancements have maintained the Allcase as an industry leader for batch processes, including hardening, annealing, normalizing, gas carburizing, carbon restoration, carbonitriding, and ferritic nitro-carburizing (Triniding™).

Ion nitriding equipment: Ion nitriding is a plasma process performed under a vacuum in the presence of an electrical charge and certain gas mixtures. The process imparts uniform single-phase metallurgical properties to materials. Surface offers bottom load, bell, pit, and horizontal loading configurations for ion nitriding.

Vacuum equipment: Surface has manufactured vacuum furnace equipment for more than 50 years, Kominek said. This expanding product line includes the Power Convection® single chamber vacuum furnace with 2- and 6-bar quenching capability. The multi-chamber furnace family includes 2-chamber, 3-chamber, and cloverleaf (6-chamber) configurations. The multiple-chamber configuration allows for higher production with separate high-heat, low-pressure carburizing, and high pressure quench (up to 20-bar) chambers. The VacuDraw® vacuum temper furnace completes the line and includes sizes ranging from 36-48-36 to 60-90-60. Surface's patented gas-fired vacuum furnaces have been in use for more than 30 years as well.

Atmosphere generators: Surface offers reliable, easy-to-maintain, and economical on-site atmosphere generation equipment that includes RX® endothermic gas generators, DX® exothermic gas, NX® nitrogen, and HNX® hydrogen generators.

Engineered products: Engineered equipment encompasses a wide variety of batch and continuous designs engineered to order to meet customer-specified thermal processing and production requirements. Surface helps customers select the right furnace based on the process and product mix, according to Gottschalk.

ENGINEERED TO ORDER

Surface can provide many engineered-to-order designs including: pit, rotary retort, rotary hearth, pusher tray, mesh belt, cast belt, roller hearth, screw conveyor, box, car bottom, strip lines, sucker rod, snap hearth, and rotating finger furnaces. Furnace type is selected based on the material processed. Designs are available for steel, cast iron, aluminum, copper, stainless steel, titanium, brass, silicon, and glass, Gottschalk said. All the designs can be either controlled-atmosphere or direct-fire, and they can be engineered to meet industry specific quality standards.

Processes performed include pre-heat for forge, normalizing, annealing, tempering, solution treatments, T5 and T6 aging for die-cast components, and a number of custom atmosphere processes including carburizing, nitriding, ferritic nitrocarburizing, and blackening performed on wrought, cast, and forged products, he said.

Advanced combustion products: A selection of thermal-processing systems are offered, such as hazardous and toxic waste disposal systems, thermal cleaning, mineral and resource recovery, chemical weapons/munitions demilitarization, carbon, graphite, and processing end-of-life tires and other waste products.

Process controls: Surface Combustion's process control systems are designed to work with all types of heat-treat equipment. The company maintains and develops its own process and mechanical motion controls and O_2 sensors to meet industry standards such as CQI-9, AMS, and API.

Surface can incorporate other commercially available control systems per request, too, Kominek said.

SERVICE, PARTS SUPPORT

With its large inventory coupled with a knowledgeable engineering and customer support staff, it's not hard to see why Surface Combustion is a success in the heat-treating industry, but it offers even more with its service and parts support, as well as its ability to rebuild and retrofit existing equipment, according to Dave Dzierwa, business unit manager — Manufacturing, Rebuild and Retrofit, Customer Service.

"Our experienced field-service engineers, product managers, and controls experts frequently remotely troubleshoot customer problems," he said. "Therefore, on-site visits are often avoided, reducing customer downtime and expenses. When telephone support can't solve the issue, Surface Combustion will dispatch a customer-service engineer to


A 2-chamber vacuum furnace.

The cast belt furnace line. (Photos courtesy: Surface Combustion)

a plant location to inspect, test, troubleshoot, or assist in the timely maintenance and restart of equipment. Surface Combustion's service support is backed by one of the largest replacement parts inventories in the industry. Critical parts and components are often shipped within 24 hours."

RETROFIT PACKAGES

Surface Combustion offers a broad range of retrofit packages, as well, according to Dzierwa.

"When extensive equipment modifications are necessary, our rebuilding and construction services can provide an alternative to new equipment regardless of the original furnace manufacturer," he said.

Maintenance and rebuilding services include: replacement of refractory lining, updating control and combustion systems, installing burner equipment, adding direct- and indirect-fired burners, electric/gas heating conversions, energy-efficient process improvements, and increased productivity modifications.

PAST, PRESENT, AND FUTURE

Surface Combustion was founded in 1915 and is headquartered in Maumee, Ohio. The building, designed specifically for the company, houses all the engineering, sales, and administrative offices. It also includes a production-oriented research and development laboratory, B.J. Bernard said.

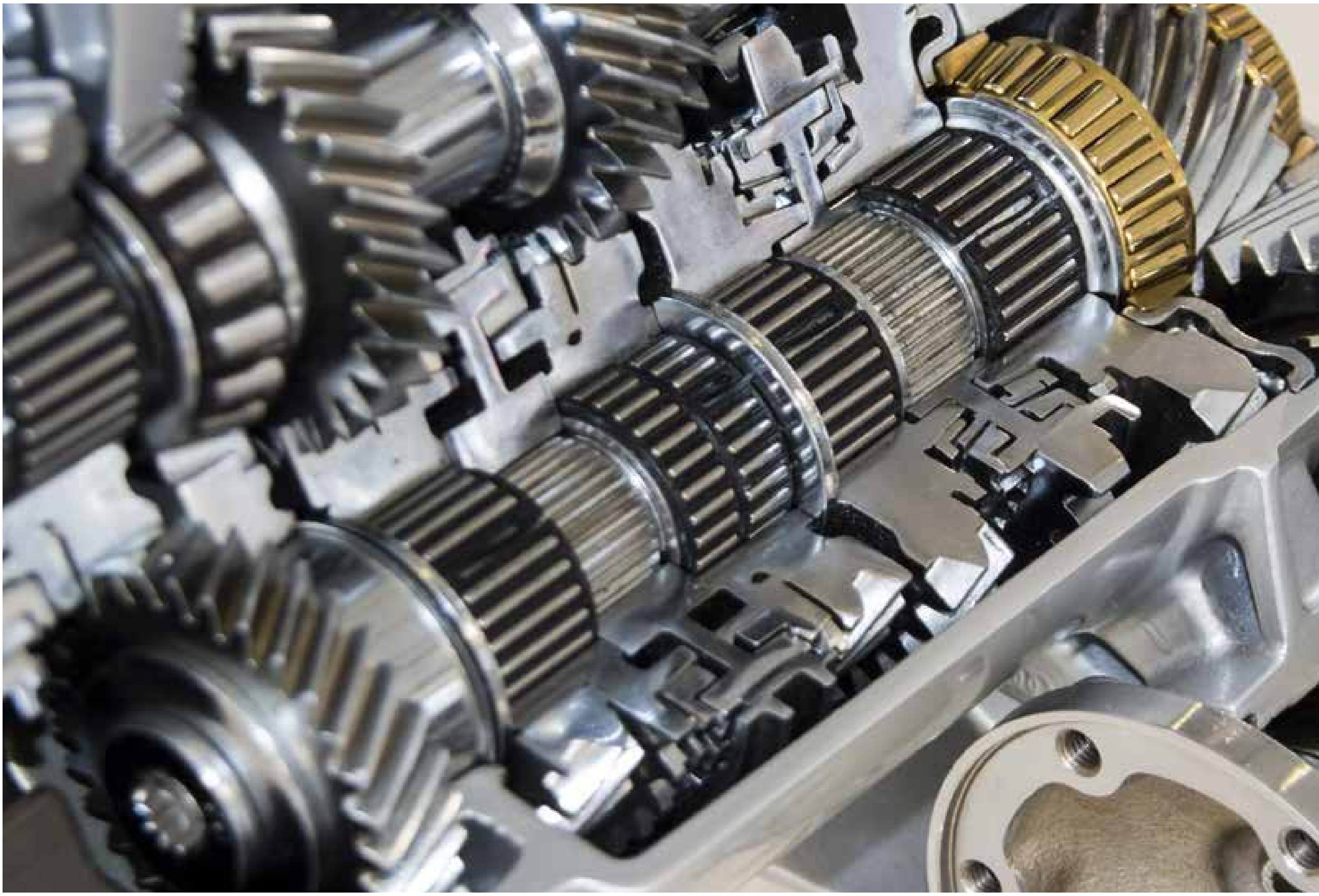
Its manufacturing facility in nearby Waterville, Ohio, was expanded to 66,000 square feet in 2014.

"With over 90 years of experience and a multi-million-dollar inventory at their disposal, our aftermarket parts (AMP) department can provide the right part the first time," said Annette Gadt, team leader, Aftermarket Parts. "Our AMP specialists develop personal relationships with their customers to help anticipate needs and possess the knowledge to recommend the correct alloy for every application. Surface's Waterville facility houses only first-quality parts and is able to ship most stock parts same-day."

But Surface Combustion is not content to rest on its decades of accomplishments. The long view has — and will continue to be — a part of its ongoing focus.

"Surface will keep pace with changing materials, technologies, and quality requirements," B.J. Bernard said. "Our ability to adapt to market and technological changes has been a key to our longevity. Surface is committed to the evolution of the heat-treat industry and always gives back by supporting educational and professional organizations."

The RX® endothermic gas generator.



Case study: Cost effective, low distortion carburizing of internal helical ring gear for transmissions

Atmosphere carburizing of large outside diameter, thin wall internal helical ring gear.

By Lonny Rickman

There are many critical factors that are assessed when designing a gear that will be used in demanding applications such as engines or transmissions. Design engineers typically assess gear material, availability, cost, formability, machineability, and heat-treat ability for the specific application. They also evaluate the materials' anticipated loads and the materials' mechanical properties, such as tensile, yield, elongation, reduction in area, thermal properties, and life cycles. A shorter summary or outline could be easily stated as component design, material selection, heat-treat method, and potential enhancements of heat-treatment processes. Many times these variables are simulated by finite element analysis (FEA).

FEA is a computerized method for predicting how the design will react to the application's environments such as vibration, noise, thermal dynamics, and whether the components will wear out, break, or work the way it is designed. FEA analysis can save a lot of development costs. Case-hardened gears, e.g. carburizing, are used for the harshest environments where strength and wear properties are essential. Case-hardened gears exhibit a 30-percent to 50-percent increase in load-bearing capacity when compared to through hardening. It is also used where gears are subjected to high sliding and rolling contact, which leads to stresses on the active profile of the gear flank and Hertzian stresses in the gear root.

