HEAT TREATING TECHNOLOGY ROADMAP UPDATE 2006 PART I

This article highlights the continuation of work to update the 1997 Heat Treating Technology Roadmap developed to achieve the Vision 2020 goals. The Research & Development Committee of the ASM Heat Treating Society (HTS) revised the 1997 version's technical research initiatives into four categories: Equipment & Hardware Technology, Process & Materials Technology, Energy & Environment Technology, and Institutional Initiatives. Previous articles in this series documented the changes made to the original roadmap. Different subcommittees reviewed different sections of the revised 2004 Roadmap, and updated them to reflect current industry activities and ranked and prioritized the initiatives within each category. The results of the Process & Materials Technology subcommittee are discussed in this article.

PROCESS & MATERIALS TECHNOLOGY

The charter of the ASM Heat Treating Society's R&D Committee is to identify future technological needs of the heat treating industry and develop the mechanisms to plan, fund, and implement R&D programs to meet these needs, and to transfer the results of these programs to industry.

Richard L. Houghton**
Process & Materials Technology Subcommittee
ASM Heat Treating Society
R&D Committee

Improved Processes and Materials

The Improved Processes and Materials initiatives were subdivided into three groups including Materials and Process Knowledge, Materials Application Knowledge – Software and Models Databases, and Model Development, and initiatives within each subgroup were ranked using the same definitions and ranking criteria as in the original 1997 Roadmap:

• Payoff (the financial return to the heat treater). The payoff of an individual initiative is relative to all other initiatives. Initiative payoffs (with the exception of environmental initiatives) in the original 1997 Roadmap document were characterized as high, medium, and low. The payoff of environmental initiatives includes value to the environment as well as public perception of the heat treating industry.

• Risk (the probability that the research can be successfully completed, thereby offering a return on investment). Risk in the 1997 document was characterized as high, medium, and low.

• Time to Implement was characterized using the 1997 guidelines: Near = 0-3 years, Medium = 3-10 years; Long = greater than 10 years.

• Priority was ranked using 1997 rankings of top, high, and medium, and a low raking also was added.

The general guiding principles used to rank initiatives were time efficiency (a high driver for the process initiative rankings) and value to the heat treating industry as a whole as opposed to a specific segment of the industry.

Discussion

Initiatives within each subgroup are sorted first by Top to Low priority and second by Payoff from High to Low. Of the three subcategories, Model Development was ranked as having the highest priority and payoff for the heat treating industry. Collectively, payoff for 74% of the initiatives is rated high, 7% medium and 19% low. It is financially important to the industry that so many initiatives have a high payoff to justify implementation costs.

Looking at the Time to Implement initiatives, 41% are ranked as Near (0-3 years), 37% Medium (3-10 years), and 22% Long (greater than 10 years). Considering the initiatives having both high payoff and short time to implement can help prioritize which initiatives could be worked on first. It is expected that many initiatives having ratings of both high payoff and near-term time to implement could be implemented within the next three years. If this comes to fruition, the industry will have made great strides toward its long-term Vision 2020 goals.

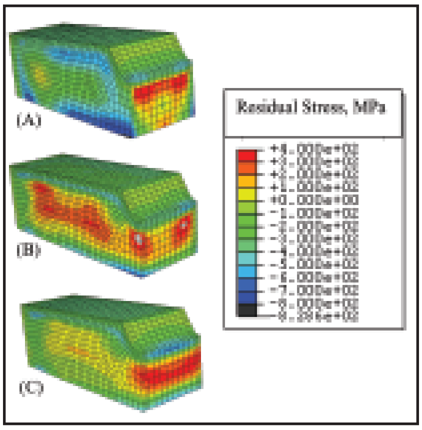
Implementation

In the past series of articles, several initiatives of the revised Roadmap that were being worked on were discussed in detail. Some of those advances are being put into use in production. Implementation of these research initiatives is critical to the success of achieving the Vision 2020 goals, and also is most difficult part of the overall task. Following are two examples of Roadmap Initiatives that are actively being worked on.

