eat treatment is one of many process steps involved in the manufacture of an automobile, which adds huge value to the final product. Even small heat treating process improvements at relatively low cost create a high value. For instance, heat treatment accounts for approximately 6% of the production cost for a gearbox, but increases the value of the component by at least 25%, probably more.

Several types of heat treatment are involved in automobile production including carburizing (gears and transmission parts, for example) and final heat treatment operations such as hardening, carbonitriding, nitrocarburizing, and nitriding. The common element for these final heat treatment processes is that they significantly increase the performance-to-weight ratio of parts (e.g., the weight of a gearbox would be at least five times greater if not carburized and hardened). Different annealing operations are used for semifinished products, such as forgings, strip, tube, and wire that will be used in different automotive parts. These processes occur earlier in the process chain. Ad-

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Freedom from decarburization and oxidation during annealing and hardening, carbon potential and case depth control in carburizing, and proper wetting in brazing are examples for which the atmosphere control is crucial. Some further examples of the importance of atmosphere control are shown in the table.

**Fig. 1 — Benefits of using proper atmosphere control in heat treating automotive parts**
Dynamic Atmosphere Control

A dynamic control system can recognize furnace atmosphere disturbances and automatically adjust the gas mixture or the gas flow into the furnace according to set points, which ensures that required quality standards are met during heat treatment. Different atmosphere disturbances may occur in the furnace, such as from furnace leaks, during loading and unloading, etc. Figure 2a shows how a constant flow rate of the gas into the furnace may result in varying atmosphere composition. By comparison, Fig. 2b shows how flow adjustments make it possible to continually maintain the atmosphere composition at set point. Dynamic control has an important impact on quality of treated parts and on total gas consumption. The blue sections of the curve in Fig. 2b illustrate potential gas savings.

The features of the dynamic control system are:
• Control of furnace atmosphere composition
• Safety purging procedures and process alarms
• Purging function to protect analyzing instruments
• Optional function for data logging
• Optional function for remote supervision

Examples of systems and related results for annealing, and carburizing, and brazing are described below.

Annealing of Steel Tubes

Increasing demand by the automotive industry for improved part quality in regard to carbon control was the motivation to develop Linde’s Carboxflex® dynamic control system for steel tube annealing based on the combination of nitrogen and endo gas atmospheres (Fig. 3). Two different gas streams (nitrogen and endo gas) can be adjusted independently, providing the flexibility to properly adjust the atmosphere composition. This flexibility meets the different requirements that the work load encounters during the annealing pass through the furnace.

The control cabinet contains a PLC for control and a PC with a touch screen as the HMI. Setting atmosphere parameters, handling recipes, setting alarms, start up and stop operations, calibrating analyzers, and viewing actual furnace atmosphere data are made from the PC touch screen.

The system offers:
• Accurate control of tube surface carbon content
• Optimized recipes that adapt the proper gas flow and atmosphere composition to a given tube dimension and tube quality requirements
• Reduced rework costs associated with oxidized, decarburized, and discolored tubes
• Special idling programs to minimize gas consumption during off production periods
• Significantly lower gas consumption compared with exogas systems
Carburizing in a Pusher Furnace

Accurate atmosphere carbon potential control in carburizing furnaces can be used to shorten carburizing time (increase productivity), to decrease the scatter in final carbon concentration and case depth, and to tailor the carbon concentration depth curve. This can be further enhanced by using an improved atmosphere analysis. It is common to base atmosphere control on the assumption that CO and H₂ concentrations are constant. Carbon potential control is accordingly based on the actual analysis of only one atmosphere constituent (typically CO₂ concentration) or the oxygen potential measured using an oxygen probe. However, this does not take into account the relationship between CO concentration and carbon potential. For control of CO₂, the relationship is expressed by:

$$C_{pot} = \frac{\text{constant} \times (\text{vol\% CO})^2}{(\text{vol\% CO₂})}$$

Consider, for example, a situation where the atmosphere carbon potential is controlled at a temperature of 930°C (~1700°F) by CO₂ analyses to be 0.80%C, with the assumption that the CO concentration is 20 vol%. If the actual CO concentration is 18 vol% instead of 20 vol%, the resulting carbon potential at 930°C will not be 0.80, but will be 0.68%C instead. The Carboflex system (Fig. 4) avoids this inaccuracy by adding the CO analysis as a controlling value. A variation of the atmosphere composition along the furnace in this type of furnace is not uncommon, which makes it even more important to analyze the CO to obtain acceptable accuracy in the carbon potential control.