Carburizing is a high-temperature heat-treat process (898-954° C) in which a higher percentage of carbon, i.e. 0.80 percent to 1.20 percent, is added to the atmosphere on materials typically containing less than 0.27 percent carbon. The depth of carbon penetration is dependent upon time and temperature of the treatment and also can be influenced by

the furnace type. After carburizing, the part is hardened by lowering to a specified hardening temperature, stabilizing, and then quenching in a suitable media, immediately followed by tempering. Please note that untempered martensite is very unstable, so the primary goal is a microstructure of primarily tempered martensite. Some of the undesirable by-products of the process may include bainite, retained austenite, carbide networking, and core ferrite.

One of the primary considerations or potential problems in developing process parameters includes material handling that does not damage, nick, or alter the gear geometry in the softened state. Other considerations include process time, carburizing temperature, hardening temperature, atmosphere, quench media, and temper to ensure optimum metallurgical properties, dimensional stability, and durability and reliability requirements for the specific application where the gear will operate.

Commercially, the heat treater needs to supply a quality product at a competitive price, while coordinating many people, facilities, and supplies with an emphasis on delivering such in a timely fashion. There are sources of variation that need to be fully defined, communicated, documented, and incorporated into the process on a consistent, repeatable, and reproducible basis.

The gear chosen for this article (Figure 1) is assembled into a 6-speed, rear-wheel drive transmission with a five-year, 60,000-mile warranty. The material chosen for this application is a finished machined SAE 5130H steel. It is classified as a "carbon alloy steel" because it has 0.27-percent to 0.30-percent carbon with 0.75-percent to 1.20-percent chromium. The chromium increases hardenability and strength at high operating temperatures. The "H" designation is for increased or more consistent hardenability and is accomplished by modifying the manganese. Manganese also increases strength and toughness. The "DI" or "Ideal Critical Diameter" is a quantitative method of determining the depth of hardenability and, in the case of this application, is 76.2 mm to 88.9 mm (3.0 inches to 3.5 inches) per SAE J406, May 1998.

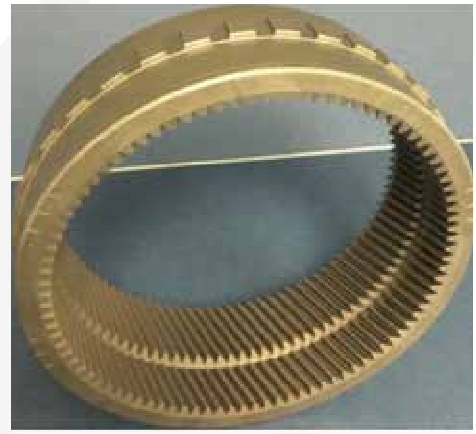


Figure 1: Outside diameter: 180.5 mm. Inside diameter: 164.34 mm. Wall thickness: 8.58 mm. Overall length: 60.8 mm.

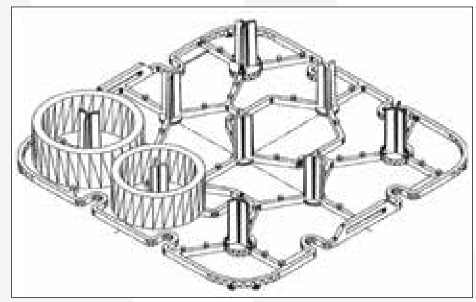


Figure 2: Heat treat fixture

PART HANDLING / RACKING

A key process control in ensuring product integrity is racking of the gear on the fixture prior to heat treat. Prior to the heat-treat process being performed, special attention needs to be placed upon heat-treat rack or fixture design (Figure 2). The fixture is typically cast from a temperature-resistant 300 series stainless steel. The size and configuration of the fixture must be conducive with the part geometry. Weight of the fixture is also critical because the fixture has to be heated and quenched along with parts. Figure 2 is a diagram of the fixture design for this application.

The gear featured in this article is internal with a 1.59 module or size of the gear tooth. A 1.59 module is equivalent to 16 DP, although it does not meet the definition of a fine pitch gear (20+ DP), at 16 DP, it presents a similar set of dimensional challenges. It is worth noting that all gear making is susceptible to nicks, dings, or damage. A soft handling, robotic system can be installed to eliminate the possibility of damaging the teeth

Figure 3: Robotic cell for dunnage and material handling.

(Figure 3). Green/pre-heat treated gears received in color-coded, returnable dunnage is a good means of ensuring product is never mixed. The dunnage is then placed on a gravity-fed rail system that transfers it to the robotic cell. The robot has two interchangeable tools designed to pick and place the top layer of the dunnage in a designated area of the cell. The PLC program then changes the tooling, which will pick and place the heat-treat fixture into the heat-treating cell. The robot then changes the tooling to soft handle, pick, and place the parts on the fixture. This is repeated multiple times until the fixture is full and ready for the next step of the process. The robot is repeatable and reproducible, eliminating operator fatigue and possible errors for heavy and light components susceptible to handling damage.

THERMAL PROCESSING

The components have been racked and are ready to enter the process cell. The first phase is pre-cleaning. This is an important aspect of the process in that any residual petroleum-based cutting fluid or rust preventative may not be compatible with the heat-treat process and could result in an oxide or chemical stain that inhibits the carbon from diffusing into the surface. The second phase is pre-heat.

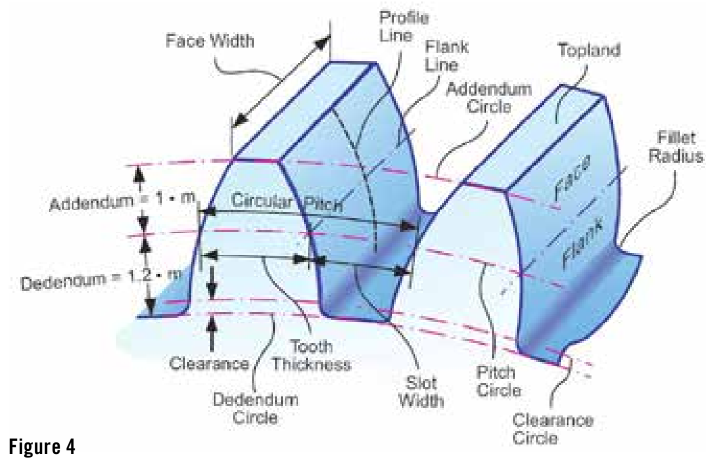


Figure 4

During this phase, a desirable pre-oxidation may be part of the process to help facilitate carbon penetration. At temperatures below Ac_1 (temperature of steel when it starts to transform into austenite), protective atmospheres of inert nitrogen may be used. As stated in the introduction, extra care must be taken to control the process time, process temperature, and process atmosphere. In a continuous

UNILATERIAL NON-NORMAL DISTRIBUTION DATA										
	R2 Lead Slope Variation				R2 Involute Slope Variation				R2 PD Circularity	
	Before Heat Treat		After Heat Treat		Before Heat Treat		After Heat Treat		Before	After
Seq #	Drive	Coast	Drive	Coast	Drive	Coast	Dive	Coast		
USL	0.08	0.1	0.08	0.1	0.032	0.032	0.032	0.032	0.2	0.2
LSL										
Target	0	0	0	0	0	0	0	0	0	0
Mean	0.01	0.008	,016	0.014	0.01	0.009	0.013	0.012	0.041	0.066
Mean Shift	N/A	N/A	0.006	0.006	N/A	N/A	0.004	0.003	N/A	0.025
Ppk	8.91	11.811	3.377	6.01	3.279	2.197	2.392	2.073	7.942	1.819
Pr	0.195	0.155	0.324	0.285	0.364	0.505	0.478	0.513	0.198	0.737
Change Pr	N/A	N/A	0.129	0.13	N/A	N/A	-0.027	0.008	N/A	0.539
Pp	5.128	6.434	3.087	3.512	2.745	1.981	2	1.095	5.052	1.358

Figure 5: Unilateral tolerances

BILATERAL NORMAL DISTRIBUTION DATA										
	R2 Lead Average Slope				R2 Involute Slope Average				R2DBB	
	Before Heat Treat		After Heat Treat		Before Heat Treat		After Heat Treat		Before	After
Seq #	Drive	Coast	Drive	Coast	Drive	Coast	Drive	Coast	DBB	DBB
USL	0.025	0.05	0.025	0.05	0	0.002	0	0.002	153.912	153.912
LSL	-0.041	-0.024	-0.041	-0.024	-0.028	-0.026	-0.028	-0.026	153.682	153.682
Target	-0.008	0.013	-0.008	-0.013	-0.014	-0.012	-0.014	-0.012	153.797	153.797
Mean	-0.008	-0.006	0.004	-0.006	-0.009	-0.007	-0.006	-0.003	153.677	153.805
Mean Shift	N/A	N/A	0.012	0.012	N/A	N/A	0.003	0.004	N/A	0.128
Ppk	10.396	7.835	4.149	3.75	2.705	2.299	1.589	0.98*	-0.083*	1.52
Pr	0.096	0.063	0.151	0.132	0.231	0.213	0.258	0.221	0.531	0.611
Change Pr	N/A	N/A	0.055	0.069	N/A	N/A	0.027	0.008	N/A	0.08
Pp	10.451	15.81	6.644	7.564	4.326	4.702	3.881	4.528	1.883	1.636

Figure 6: Bilateral tolerances (Six Sigma materials).

10 SPC Characteristics	Ppk > 1.66	< 1.66
Number of process capable before heat, i.e. Ppk > 1.66	9	1(*)
Number of processes capable after heat treat, i.e. Ppk > 1.66	7	3(*) (**)

(*) Target value for diameter between pins needs shifting pre heat treat, which will make post heat treat capable as well.

(**) Target value before heat treat needs to be adjusted so process is capable post heat treat.

Figure 7: Before and after heat-treat preliminary process capability.