***Member ASM International and member, ASM Heat Treating Society*

Example: Bending Fatigue Strength Improvement of Carburized Aerospace Gears

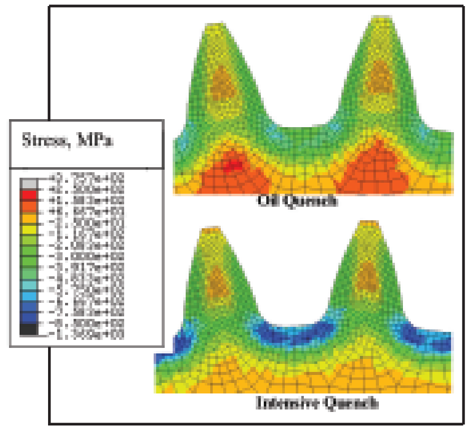
This project addresses two Process and Materials Technology initiatives; the development of processes alternatives to carburizing and model development. This U.S. Army-sponsored project is designed to improve helicopter gear fatigue life through the unique application of an innovative quenching technique, with the achievement of substantially higher and deeper residual compressive surface stress. As a result,



Predicted cross section residual stress contours for three quenc configurations. Photo courtesy of Deformation Control Technology Inc., Cleveland, Ohio.

a goal to improve the power density and life of existing helicopter transmission gear systems and to accomplish the improvement with no change in the dimensional configuration of the gearbox assembly was validated.

The concept used a novel heat treatment process called intensive quenching (IQ Technolgies Inc., Akron, Ohio; www.intensivequench.com) to facilitate enhanced residual surface compressive stresses with the subsequent substantial material fatigue life improvement. The innovative accomplishment of this project was largely implemented by the substantial advances made by Deformation Control Technology Inc.'s (Cleveland, Ohio; www.deformationcontrol.com) advanced capabilities and computer simulation studies. This included detailed studies of existing microstructure and metallurgical/strength capabilities of the conventional process and a detailed study and validation of the resulting improved metallurgical transformation reactions (by the intensive quenching technique) and its affect on



Residual stress profile comparison after heat treat through tooth/root cross section. Photo courtesy of Deformation Control Technology Inc., Cleveland, Ohio.

the kinematic strengthening of the part surface to generate the substantially enhanced level of the residual compressive stresses.

This case study provides an excellent example of progress being made using the latest techniques in scientific computerized simulation/analysis that predict and validate a substantial improved performance capability using intensive quenching technology.

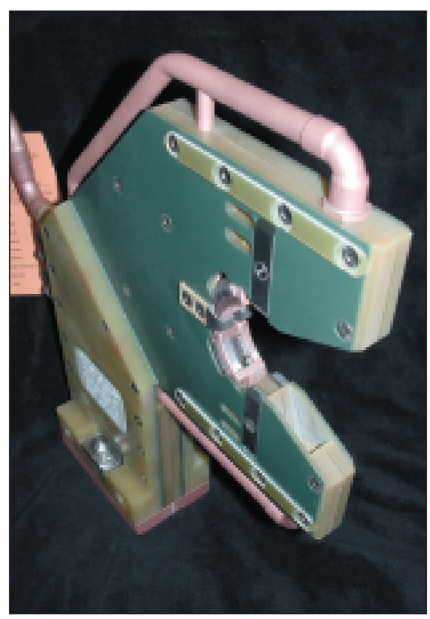
Example: Improved Induction Coil Design

This example is related to the Improved Process and Materials Technology Initiatives section, and is specifically directed at the first item under the Materials and Process Knowledge section; that is "Produce improved induction coil design tools to reduce trial and error."

This Roadmap subset initiative has received relatively limited concentrated attention by manufacturers and users of induction heating equipment. This tooling technology has grown from its beginnings that started with primarily fabricated copper tubing construction, which was largely dominated by small tooling fabricators, while many of the major induction heating manufacturers concentrated on developing newer sophisticated power-generation equipment and complex automation equipment. The rapid development of improved tooling and its durability was hampered by the limited access to a true extended-term test bed facility to support evaluation validation of the failure mechanisms.

Induction tooling inductor coils and accessory components are highly application specific, and, therefore, the factors involving the mechanical design and electrical/magnetic effect considerations to meet process specifications and needed durability require an in-depth understanding of induction heating electrical technology, induction heating application engineering, and metallurgical/thermal reactions, as well as a sound understanding of the economics involved in high-volume, high-speed automated handling facilities.

A limited number of the full-service induction heating manufacturers have the required total comprehension of the challenges and recognize that the correct solution lies in applying a structured scientific approach using the latest advances in computerized analytical procedures backed by a sound understanding of the mechanical, physics, electrical, and metallurgical science disciplines to provide the optimum solution for today's industry demands.



Custom induction coil design. Photo courtesy of Ajax TOCCO Magnethermic Corp., Warren, Ohio.