In addition, a simulation program to calculate carbon concentration profiles from process recipes is used to minimize the carburizing time. Combining this with accurate atmosphere control (Fig. 4) resulted in shorter process times due to the improved precision in obtaining target case depths and surface carbon concentrations, postponement of investments in new furnaces due to approximately 15% increased carburizing capacities, and the possibility to tailor hardness/residual stress profiles for optimum fatigue properties [1].

Brazing of Steel Parts

Brazing stainless steel injectors and fuel pipes for cars typically is conducted in a mesh belt furnace (Fig. 5) using a hydrogen-nitrogen atmosphere. A Hydroflex® dynamic atmosphere control system consists of an atmosphere supply system for nitrogen and hydrogen, an analyzing system (sampling flow train and analyzing instruments), gas flow control, and PC or PLC and related software and a touch screen as the human machine interface (HMI).

The analyzing instruments and the HMI are located in the control cabinet (Fig. 6). A gas sample taken from each furnace zone is pumped to the control cabinet to measure oxygen, dew point, and hydrogen.

Two control loops of the system are shown in Fig. 7. Total nitrogen-hydrogen gas flow and the nitrogen-hydrogen ratio are controlled by the oxygen potential of the atmosphere in the heating zone (calculated from the measured dew point and hydrogen concentration). Nitrogen flow is controlled by the oxygen content (ppm O₂) in the cooling zone.

An increase in the actual atmosphere oxygen potential above the set point first increases the total nitrogen-hydrogen flow. However, if the set point is not reached, the nitrogen-hydrogen ratio is reduced (increased share of hydrogen). In the cooling zone, an increase in the atmosphere oxygen content (ppm O₂) increases the nitrogen flow. The set points for oxygen potential and ppm O₂ in each of the control loops are defined from theoretical and experience values.

The system has extra functions for...
New ASM Materials Camp locations in 2006
- Edinboro University
- Iowa State University
- McGill University
- The Ohio State University
- Penn State University
- University of Calgary, Alberta
- University of Maryland
- University of Texas-Dallas
- University of Toronto
- Worcester Polytechnic Institute

ASM Materials Camps in 2005 Graduate a Record Class of 900
In 2005, nearly 900 high school students or teachers graduated from an ASM Materials Camp. More than 1,800 have graduated since the program's founding in 2000.

ASM/Roberts Challenge: Every

ASM members and guests attending the ASM Annual Awards Dinner in Pittsburgh were the first to hear the official news. The ASM/Roberts Challenge campaign has gone public, revealing early gifts and pledges of $522,000, representing 52% of the $1 million goal to date.

Dr. George A. Roberts, FASM, Honorary Member and Past President of ASM International (1955) and Past Chair of the ASM Materials Education Foundation, issued a challenge that will give the Foundation the means to expand ASM Materials Camps and other educational programs in the years to come.

Dr. Roberts has challenged the ASM membership to step up and make a difference. He will contribute $1 million in matching funds to the ASM Foundation if the membership, staff and friends of ASM contribute $1 million to the ASM/Roberts Challenge...and if ASM matches both, dollar for dollar! Which means that every dollar donated to the ASM/Roberts Challenge will quadruple!

Asphahani Named Chair of ASM/Roberts Challenge Campaign
Personal Gift ‘Extremely Generous’
Past ASM International President (2001) Dr. Aziz I. Asphahani, FASM, has been named Chairman of the ASM/Roberts Challenge Campaign. He has served on the ASM Foundation Board for many years, and was Foundation Board Chair in 2004.

"Aziz and his wife, Wendy, have set the pace for others to follow," said Prof. Tom Stoebe, 2005 Foundation Board Chair. "Their personal gift of $150,000 sets a high standard for others, and is extremely generous." Dr. Asphahani has recruited a team of volunteers to support his efforts.

Staff ‘Lead Team’ Sets Personal Example
Under the strong leadership of ASM Managing Director Stan Theobald, members of the senior staff at ASM have accepted the ASM/Roberts Challenge. 100% of senior staff have contributed, with pledges from these 10 staff associates nearing $50,000 collectively. Other ASM staff associates are joining the bandwagon too, with final results of staff participation to be announced soon.

George Roberts on persistence: “It’s like Mark Twain said: ‘Put all of your eggs into one basket and watch that basket.’”