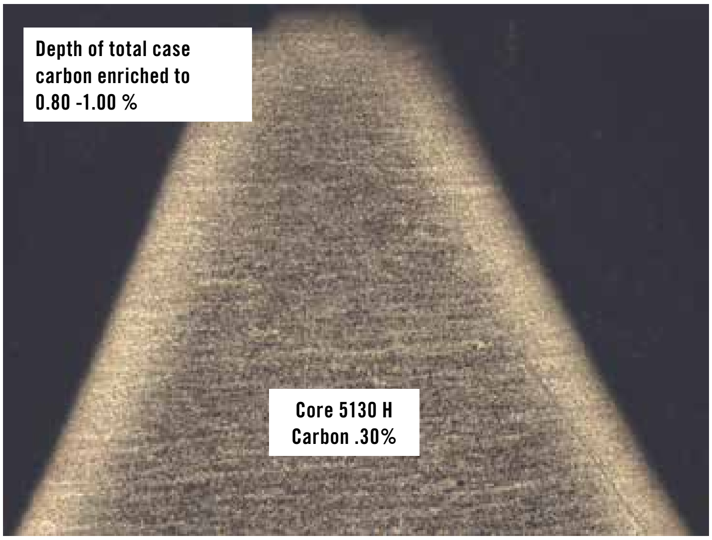


Figure 8

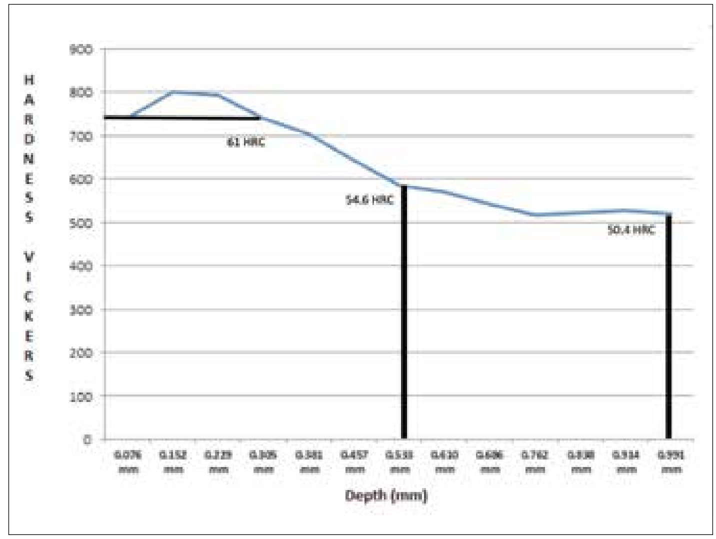


Figure 9: Typical microhardness graph.

pusher furnace, process time is determined by taking the number of trays/fixtures, tray positions, and rows in the furnace and dividing the value by the total time necessary to soak for a determined period of time, which is temperature dependent, e.g. the higher the process temperature, the shorter the cycle time. This becomes the "push rate," which determines throughput.

Figure 4 is gear geometry nomenclature. For more detailed definition see "Nomenclature and Definitions" in the appendix of this article.

STATISTICAL ANALYSIS

Unilateral tolerancing (Figures 5, 6, 7) is asymmetric and specifies a deviation in one direction, plus or minus. Unilateral tolerances for this article were evaluated as "non-normal" distributions. This article has upper specification limits, with zero being the target. As a result, Ppk (performance statistics) are based on Z-Upper, the value of the USL – Xbar/3 sigma. Pr, or percentage of tolerance or variation, is based upon 6 sigma/tolerance, and Pp or process potential is based upon Tolerance/6 sigma. Dimensional test are as follows:

Bilateral tolerancing — symmetric tolerancing that has two equal plus-or-minus deviations from nominal — can exhibit a normal distribution, and in this article, tests for normality were conducted, and the process can be centered and variation reduced. Ppk is a measure of location and variation. Ppk is calculated by Z-min, which is defined as the minimum value between Z-Upper (USL – Xbar/3 sigma) or Z-Lower (Xbar – LSL/3 sigma) If the Xbar is greater than the nominal target value, default to Z-Upper, and if less than Xbar, target Z-Lower. Ppk can be a negative number. Pp is a measure of variation only and is always a positive number. Pr is a measure of variation only and is the percentage of the tolerance used in the distribution. Pr is always a positive dimension.

As a result of the before and after heat-treat test results, the pre-heat slope drive average target value was shifted by 0.006 mm to center the process resulting in a post Ppk > 1.66, The coast involute slope average pre heat treat nominal was shifted by 0.009 mm to center the process, resulting in a post heat treat Ppk > 1.66. Diameter between balls pre heat treat target value was shifted by 0.008 mm, resulting in post heat treat Ppk > 1.66.

Characteristic	Specification	Test Results Comments	
		Average	Range
Surface hardness	HR30N 75.5 – 82	79.42	4
Core hardness	HRC 30 – 52	46.2	5.8
Total case depth	0.3 - 0.6 mm	0.4mm	0.08mm
Retained austenite	30% Max Figure 11	9%	15%
Surface bainite	0 @ Root Figure 12	0	N/A
Intergranular oxidation	</= -0.03 mm Figure 13, 14, 15	0.006mm	0.002mm

Figure 10: Metallurgical specifications and test results derived from 30 datapoints.

Case depth specifications are critical when case-hardening a gear. Tooth size and geometry are taken into consideration, because the base chemistry will be altered on the surface of the gear during the carburizing portion of the heat-treat process. When parts reach carburizing setpoint temperature, the atmosphere is carbon enriched to achieve equilibrium of about 0.90 percent carbon. The base material core properties are not affected, so the carbon remains the original 0.30 percent. The outer layer morphology will be changed to 5190H according to the depth of carbon penetration. Total case depth is a visual measurement of the depth of carbon penetration (Figure 8). The "effective case depth" is derived from testing microhardness traverse indentations at various interval depths to a given hardness value on a properly prepared test specimen using a "Vickers" diamond, pre-determined gram load, preset dwell time, and denoting its symmetry and size (Figure 9). The harder the carbon-enriched layer, the smaller the diamond penetration. Test methods for microhardness testing are governed by ASTM E-384.

Metallurgical specifications and test results derived from 30 datapoints are outlined in Figure 10.

Atmosphere carburizing, oil quenching, and tempering are parts of the cost effective, viable process for gears that requires strict, repeatable, and reproducible metallurgical and dimensional controls. The process allows the design engineer more choices in raw material selection worldwide. The process is mature, robust, durable, reliable, and repeatable. Based upon the author's 40-plus years of manufacturing, engineering, and process development experience, the comparison table (Figure 16) rates the two processes.

APPENDIX

Nomenclature and definitions:

Hertzian contact pressure: Occurs in the center of the contact surface of two bodies that are pressed together.

Lead Average of the high and low points OR total helix deviation from optimal on the flank of a gear tooth OR average of the best fit of slopes of individual traces, i.e. accuracy of helix angle accuracy.

Lead Variation: Difference from high to low points from optimal on the flank of a gear tooth OR the variation within one particular inspection trace comparing the difference between highest and lowest point.

Lead Measurement: The method used to measure helix angle accuracy both and angle and form.

Involute Average of high and low points from start to end of active profile.

Involute Variation: Difference from high to low from optimal from the start to end of active profile.

Lead Crown: Highest point on flank of gear tooth.

Involute Crown: Best fit curve or profile barreling on active profile of gear tooth.

Flatness: A zone between two parallel planes within which a surface must lie. Since flatness is applied to an individual surface, this tolerance does not need to be related to a datum.

Roundness has four primary assessments:

1. Minimum radial separation with concentric circles enclosing the least radial separation.
2. Minimum circumscribed circle, which is the smallest circle fitted around a circular profile.
3. Referenced circle, which is the measured circular profile that calculates the minimum sum of all profile deviation.
4. Maximum inscribed circle, which is the largest circle fitted around a circular profile.

Circular tooth thickness: Length of the arc between the two sides of a gear tooth on the pitch circle. Can also be measurement or diameter between balls or pins.

METALLURGICAL PHOTOMICROGRAPHS (REFERENCED IN FIGURE 10)

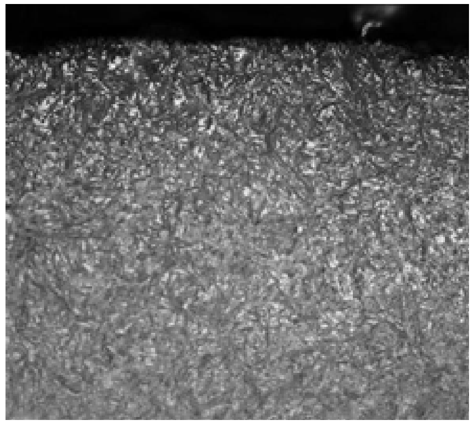


Figure 11: Pitch line retained austenite average 9%.

Figure 12: Pitch line non-martensitic (bainite) transformation.

Figure 13: Root of gear and IGO test location at 60°.

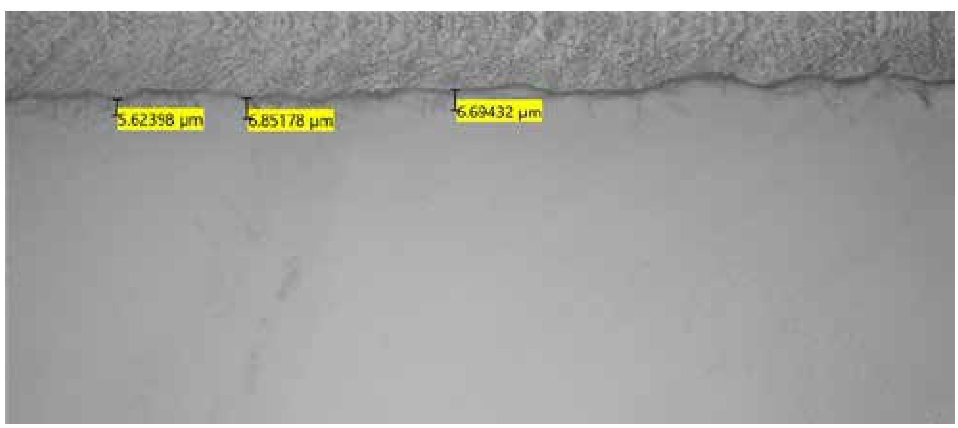


Figure 14: Gear root at 60° with average of 0.006 mm IGO. Grade 3 AGMA 923-B05 allows up to 0.012 mm IGO.

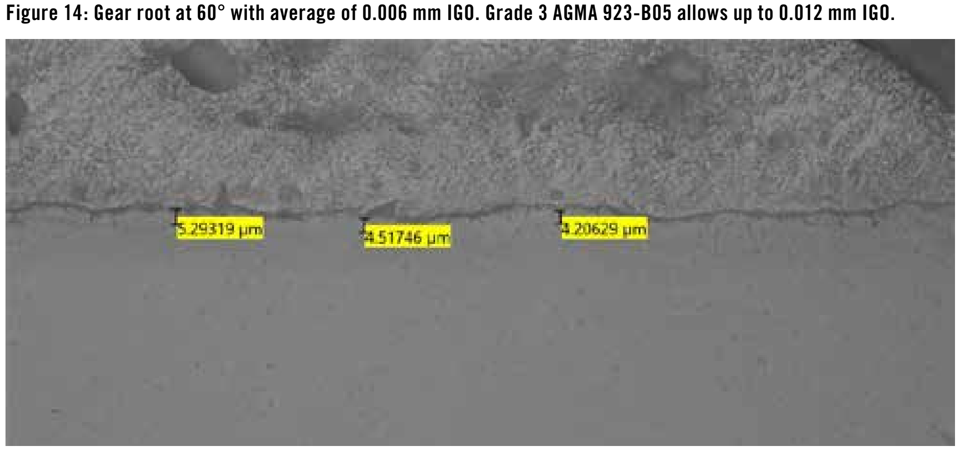


Figure 15: Gear flank with average of 0.0045 mm IGO.