Current computerized mathematical tools (FEA, FDA, and BEM) are still not fully developed to handle of all the interrelated variables in a full three-dimensional (3-D) format. Also, a complete set of materials characterization databases are not fully docu-

Improved Process and Materials Technology Initiatives

Materials and Process Knowledge	Payoff	Risk	Time to implement	Priority
Produce improved induction coil design tools to reduce trial and error.	High	Low	Near	Top
Develop high T (>1010°C, or >1850°F) carburizing steels having grain growth resistance.	High	Low	Near	High
Research implications and feasibility of high-temperature (>1010°C) carburizing, including atmosphere and vacuum carburizing processes, to shorten cycles.	High	Low	Near	High
Develop shorter nitriding processes.	High	Low	Medium	High
Determine phase transformation kinetics during rapid heating to reduce heating time.	High	Medium	Near	High
Develop materials and processes as alternatives to carburizing; e.g., limited hardenability steels and modified quenching processes such as intensive quenching.	High	Medium	Medium	Medium
Develop alternative methods of surface hardening for high-production applications.	High	High	Long	Medium
Improve understanding of tempering/aging processes for induction, magnetic, and furnace processes to reduce variation and processing time.	High	Low	Near	Medium
Develop more effective processes of surface modification.	Low	High	Long	Medium
Determine influence of rare earth elements on microstructure evolution (development) during heat treating.	Medium	Low	Long	Medium
Develop materials and understand the limits of cryogenic processing.	Low	Medium	Near	Low
Develop heat-treating processes for new materials including ferrous and nonferrous alloys, composites, and polymers	Low	High	Medium	Low
Materials Application Knowledge: Software and Models Databases				
Develop software for material selection incorporating a materials properties database in which the user enters desired properties and the output is candidate materials and their required heat treatment.	Low	Medium	Medium	Low
Develop process models that can relate materials characteristics to failure performance in which the user enters application-specific criteria (e.g., wear, forces, corrosion) and the output is a material/microstructure specification. (NOTE: The model should be capable of use in reverse to confirm a failure analysis.)	Low	Medium	Medium	Low
Model Development				
Develop continuous on-heating and on-cooling transformation data for a range of materials, including the effects of variation in steel mill processing, chemistry variation and nonhomogeneous microstructures on transformation kinetics.	High	Low	Near	Top
Develop a database of thermal and mechanical properties from room temperature to heat treat temperature.	High	Low	Long	Top
Develop data correlating heat treatment processing with final properties.	High	Low	Near	Top
Develop model for volumetric strains resulting from transformations during heating and cooling.	High	Medium	Medium	High
Integrate the phase transformation model into a software tool.	High	Low	Near	High
Develop low-cost methods to obtain database data.	High	Medium	Long	High
Develop probes to determine heat transfer characteristics in production. equipment for use with diverse media and components.	High	Medium	Medium	High
Develop industry standards for testing and obtaining data for transformation models, which include heating in furnaces and other media; quenching in oil, water, polymer, salt, air and vacuum; and spray cooling.	High	Low	Medium	High
Develop thermomechanical model with material and atmosphere interactions.	High	High	Medium	High
Link models to process control system for real-time process control.	High	High	Long	High
Develop thermochemical models of atmosphere-material interactions during carburizing, nitriding, and high-temperature carburizing processes.	High	Low	Near	Medium
Develop thermomechanical model for predicting cooling rate, residual stress and properties in components.	High	Low	Near	Medium
Further develop computational fluid dynamics to understand and produce more efficient uniform heat transfer.	Medium	Medium	Medium	Medium

To review all previous articles discussing updates to the Roadmap, visit www.asminternational.org/hts.

mented to support a complete simulation analysis.

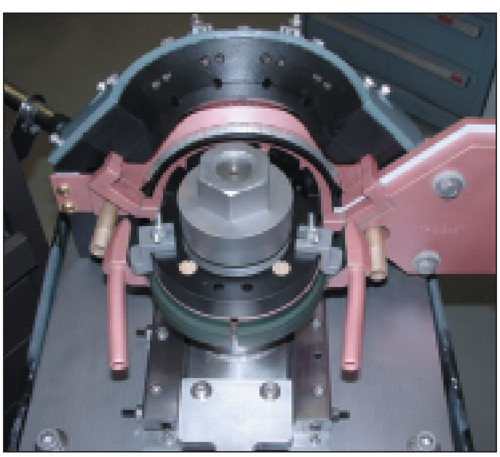
Therefore, induction-heating engineers have developed specialized skills to manipulate the existing formats to suit the specialized conditions of each specific application. There currently are no readily available plug and play fully capable models.