On the ASM/Roberts Challenge: “It’s always fun to invest in something that quadruples in value right away. Talk about leveraging the impact? In a lottery there is only one winner. In this challenge there are 36,000 ASM members who have an opportunity to contribute—that’s 36,000 winners!”

On philanthropy: “We rely upon individuals to ‘pay for prosperity’ and return resources to good purposes in life. I believe that given the opportunity to be philanthropic, most people would be responsive.”

On ASM Materials Camps: “This program provides a great opportunity for young people, to enthrone them, to encourage them, to get them more interested in the breadth of opportunities that materials make possible.”

Keep a Good Thing Growing. Contribute to the ASM Materials Education Foundation.
100% of Foundation Board Personally Contribute

As official “pacesetters,” trustees of the ASM Materials Education Foundation Board (right) have each made personal pledges of financial support. Collectively, Foundation leaders have pledged more than $450,000.

Dollar Donated Will Quadruple!

Top 5 “Leadership Level” Personal Gifts Revealed

In the past few months, ASM Foundation has solicited support from members of the immediate ASM family. Many major gifts have been pledged. Here is a summary of the five largest individual gifts (to date):

- $150,000 Aziz and Wendy Asphahani
- $ 75,000 Dave and Barbara Krashe
- $ 60,000 Don and Eileen Muszka
- $ 35,000 Dick and Jeanie Pittler
- $ 25,000 Al and Julie Romig

ASM Board of Trustees Gets Progress Report

The ASM Board of Trustees learned more about the impact, progress and future Strategic Plan of the ASM Materials Education Foundation during a briefing session in September. Individual ASM Trustees pledged their full personal support, led by ASM Treasurer Paul Huber and his wife, Francie, who responded immediately with a pledge of $10,000.

Corporations Quick to Respond

In addition to gifts from individual ASM members, major corporations are setting the pace:

- Lockheed Martin Corporation: $75,000
- Engineering Systems Inc. & Employees: $30,000
- Buehler Ltd. and Employees: $30,000

Profile: Dr. George A. Roberts, FASM

Entrepreneur, Innovator, Business Leader and Philanthropist

Born:
1919 in Uniontown, Pa., 40 miles south of Pittsburgh.
Father was the Point Marion Superintendent of Schools.

Education:
Attended U.S. Naval Academy for two years, but lost appointment due to system-wide downsizing. Went to visit Carnegie Tech to meet the Dean of Engineering. When asked what area he wished to study, he replied mathematics, but was encouraged to consider metallurgy. Enrolled at Carnegie Tech in 1939 as a junior. Received his B.S degree in 1939; completed his M.S. and D.Sc. in 1942. Doctorate mentor Robert F. Mehl, chair of the Department of Metallurgy, became a lifelong friend. Member of Beta Theta Pi fraternity. Has served on the Board of Carnegie Mellon University, is a Life Trustee, and was the benefactor that founded Roberts Hall.

Professional Career:

During his business career, became associated with both Presidents Bush and was a golf partner of President Ronald Reagan. Lifelong friend of Arnold Palmer. Involved with friend Bob Hope’s Desert Golf Classic. Avid collector of French impressionist art. Lives in Dallas and Palm Springs with his wife Miriam (“Mimi”).

Active in numerous professional societies. ASM honors include ASM Fellow, ASM President, ASM Honorary Member, Gold Medal, and Medal for the Advancement of Research. Member of the National Academy of Engineering.
safety and operational purposes, which can be integrated into the system. The following are examples of possible safety sequences:

- Low furnace temperature alarm shuts down the system and initiates nitrogen purging.
- Low nitrogen pressure (nitrogen supply) shuts down the system
- Extinction of safety flames at furnace entrance or exit shuts down the system, but nitrogen flow remains
- Oxygen concentration higher than 800 ppm results in a sound alarm and initiates nitrogen purging
- A dew point higher than +18°C (+64.5°F) results in a sound alarm and initiates nitrogen purging
- Low nitrogen flow results in a sound alarm
- Low hydrogen flow results in a sound alarm

Experienced benefits of the Hydroflex system include:

- Process stability and reaction against external atmosphere disturbances
- Less scrap and rework
- Recipes having process set points for required parts quality
- Optimum gas consumption
- Increased furnace use due to quick start up
- User-friendly screen interface showing different views and access levels
- Easy implementation at existing installations and furnaces
- Possibility to customize views, specific functions, etc., according to requirements

Brazing of Aluminum

Brazing aluminum coolers and air-conditioning equipment is commonly performed in continuous furnaces using a pure nitrogen furnace atmosphere. A flux is used to improve wetting. The amount of flux needed can be minimized by proper atmosphere control; that is, by keeping the oxygen and the water-vapor concentrations in the atmosphere below certain maximum limits. Both oxygen and water vapor enter the furnace atmosphere through leaks and furnace openings. Figure 8 illustrates the importance of atmosphere control for brazing quality, showing the brazing result for an atmosphere having less than 50 ppm oxygen, but with a varying dew point.