COMPARATIVE ANALYSIS OF ATMOSPHERE VS. VACUUM CARBURIZE AND HARDEN			
Variable	Atmosphere	Vacuum	Comments
Process knowledge	Advantage		
Public perception		Advantage	In the past 10 years, vacuum technology has evolved and is being heavily marketed
Operating cost	Advantage		Gas Vs Electric
Cost per unit to process	Advantage		
Capital equipment cost	Advantage		
Equipment longevity	Advantage		
Preventive maintenance	Advantage		Hot zone soot and degradation
Base material selection	Advantage		Quench severity allows for larger range of selection
Impact on work environment / housekeeping		Advantage	Vacuum technology may not have oil, no process gas burn-off.
Higher process temperatures	Equal	Equal	Both processes can operate at higher temperature, but exceeding 954° C / 1,750°F in both processes can cause undesirable grain growth
Real time atmosphere feedback and control	Advantage		Vacuum relies on computer modeling, trial and error
Quench Severity	Advantage		Liquid media cool the component quicker than inert gas, regardless of backfill pressure
Metallurgical IGO			Absence of intergranular oxidation (IGO). Please note: If post machining or shot peening is performed, then IGO, if any, is eliminated. Both processes meet AGMA Class 3.
Metallurgical core ferrite	Advantage		Faster quench rate
Throughput	Equal	Equal	Equipment type, size dependent
Recycling	Equal	Equal	Oil and helium
Dimensional control / consistency	Equal	Equal	See studies outlined herein

Figure 16

Surface bainite: A transformation product in solid steel developed from austenite at temperatures intermediate between those where pearlite and martensite form. Lowers base material toughness. Quench rate too slow plus high percentage of carbon.

Intergranular oxidation (IGO): A phenomenon that occurs as a result of gas carburizing due to the process-gas decomposition. Primary concern of IGO is focused in the gear root at 60 degrees from the midpoint, which could lead to intergranular fracture when the gear tooth bends or deflects. See AGMA 923 B05 for grade definitions.

Retained austenite: A solid solution of one element in the face-centered cubic iron; unless otherwise specified, generally considered carbon. This phase is unstable and can be brittle, leading to sub-surface fatigue. Quench rate too slow plus high percentage of carbon.

Carbide networking: High carbon content plus excessive soak times plus temperature.

Core ferrite; see core hardness: Solid solution of carbon in body-centered cubic iron, a constituent of carbon steels. Essentially carbon-depleted iron.

Hardenability of steel definition: The property of steel that governs the depth to which hardening occurs in a given cross section of a material.

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6. Case depth measurement: SAE J423
7. Hardness testing: ASTM E18

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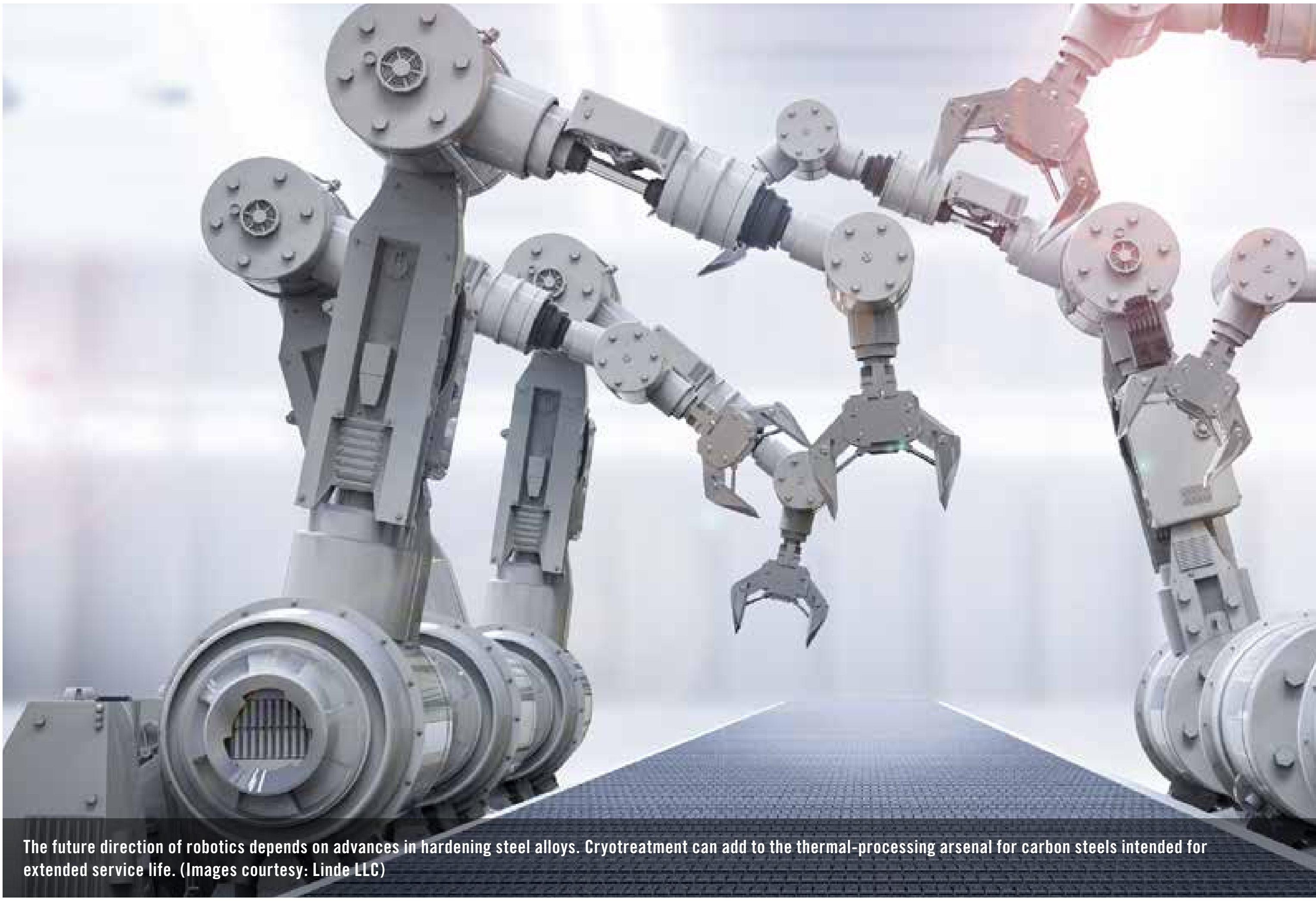

The future direction of robotics depends on advances in hardening steel alloys. Cryotreatment can add to the thermal-processing arsenal for carbon steels intended for extended service life. (Images courtesy: Linde LLC)

Extending Performance

Can sub-zero treatments give robotic gears a hand?

By Akin Malas

Metal gears and precision components of all types are in growing demand for robotics, particularly in industrial sectors such as automotive, aerospace, and machinery. Innovative gear designs make possible industrial and service robots capable of virtually any desired motion. Sequences can be programmed for specific operations, from welding and assembly, to even delicate tasks such as minimally invasive surgeries guided by a physician.

Spending on robotics has increased at a compound average growth rate in excess of 15 percent, and the pace appears to be accelerating. By 2025, about 45 percent of all manufacturing tasks around the world are expected to be automated — up from just 10 percent two years ago.[1] In addition, service robots also are moving into life and projected to grow to $46 billion over the next few years, up from just $7 billion in 2015. [2] Dedicated mobile robots already can roam properties for security threats, clean pools, and mow lawns.

Metal gears and other machine parts for robots need to be designed for dimensional stability and, depending on the task, to withstand friction and heavy loads often with high torque, high speeds, and repeated load- and temperature-cycling. They also may be expected to perform under such adverse conditions for extended periods while providing years of reliable service. These demands make not only the surface hardness of parts important but also their long-term durability.

Case hardening improves the surface hardness of many tool steels including those used in gears. Heat-treatment operations, equipped with advanced furnace-atmosphere control systems, are now at the forefront for quality and productivity for carbon control in carburizing steel parts, both large and small, which is followed by quenching and tempering, or quenching and sub-zero treatment followed by tempering.

Regardless of the size of the part, hardening should not detract from the internal structure. As gears and other parts are designed smaller and lighter or expected to sustain higher operating forces, performance over long periods becomes more challenging. But if metallurgical challenges can be addressed, achieving desired parts performance with less material and fewer rejects can reduce manufacturing costs. Also, if steel alloy gears can be successfully manufactured for improved durability, then that also reduces maintenance and operating costs for manufacturers. Correctly applied, sub-zero treatments can help further these goals, both in terms of surface hardness and superior wearability.

"Correctly applied" means starting with parts made from quality alloys because the hardness, wear resistance, and stability of components ultimately depends not only on the design, but on the underlying composition and molecular structure of the alloy. Sub-zero treatment can alter the phase structure of the metal to help further improve quality and finished-parts performance.

In addition to high-alloy steels, sub-zero treatment also can help strengthen and extend the life of non-ferrous metal parts and components, including age-hardened aluminum alloys. While steel-alloy gears are often designed for reduced weight, aluminum alloys may be preferred in many mobile applications, for example, to further reduce weight, or to meet specific performance or cost requirements.

Sub-zero treatments fall into two broad categories: cold treatment and cryotreatment (below -120° C (-184° F), which follow heat treatment and quenching. Cold treatments typically involve lowering the temperature to between -70° C (-94° F) and -110° C (-166° F) (Treatments should follow the quench within an hour to keep the retained austenite from stabilizing.) In some cases, the temperature can be dropped even lower to further improve the performance of the steel. Ultra-cold temperatures may be especially beneficial for high-alloy steels including carburized tool steels, suited for many types of gears.

HARDENING AND STRENGTH

Minor metals — including chromium, tungsten, molybdenum, titanium, niobium, tantalum, and zirconium — are used as alloys because they form strong carbides that increase the hardness and strength of the steel. Such alloys are excellent for hot-work tool steel and high-speed steels used to make cutting tools such as taps, drills, reamers, slitting saws, form-turning tools, gear hobbing, and gear-shaping cutters. Carbides can increase the strength of steel, but their size, distribution, and the underlying microstructure of the final steel are critical for performance and extended wear.

During quenching of a steel alloy from its austenitizing temperature, hard martensite begins to form. However, significant levels of soft austenite remain after quenching, which reduces overall hardness, and can affect machinability and cause stress cracks. Tempering continues to convert retained austenite, but successive heat tempering and cooling back is time consuming and up to six tempers may be needed. This may be acceptable for high speed steels that can retain their hardness at tempering temperatures up to 550° C (1,020° F), but each temper can take as much as four or five hours.

Condition	Retained Austenite	Percent Reduction
BEFORE as quenched	42%	
AFTER -120° C / 1 hr	27%	36
AFTER - 150° C / 24 h	23%	45

Table A: Reductions in retained austenite before and after sub-zero treatment.