The following techniques provide an understanding of present state of the art that is being used:

• Advanced Application Computerized Math Tools - Computer simulation models optimize induction-coil geometry design to meet a specific thermal profile. This must adequately characterize the dual-phase, magnetic/nonmagnetic phases of both the underlying core structure and surface volume portion together with transition zone plus the respective volume fractions. Such simulation studies produce optimum frequency, power densities, and heat times.

• Equipment Hardware Advances - Major advances have been made in the flexible capability of new solid-state, high-frequency power supplies and precise frequency selection matching/tuning hardware to not only optimize the resulting hardness profile and process productivity, but also to provide processing parameters to reduce interrelated thermal and mechanical stress on the inductor coil itself.

• Inductor Coil Thermal Transfer Operational Improvements - Enhancement of inductor coil durability and life expectancy is directly related to the ability of adequately removing the I^2R heat losses generated by the high-current densities that flow through inductor coils. Therefore, the design, size, and placement of cooling water passages are critical. To obtain full benefit of these considerations requires the latest techniques in heat flux-transfer calculations and cooling-water surface velocities with controlled turbulence. FEA modeling of the electrical current in the coil along with its dynamic shifts during processing must be analyzed to ensure safe operating limits.



Custom induction coil design. Photo courtesy of Ajax TOCCO Magnethermic Corp., Warren, Ohio.

• Mechanically Applied Forces (Lorenz Forces) - The electromagnetic action created by the inductor coil generates a reactive mechanical force between the part and the inductor coil that is inversely proportional to the selected frequency. These can be substantial particularly on higher power applications. There is also a component of the thermally generated mechanical forces within the induction coil that must be given proper consideration in the design of the supporting mechanism applied to the induction coil configuration to provide the necessary rigidity and mechanical position repeatability without having an adverse effect on coil operational durability.

(Previous articles discussing updates to the Roadmap were published in *HTP* Jan./Feb., Mar./April, May/June, July/Aug., and Sept./Oct. 2004), and are available on the ASM Heat Treating Society Web page (www.asminternational.org/hts). Additional articles covering the other Roadmap categories of Equipment & Hardware Technology, Energy & Environment Technology, and Institutional Initiatives will appear in future issues of *HTP*.

Acknowledgement: The writer thanks George Pfaffmann, FASM, Ajax Tocco Magnethermic Corp. for technical input for this article.

For more information:
Richard Houghton is quality manager, Hayes Heat Treating, 800 Wellington Ave., Cranston, RI 02910; tel: 401-467-5201; fax: 401-785-9190; e-mail: rhoughton@hayesheattreating.com.

The HTS Research & Development Committee is working closely with the Center for Heat Treating Excellence (CHTE) located at Worcester Polytechnic Institute (Worcester, Mass.; http://www.wpi.edu/Academics/Research/CHTE) to create a database of heat treating research, which is an excellent way for those conducting heat treating research to catalog their work and make it available for review.

ASM Heat Treating Society R&D Committee

Chairman: Gerard M. Ludtka, FASM, *Oak Ridge National Laboratory*
Vice Chairman: Richard L. Houghton, *Hayes Heat Treating Corp.*
Past Chairman: John E. Morral, FASM, *Ohio State University*

Members:
Robert J. Gaster, *John Deere Technology Center-Moline*
Arthur Griebel, *Climax Research Services*
Michael L. Johnson, *Caterpillar Inc.*
D. Scott MacKenzie, *Houghton International Inc.*
David L. Milam, *Timken Co.*
George D. Pfaffmann, *Ajax Tocco Magnethermic Corp.*
Satyam Suraj Sahay, *Tata Research Centre*
Stephen J. Sikirica, *Gas Technology Institute*
Wallace J. Titus, *Williams Industrial Service Inc.*
James Wade, *Taratec Corp.*
Douglas P. Welling, *Dominion*
Andrew P. Wieczorek, *Rotoflex International*
Daniel H. Herring, *The Herring Group Inc.*
Dan Backman, *Worcester Polytechnic Institute*
Mary A. Wells, *University of British Columbia*
Charles Kuehmann, *QuesTek Innovations LLC*
Lloyd Nelson, *Paulo Products*

Staff Liaisons: Ed Kubel, *ASM International*