Lowering the dew point has a considerably positive affect on the brazeability of aluminum. For the lowest flux load (1.1 mg/m²), the dew point must be lower than -45°C (-50°F) to achieve “very good” wetting and brazeability. For the highest flux load (3.2 mg/m²), a dew point of -35°C (-13°F) is sufficient to obtain good brazeability. Tests using an atmosphere containing 400 ppm oxygen results in “bad” or “poor” brazeability for all combinations of flux loads and atmosphere dew points. Dynamic atmosphere control following the principles described produces high quality brazing results with minimum flux consumption and gas savings on the order of 20 to 35%.
Data Collection

Data collection is an additional option that can be added to the dynamic control systems. With the system, data from the central factory supervision system are combined with logged process data from the control system. The combined data are stored and can be viewed and evaluated for statistical analyses for process improvement. The historical data also are used for traceability and to minimize the number of parts scrapped after furnace disturbances. Figure 9 shows a principal set up for data collection.

The process control PC receives identification data for a specific batch either from a bar code reader or manual input. The data-collection database stores the input data (including date and time) and matches it with order details and heat treatment recipe for the order from the central supervision system. When the heat treatment process is started, process data are logged and added to the database. The data registered can be viewed online on the process data screen (Fig. 10).

The collection of process data is stopped when the batch leaves the furnace, and all information for a specific batch is stored first on the process PC and later transferred to the central supervision system. The system matches each batch with its correct information even if the operation is interrupted and batches are interchanged or divided.

Remote Supervision

Remote monitoring of processes has long been available. The technique in combination with dynamic atmosphere control systems opens new possibilities for heat treatment. The responsibility of supervision (the correction of irregular operation and maintenance) can easily be transferred to an external party at a remote supervision center. (The party assuming this responsibility must of course have the required heat treatment expertise.)

Following is an example of remote supervision of a hardening line. The hardening atmosphere itself is locally controlled by a dynamic Carboflex system, but the system and atmosphere supply are remotely monitored and supervised.

Figure 11 shows the system communication set-up. The signals for gas-flow, pressure, temperature, etc. from the endo gas generator and nitrogen supply are sent through a secure internet connection to the remote supervising center. The supervision center is responsible for proper actions taken by the service engineers when needed within a specified time. The system is in this case not actively controlled remotely, only supervised. All alarms are shown on the remote screen and they also appear as SMS messages sent to the service engineer on duty.

Figure 12 shows a remote screen view during supervision. The display shows the pressure of the incoming natural gas and air mixture; endo gas generator (catalyzer) data for temperature; CO, CO2, and CH4 concentrations; and dew point. Other views show set points, nitrogen pressure, need for back up gas, etc. Data are collected and stored as described above.

To ensure gas delivery, an additional endo gas generator was installed as back up, as well as gas cylinder storage with carbon monoxide and hydrogen gas. These back up supplies enter automatically if the regular supply fails and enables the gas supplier to guarantee a continuous ready-made furnace atmosphere supply 24 hours a day, seven days a week. The gas supplier is in this case also the owner of the generators and the nitrogen supply tank.

Remote supervision is a tool that also enables an external party having
the required heat treatment expertise (in this case the gas supplier) to be responsible for the furnace operation and maintenance. This new concept for supply and remote monitoring opens possibilities for the heat treater to out-source part of its operation.

Summary
Control systems for heat treatment are integral parts of the quality system and are used to continually improve process capabilities (e.g., reducing tolerances, etc.), productivity (reduced process time, labor, storage, etc.), safety (handling of flammable gases etc.), and downstream operations (easier grinding, surface coating, etc.), parts properties (strength, dimensions, scatter, etc.), as well as to provide input for development (new materials, new specifications, etc.). Benefits of such systems include increased product value, reduced manpower needs, reduced rework costs, process documentation, minimized gas consumption, failure tracking, and partly (but not fully) compensation for lack of specialist competence.

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References