Carburizing steels, in particular, will contain unacceptable levels of retained austenite after quenching, but case hardness begins to fall significantly above 180° C, which limits the tempering process.

For many tool steels, conversion of the soft austenite phase to a martensitic structure requires sub-zero treatment after quenching and before tempering. Cryotreatment with nitrogen at temperatures below -120° C (-184° F) creates conditions for the subsequent nucleation of very fine carbides in steel alloys. Material performance of alloys can sometimes be further improved with even colder temperatures, and make possible a full martensitic structure supersaturated with nano-sized carbides. [3]

For example, experimental studies on common carburizing steels show that the longer and colder the cryotreatment, the more the retained austenite in the case is converted to martensite. Table A shows the reduction in retained austenite in case-hardened 21NiCrMo2 gears after quenching cold treatments of -120° C (-184° F) for one hour and -150° C (-253° F) for 24 hours, compared with quenching alone. Samples in all tests were followed by tempering at 175° C (347° F) for one hour.

Cryotreatment can improve the microstructure of steel to extend the wear resistance and life of parts for robots and other machines.

Figure 1 shows the residual stress profile on the gears after the two different cold treatments. The maximum compressive stresses were produced by treatment at -120° C (-184° F). [4]

It should be noted that cryotreatment markedly improved the microstructure at the surface (see Figure 2 below) but had a negligible effect on the core properties. The case microstructure appeared more homogenous and refined after cryotreatment. Different steel alloys will respond differently to cold treatment based on their composition and structure.

Figure 3 graphs the level of retained austenite in a low alloy carbon steel after two different austenitizing temperatures followed by cryotreatment at -183° C (-297° F). Note that a much lower volume of retained austenite was achieved in the sample austenitized at a full 80° C (144° F) cooler than the 1,100° C (2,012° F) sample, and results were also much more stable.

With tempering, the face-centered cubic (FCC) structure of austenite changes into the body-centered tetragonal (BCT) crystal of martensite. It is a diffusionless transformation that results in a rapid rearrangement of atomic positions. Martensite crystals are needle-like, and the shear-strain determines the shape of the plates. Tempering allows the supersaturated carbon to form transition carbides, which relieve micro-stress in the martensitic matrix to help prevent cracking.

Sub-zero treatment offers a high degree of time and temperature control compared to quench hardening. While it is possible to convert the retained austenite in many tool steels to martensite through multiple tempering stages, sub-zero treatments in the -90° C (-130° F) to -150° C (-238° F) range can reduce the number of tempers (See Figure 4). This can mean significant time and cost savings in the hardening process.

WEAR RESISTANCE

Cold treatments can be highly effective at improving the wear life of steel, especially carburized steel. However, when martensite undergoes cryotreatment, dislocations form nucleation sites where fine carbides precipitate after the steel is tempered. The formation of coherent transition carbides in the hardened steel can result in dramatic improvements in wear life. The colder treatment further reduces retained austenite, promotes the formation of nano-carbides, and can dramatically improve wear resistance. For most gears and machine components, extended life is the goal.

While cold treatment in the -70° C to -120° C (-94° F to -184° F) range can significantly improve material performance, practice has shown an even greater effect may be achieved in many carbon steel alloy parts with cryotreatment below -120° C (-184° F) or deep cryotreatment below -190° C (-310° F).

Table B compares the percent improvement in wear resistance after cold treatment at -79° C (-110° F) and after cryotreatment at -190° C (-310° F) on several types of steel alloys, including high-carbon/chromium steel (D2), tungsten high-speed steel (T1), oil-hardened cold-work die steel (01), and bearing steel (52100). Some alloys respond better than others and at different treatment temperatures. For another high-speed tungsten steel (T2), the percentage improvement after cold treatment at -79° C (-110° F) was about half as much as T1 steel. [5]

Table C shows tool life improvements using sub-zero treatment for various types of tooling. Progressive dies, for example, achieved an

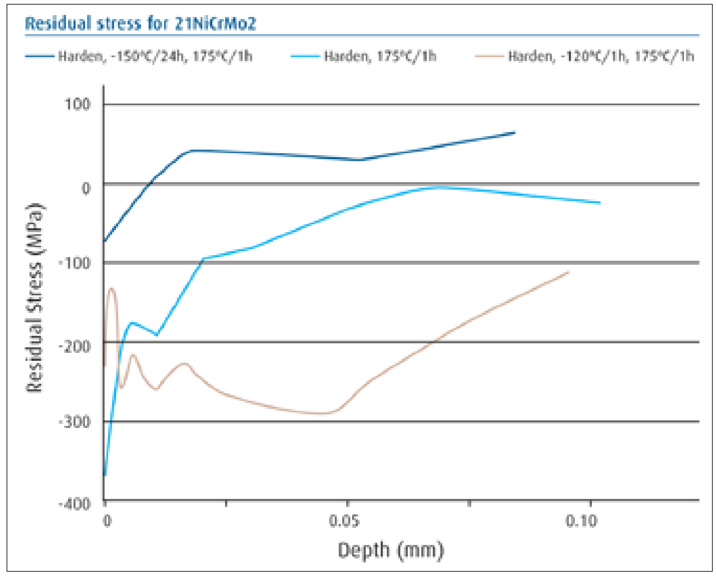

Figure 1: Residual stress profile.

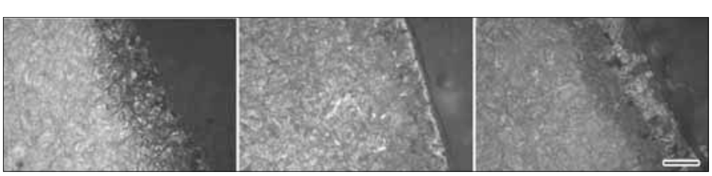

Figure 2: Case microstructure of 21NiCrMo2 gears after: a) quenching, b) quenching followed by cryotreatment at -120° C for 1 hour, and c) quenching and cryotreatment at -150° C for 24 hours. (Images are at 20 microns). Note the reduction in retained austenite, the white phase between martensite laths. [4]

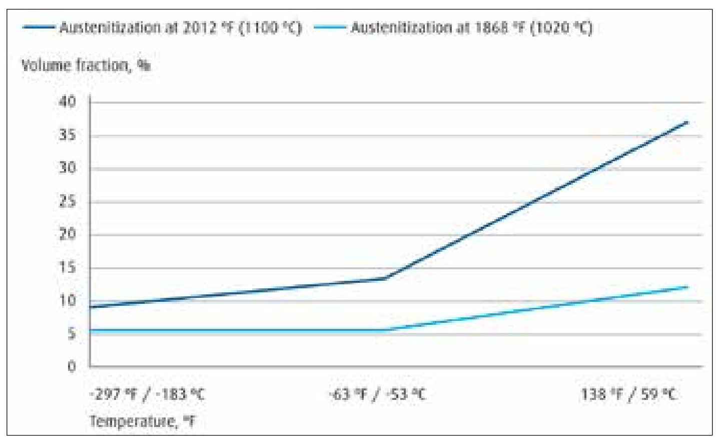

Figure 3: Level of retained austenite after austeniitizing at two different temperatures, followed by cryotreatment and final warm up.

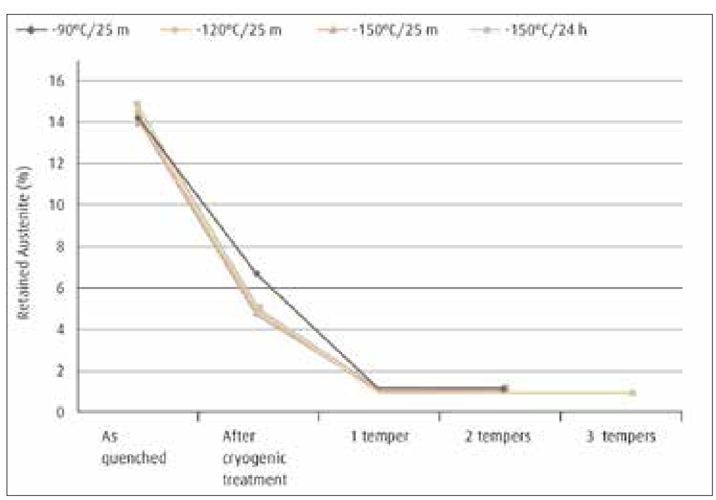

Figure 4: Effect of sub-zero treatment on retained austenite in D2 tool steel. Subzero treatments in the -90° C to -150° C range (-130° F to -238° F) can reduce the number of tempers sometimes to one. [6]

improved wear ratio of 6.25 times, with an average life of 250,000 hits after sub-zero treatment vs. 40,000 hits before this treatment.

DIMENSIONAL STABILITY

Some hardened precision-steel components, such as gears, bearings, and rollers, are subject to high mechanical stresses throughout their service life. Under operating conditions, small dimensional changes in the component can occur over time, and these can be critical to performance of parts with extremely precise tolerances. Cryotreatments can help eliminate a cause of such distortions at the outset to greatly improve dimensional stability. At room temperature, retained austenite is unstable and slowly decomposes over time. Sub-zero treatment can transform virtually any retained austenite present in the microstructure to martensite.

Depending on the alloy, cold-processing conditions and desired design goals, repeated tempering might not be necessary to produce a fully stable structure ready for machining. However, when precision tolerances are required, multiple cycles of cold treatment and tempering may be needed to achieve the highest levels of microstructural stability. [5]

Steel	Description	At -110ºF (-79ºC)	At -310ºF (-190ºC)
AISI (USA)	Materials showing improved wear resistance	Percent	Percent
D2	High carbon/chromium steel	316	817
S7	Silicon tool steel	241	503
52100	Bearing steel	195	420
01	Oil-hardened cold work die steel	221	418
A10	Graphite tool steel	230	264
M1	Molybdenum high-speed steel	145	225
H13	Hot work tool steel	164	209
M2	Tungsten/molybdenum high-speed steel	117	203
T1	Tungsten high-speed steel	141	176
CPM 10V	Alloy steel	94	131
P20	Mold steel	123	130
440	Martensitic stainless steel	128	121

Table B: Improvements in wear resistance of tool steels after sub-zero treatment [7].

Tooling	Average Life BEFORE	AFTER Sub-Zero Treatment	Wear Ratio
End mills used to cut C1065 steel	65 parts	200 parts	3.07
Hacksaw blades used to cut bosses on M107 shells	4h	6h	1.50
Zone punches used on shell casings	64 shells	5820 shells	82.50
Nosing thread dies used in metal working	225 shells	487 shells	2.16
Copper resistance welding tips	2 weeks	6 weeks	3.00
Progressive dies used in metal working	40,000 hits	250,000 hits	6.25
Blanking tool of heat treated 4140 and 1095 steel	1000 pieces	2000 pieces	2.00
Broach used on a C1020 steel torque tube	1810 parts	8602 parts	4.75
Broaching operation on forged connecting rods	1500 parts	8600 parts	5.73
Gang milling T-nuts from C1018 steel with M2 cutters	43.5 psi	203 psi	4.67
AMT-38 cut-off blades	60 h	928 h	15.47

Table C: Tool life before and after sub-zero treatment.

COLD AND CRYOTREATMENT

After any sub-zero treatment, the final processing step must always be a temper to transform any newly formed, untempered martensite. While sub-zero treatment changes retained austenite to the BCT martensite structure, heat tempering results in the precipitation of a finer distribution of carbides.

Sub-zero treatment temperatures can be achieved through direct or indirect cooling methods. Liquid nitrogen (LIN) is used in both direct and indirect treatment processes. With indirect cooling, a refrigerant circulates inside the coils of a mechanical freezer but never touches the parts. However, direct cooling is the most efficient means to achieve the lower cryotreatment temperatures for controlled cold processing of steel, and LIN can deliver much colder temperatures. Nitrogen is liquid at -196º C (-321º F). With direct cooling, when the nitrogen is released into the cryotreatment freezer at normal pressure, the circulating cryogenic gas removes BTUs directly from the parts as well as from the surrounding atmosphere.

The holding times for cryotreatment processes will depend on the composition of the alloy including any impurities, the part's design and mass, as well as treatment objectives. The microstructure is essentially set when the temperature throughout the part is uniform. This means smaller parts can be processed faster, often with holding times of just 1-2 hours. Larger components may require 4-6 hours or more. In conjunction with material parameters, numerous factors have an impact on how sub-zero treatments affect a metal alloy, including time, temperature profile, number of repetitions and tempering practice, and prior heat treatment.

BATCH AND CONTINUOUS SUB-ZERO FREEZERS

Cold-treatment freezers are available in a variety of sizes and configurations to meet varying production requirements, including for continuous or batch processing.

For continuous processing of small parts, the cryogenic tunnel freezer in Figure 5 can be installed in front of the tempering unit to accommodate higher production rates for treatments down to -110° C (-166° F). Parts move through the tunnel freezer on a conveyor that avoids extra handling and transport. The cold-treatment process can be controlled by adjusting the conveyor speed and injection of cryogen. Thermocouples can be added to measure inner and outer temperatures of parts to reduce the likelihood of cracking.

To fully benefit from sub-zero treatment, some components may require temperatures at or below -120° C (-184° F) for 24 hours or more. New cryotreatment freezers equipped with LIN can achieve these temperatures and control batch processes to within 1 degree. For batch processing, top-loading sub-zero cabinets and front-loading boxes are options for longer and colder treatments. They may be built to custom sizes to meet specific requirements, and multiple units are often needed to meet production demands. Front-loading freezers may be equipped for rack loading.

The front-loading cryogenic box freezer shown in Figure 6 can deliver cryotreatment of metal parts and components to -150° C (-238° F). For the cryo-treatment, a valve controls the injection of LIN, and a fan and flow-guiding plates ensure an even temperature inside the chamber for optimum performance and efficiency. Parts can be loaded into the top-loading sub-zero freezer shown in Figure 7 either manually or by hoist or overhead crane for large parts or heavier batches. This freezer is also designed to deliver cold treatments to -150° C (-238° F). The front-loading box freezer shown in Figure 8 is designed for batch thermal processing in the -120° C to 60° C range (-184° F to 140° F). Low-level heating at the end eliminates any condensation on treated parts.

Leading industrial gas suppliers offer expertise and laboratory services in customizing solutions for a range of thermal treatments. As robotics continue to push performance demands of metal alloys and precision parts, engineering and control systems can make the difference in maximizing the value of cryotreatment processes.

Figure 5: CRYOFLEX™ T sub-zero tunnel freezer.

Figure 6: CRYOFLEX front-loading sub-zero box freezer.

Figure 7: CRYOFLEX B top loading sub-zero cabinet freezer.

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Figure 8: CRYOFLEX C sub-zero front-loading cabinet freezer.

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Single-piece flow case hardening can be worked into in-line manufacturing

An operational system is introduced for a truly single-piece flow method of case hardening by low-pressure carburizing and high-pressure gas quench.

By Maciej Korecki, Emilia Wołowiec-Korecka, Agnieszka Brewka, Piotr Kula, Leszek Klimek, and Jacek Sawicki

Case hardening by carburizing is the most common heat treatment in mass production, which relies on atmosphere or vacuum carburizing followed by oil or gas quenching and finally by tempering. Parts being heat-treated undergo the process in a configuration of a batch that consists of hundreds or thousands of pieces. It's obvious a particular part achieves different process parameters in terms of temperature, atmosphere, and quenching depending on its position within the batch. Parts from the batch outside get a temperature sooner, a richer atmosphere, and more effective quenching than parts within the batch center. It leads to large result variation on parts within the batch, making an effective case-depth deviation as much as about 50 percent nothing unusual. Similarly, the hardening distortions are unpredictable and unrepeatable.

Modern industry requires more precise and repeatable results, which become out of the range of traditional technologies and equipment based on the batch method. Elimination of batches and a focus on an individual part is the only way for considerable improvement of the situation.

The article will introduce the first operational system for a truly single-piece flow method of case hardening by low-pressure carburizing and high-pressure gas quench. The system treats every single part the same way and provides the same process parameters, which results in extremely accurate and repeatable effects. Quenching of a single part in a specially designed chamber allows for control and significant reduction of distortions so much that some hard machining operations can be eliminated, as well as press quenching. The single-piece flow heat treatment method corresponds well with a manufacturing chain and can be directly integrated into in-line manufacturing, cooperating directly with machining centers. In such a case, materials handling and logistics are excluded, which saves cost and time.

The results achieved on a series of automotive gears prove outstanding accuracy

and repeatability with significant distortion reduction. Also productivity and process costs are competitive. All proven advantages and savings make the single-piece flow case hardening system a sign of incoming revolution in heat treatment.

INTRODUCTION

In traditional case-hardening systems, parts are configured and processed in batches on special fixtures (Figure 1) and undergo the whole case-hardening process in such a configuration. This means each part in a batch is affected by the process conditions in a unique manner based on its position within the batch. Each part is affected differently regarding the heating rate, composition of the process atmosphere, and intensity and direction of the cooling medium. There is no doubt the parts in the outer layers of a batch are heated more quickly and to a different temperature (according to the temperature distribution within the batch), as the atmosphere around them is "richer," and they are quenched more intensely, compared to the parts toward the center of the load. The result is that parts inside the batch have different physical and metallurgical properties than those on the outside of the batch, e.g., surface and core hardness, microstructure, and especially the effective case depth [1][2]. That's why forced and accepted industry requirements of case depth variation are ±30 percent, which even for industry is very, very tolerant.

Non-uniform quenching results in temperature gradients within each part resulting in thermal stresses and a non-uniform transformation of the microstructure. This ultimately results in large deformations of the part being quenched. Quenching results are made even worse by the fact that the quenching stream within the batch is dispersed and each part is cooled differently based on its position within the batch. A critical summary of batch 2D quenching (especially oil quenching) shows it is an uncontrolled and non-uniform process, producing great deformations within each part and little consistency within the batch. Distortions have to be removed by final machining or other correction methods. Costs of these operations are huge — for the German industry, it's about 2 billion euros a year [3], while a global estimation is about 20 billion euros.

Material handling of batch loads is typically complicated and costly. Gears are produced individually. After being shaped, they are collected, packed, protected, and transported to the case-hardening department (captive) or to an external firm (commercial), which can sometimes be hundreds of kilometers away. The gears are then unpacked, washed, and racked in order to form batches on fixtures designed specifically for the case-hardening process. Following an oil quench, the parts are washed again, dismantled, packed, protected, and transported back to the mechanical pro-

Figure 1: Typical batch composition.

cessing department. The whole undertaking may be divided into more than 10 operations and take days. These handling costs consume considerable resources, including time, materials, money, and damages.

Batch processing also has other quality, material-handling, and cost pitfalls. For example, monitoring and reporting on the case-hardening process are for the entire batch and not for individual pieces within the batch. That makes it difficult, or even impossible, to introduce and implement tighter quality standards.

The previously mentioned weaknesses come from the batch method and cannot be overcome. If more improvement is necessary in terms of a result's precision and repeatability, distortion's reduction and control, and in-line production's integration, the only way is the real single-piece flow heat treatment, which guarantees ideally the same process parameters for every single part in a series.

A SINGLE-PIECE FLOW CASE HARDENING BY LPC AND HPGQ

Figure 2 shows a vacuum furnace for case hardening of gears or rings using LPC and high pressure gas quench (HPGQ). This system fully meets the criteria of a single-piece

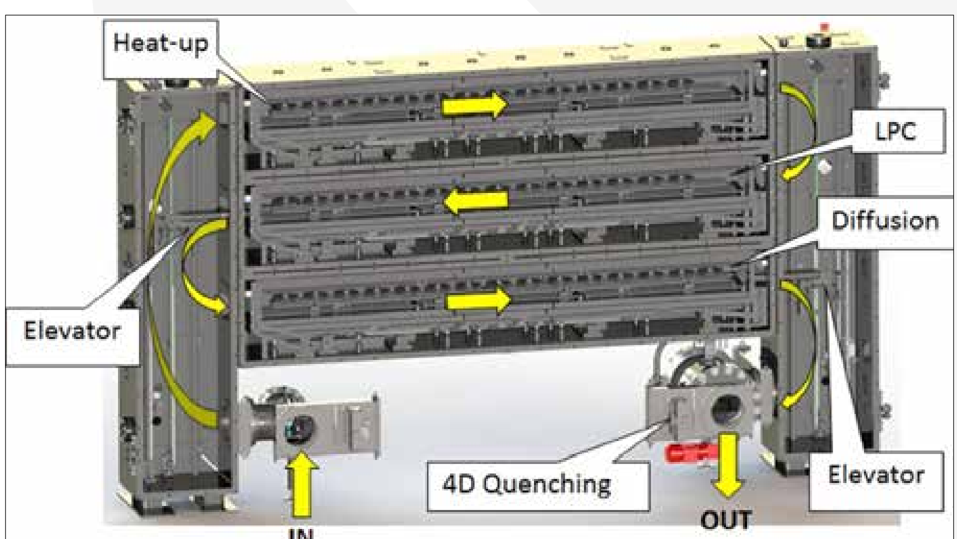

Figure 2: The vacuum furnace for single-piece flow case hardening.

flow method and has all the accompanying advantages contrary to other solutions [4][5]. The furnace consists of three horizontal chambers: the first one for heating up, the second for low pressure carburizing, and the third for diffusion and pre-cooling before quenching. Additionally, a separate loading chamber and a quenching chamber (that doubles as an unloading chamber) are connected. Parts are transported between chambers by two vertical transport elevators attached to each side of the system.

The single-piece flow process runs in the following manner:

- A single gear is placed inside a loading chamber.
- It is transported and loaded into the heating chamber.
- A walking beam mechanism indexes the gear through all the positions until the gear reaches the target carburizing temperature.
- The gear is transported and indexed through the LPC where the surface is saturated with the right amount of carbon.
- The part is transferred and indexed through the diffusion chamber where the desired carbon profile is achieved, and the temperature is decreased before quenching.
- The gear is transferred to the gas cooling chamber where it is quenched.
- The gear is removed from the quenching chamber and is ready for temper.

Each gear follows in sequence and is processed the exact same way, with the exact same process parameters, guaranteeing the highest level of precision and repeatability.

LEAN MANUFACTURING

The new concept of single-piece flow case hardening is intended to be installed and operated directly on the manufacturing floor next to a CNC machine and was designed so that its footprint was similar to a CNC machine (Figure 3). It can be installed on new production floors or at sites previously occupied by other machines, including CNC machines. A newly machined gear can be introduced into and released from the case-hardening system as frequently every 30 to 60 seconds (throughput up to 1 million parts a year). The system can be completely integrated into the continuous, lean production manufacturing line, thus eliminating many, if not all, batch material handling steps. It corresponds very well with an idea of Industry 4.0, too.

Also, please notice the system does not use fixtures for load racking. As noted previously, this helps reduce operating costs, including the cost to purchase and replace fixtures, as well as the consumption of energy.

THE FIRST, OPERATIONAL SINGLE-PIECE FLOW CASE HARDENING SYSTEM

The first complete and automated single-piece case-hardening line has been developed based on the furnace UniCase Master®. The line consists of the main furnace and accompanying devices and systems necessary for the process realization from beginning to end, among other things: manipulators, a tempering furnace, cooling chambers, a gas system, a vacuum pumping system, etc. (Figures 4 and 5). The line has the following technical parameters:

- Part diameter: 8 inches / 200 millimeters
- Part height: 2 inches / 50 millimeters
- Part mass: 8.8 pounds / 4 kilograms
- Number of positions in a process chamber: 15
- Tact: min. 30 seconds
- Temperature: 2,012° F / 1,100° C

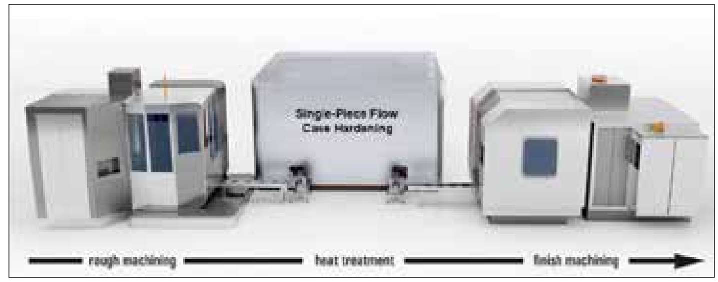

Figure 3: Integration of the single-piece flow case hardening in lean manufacturing.

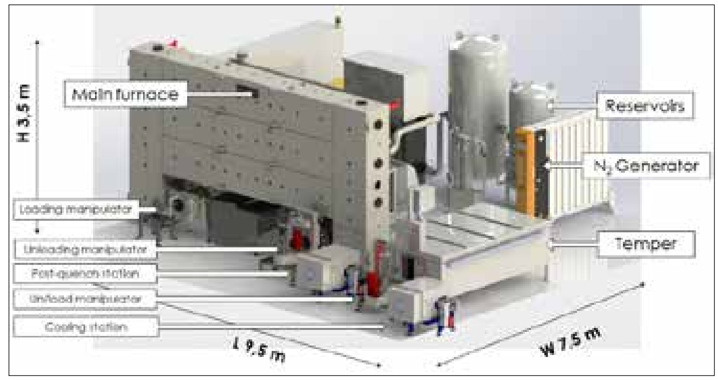

Figure 4: A complete, automated line for single-piece flow case hardening.

Figure 5: The first, real single-piece flow case-hardening system.

- Quenching: 10 bar N_2
- LPC (FineCarb): acetylene
- Installation area: 24.6 x 31.2 feet / 7.5 x 9.5 meters
- Power: 150 kW

The carried-out tests have confirmed the correctness of the technical solutions and the operating and technological parameters. Transport mechanism reliability and full control of the technological result have been achieved. The system has been tested in hundreds of tests over a wide range of parameters: at temperatures between 840 and 1,060° C and effective case depth within 0.30 to 1.5 mm.

A high-result precision and replicability, as well as a significant reduction of hardening deformations have been obtained.

PRECISE CARBURIZING (LPC)

To confirm the accuracy and repeatability of carburizing (LPC), two types of tests were carried out on a part series. The first test consisted of checking the evenness of carbon transfer from the atmosphere to the part surface through a measurement of the mass of carbon introduced during the process (gravimetric method). To this end, the parts were weighed before and after the process; the

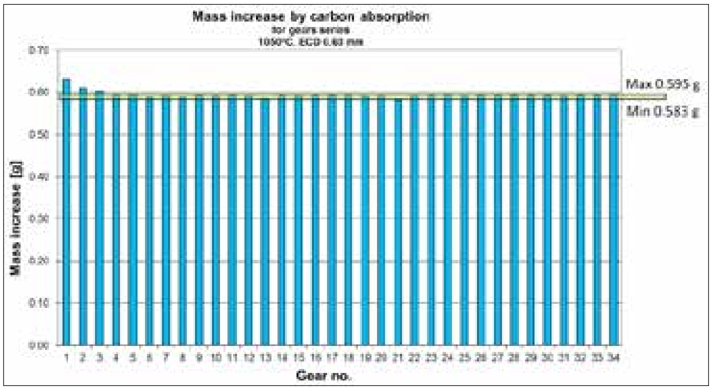

Figure 6: Carburizing evenness according to the absorbed carbon mass.

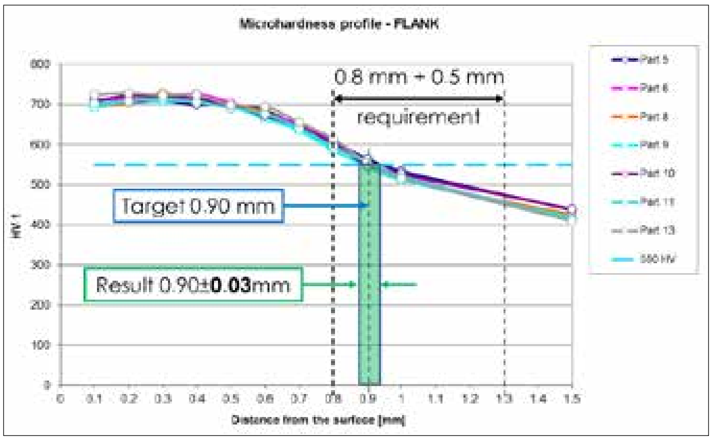

Figure 7: Carburizing evenness according to the hardness profiles.

weight increase reflects the absorbed carbon mass. The test was carried out on wheels with a diameter of 96 millimeters and a mass of 550 grams; their weight was specified with an accuracy up to ±2 milligrams. Figure 6 shows the diagram of the weight increase measurements for the part series. Except for the first three wheels that were introduced to the empty device and that show slightly greater weight increase, the whole series ranges from 583 to 595 milligrams. This means accuracy and repeatability unattainable in no other method, i.e. ±1 percent.

However, the same carbon absorption does not have to mean the parts have obtained the same carbon profile and hardness profile. Therefore, to confirm the results, the second type of test measured the hardness profile. The test was carried out on gear wheels with a diameter of 180 millimeters, carburized and quenched within the effective case depth of 0.9 millimeters (550 HV). The results are shown in Figure 7. Of the wheels selected from the series, the correct hardness profile was obtained and the effective case depth was 0.90 millimeters with ±0.03 millimeters, i.e., repeatability has been ±3 percent.

This result is unattainable with traditional methods. In addition, special attention should be paid to make sure the hardness profile measurement accuracy itself is stuck with the comparable error, so in all probability, the repeatability of actual results is even better.

4D QUENCHING®

The new concept also allows for significant improvements in the quenching process, specifically the reduction of distortion. This is done primarily using a high-pressure gas quenching system installed in the quenching/unloading chamber (Figure 8).

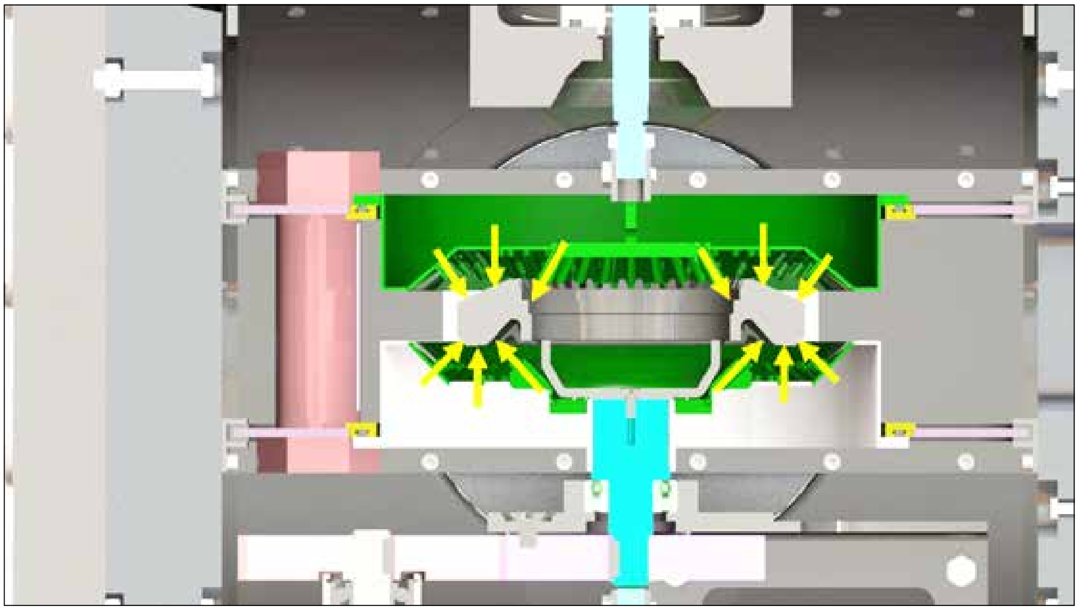

Figure 8: 4D Quenching chamber with the quenched part by gas fluxes.

The system uses a proprietary arrangement of cooling nozzles that surround the part and ensures a uniform flow of cooling gas from all sides: top, bottom, and side. We refer to this as "3D" cooling. In addition, a table spins the part, further enhancing quench uniformity. We refer to the spinning motion as the fourth dimension, allowing us to "4D" quench gears for the best possible uniformity. The cooling nozzles allow us to achieve up to 10 bar quenching results — comparable to oil quenching — without the use of helium. Because the cooling nozzles can be adjusted to fit the gear's precise size, quenching is optimized, and distortion is significantly decreased.

DEFORMATION REDUCTION

In order to check and compare deformation, tests of detail quenching in the 4D Quenching chamber are compared with the traditional method of batch in oil in two positions: vertical and horizontal. The tests were carried out on a series of hypoid gears (ring gears) with a diameter of about 200 millimeters (Figure 9). The gears were carburized and quenched to obtain an effective case depth of 0.8 millimeters (550 HV) and tempered at 180° C.

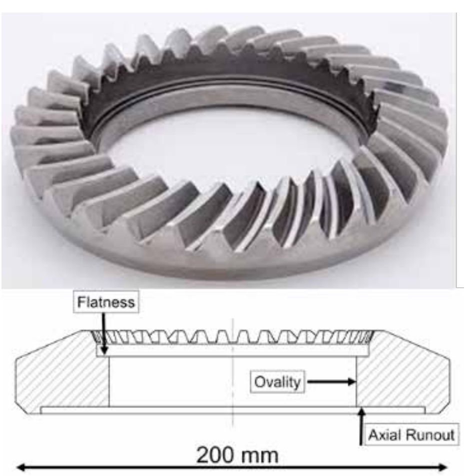

Figure 9: Hypoid gear for distortion tests.

The deviations were measured in the following places (Figure 9):

- Flatness of top surface of the internal hole.
- Axial runout of bottom surface of the internal hole.
- Ovality of the internal hole.

The distortion-measurements summary is shown in Figure 10 in many ways, such as:

- Min: minimal value
- Max: maximal value
- Avr: average value
- Diff: Max-Min value
- Dev: standard deviation

The flatness deviation for the vertical oil quenching has reached up to 25 to 52 micrometers and more, and 34 to 77 micrometers in the horizontal position. Larger flatness distortion in the horizontal position is very characteristic for directional, vertical parent of quenching oil flow. The same flatness deviations after uniform hardening in the 4D Quenching chamber obtained the results in the range from 5 to 25 micrometers, i.e. two to three times better. The variation of results measured by the standard deviation is up to five times more precise in the 4D Quenching comparing to traditional batch quenching in oil.

The ovality deformations after oil behave contrary between vertical: 40-95 micrometers and horizontal position: 33-82 micrometers. The horizontal position is preferred as slightly less prone to distortion, which is in relation to the oil flow vertical direction. Nevertheless the 4D Quenching reached ovality deviation from 10–38 micrometers, which is again two, three times less and more precise.

In the case of the axial run-out, the deformations are 56-120 micrometers for oil and 20-65 micrometers for the 4D Quenching chamber, i.e., two-times less.

In general, the possibility of a significant (double or even quadruple) lowering of the hardening deformations of parts in the individual quenching chamber (4D Quenching) has been confirmed, although these results are not final because they have been done as a first shot. Much better results are expected to be obtained while dedicated optimizing programs are applied in terms of design of the 4D Quenching nozzles and quenching process parameters. In many cases, final hard machining and press quenching won't be necessary.

SUMMARY

In turn, at the innovative system, single-piece flow — UniCase Master®, the technological result precision and replicability have reached an, as yet, unattainable level, while their dispersion has been reduced tenfold. However, the quenching chamber, 4D Quenching, allows for deformation control and reduction by several times. This results in a significant reduction of the finishing operation and its costs and, in many cases, its elimination. The integration of the heat treatment directly into the production chain eliminates the material logistics costs and shortens the production time, as well as allowing for traceability and an in-line check of each part during production.

The main benefits the single-piece flow case hardening can deliver are:

Single-piece flow:

- 10 times improved results precision and repeatability.
- 100 percent traceability, individual part monitoring, and reporting.
- 100 percent single part in-line testing after case hardening.

Lean manufacturing:

- 100 percent integration into continuous production lines.
- High throughput.
- Zero cost of material handling logistics.
- Zero cost of heat-treatment fixtures.

4D Quenching®:

- 2-4 times less distortion size.
- 2-4 times less distortion variation.
- 2-4 times less hard machining operation.
- Elimination of some hard machining operations and press quenching.

Low Pressure Carburizing / High Pressure Gas Quenching:

- Elimination of IGO.
- Fast high temperature carburizing (up to 5 times).
- Elimination of fire and explosion hazards.
- Clean and environmentally friendly production.

The solution determines a revolutionary direction of changes and development of heat-treatment technology and equipment for the modern industry and fully complies with present and upcoming requirements.

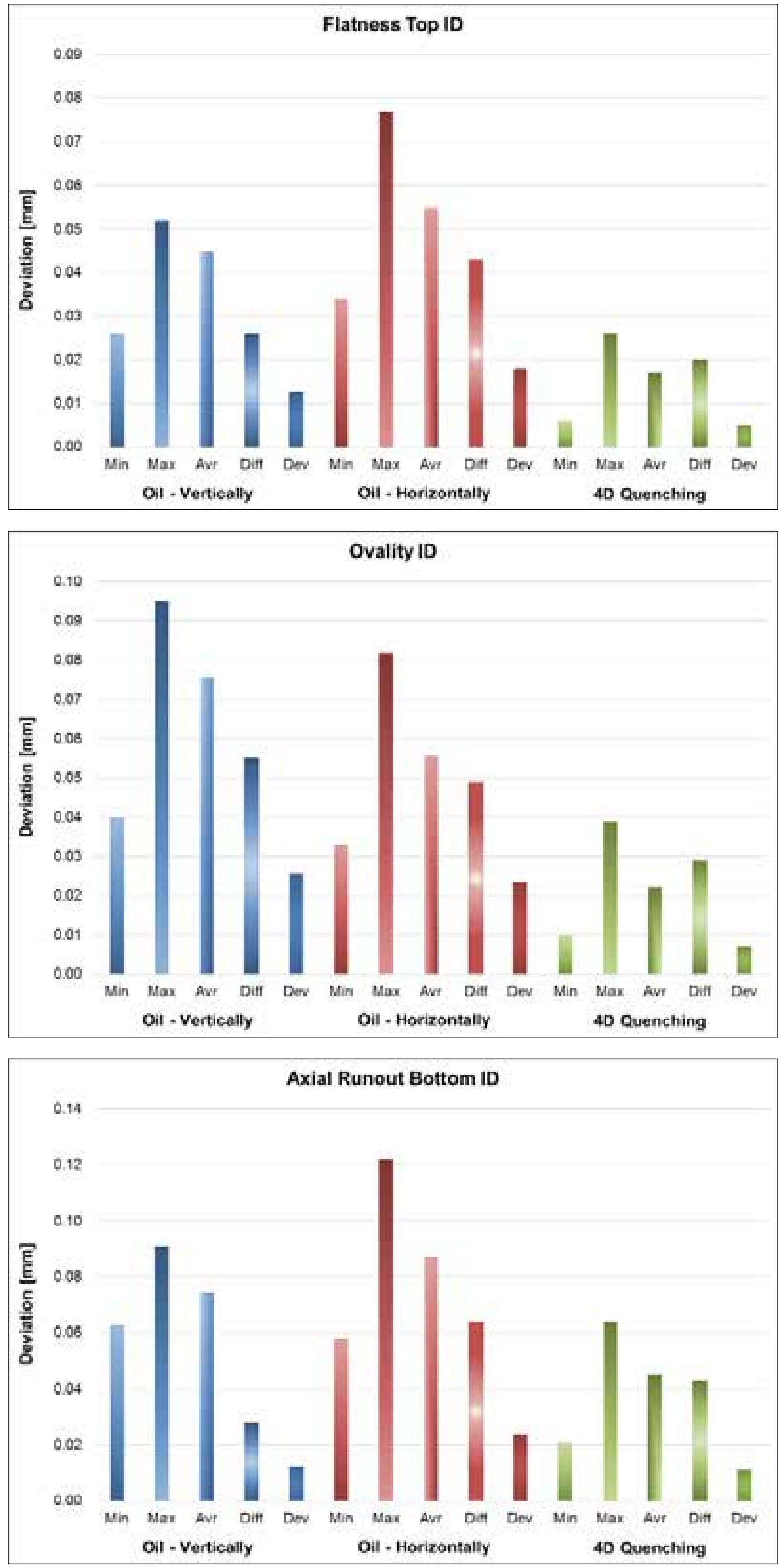

Figure 10: Comparison of the case-hardening deviations after different quenching methods.

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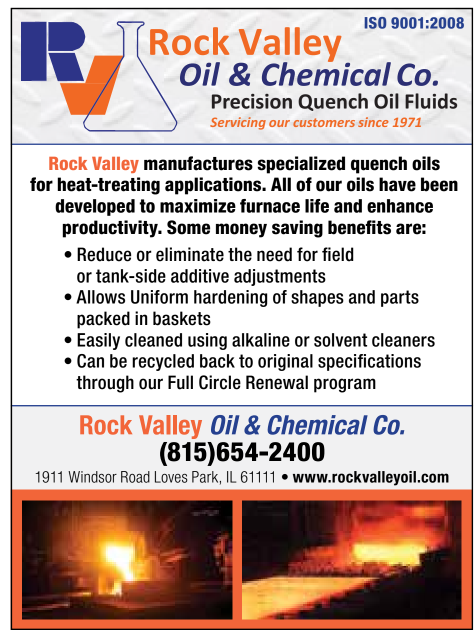

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WHAT IS PREMIER'S MISSION?

To provide heat-treating systems that are dependable as well as innovative, with performance-proven technology that will enhance the physical properties and surface characteristics of a variety of materials as per customers' requests.

HOW DID PREMIER FURNACE BEGIN?

As a field service engineer 25 years ago, working on all types of furnaces, I recognized some design flaws or ways to improve performance with better components or manufacturing. I founded the company in 1999. The name 'Premier' seemed appropriate, as that has always been our goal — to build premier furnaces.

WHAT PRODUCTS AND SERVICES DOES PREMIER OFFER?

Premier/BeaverMatic offers a variety of heat-processing products as well as service and spare parts. We are well respected in the industry, with internal quench furnaces, tip-up, manipulators, quenching systems, car bottom, box, temper, roller hearth, belt, pusher, spray/dunk washers, endothermic and exothermic gas generators, transfer carts, and many custom systems. We offer 24/7 field service on most major furnace systems, carry many in-stock spare parts, and provide technical advice.

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Our name says it all, and this is backed by our customers' use of our performance-proven designs. We could have used other names, such as chief, leading, primary, supreme, or topline because we are the top of the line in thermal-processing systems.

FOR MORE INFORMATION: www.premierfurnace.com or www.beavermatic.com

Premier Furnaces President Don Selmi credits hard work, quality products, innovation, and ongoing customer satisfaction as keys to the company's success.