UNDERSTANDING NADCAP ACCREDITATION
INDUCTION COUPLED THERMOMAGNETIC PROCESSING
Your Partner for Quality Induction Solutions

At Inductoheat we provide you with proven induction heating solutions that are designed to meet CQI-9 quality standards. We develop and build heavy-duty induction heating, induction forge heating and induction heat treating equipment that incorporates the latest in quality monitoring technology.

Inductoheat proudly serves the automotive, off highway, alternative energy, heavy truck, aerospace, heat-treating and forging industries. Inductoheat’s experienced team of scientists, metallurgists, engineers, application experts and aftermarket representatives stand ready to take the risk out of your buying decision.

Inductoheat, Inc. Madison Heights, MI • 800.624.6297
www.inductoheat.com

Call or click today to learn more about our induction heating systems!
OBTAINING NADCAP ACCREDITATION: HELPFUL GUIDELINES FOR PASSING YOUR AUDIT, PART I

Nathan Durham

Learn how to simplify the process of obtaining Nadcap accreditation for your heat treating facility by paying heed to some of the challenges others have experienced.

INDUCTION COUPLED THERMOMAGNETIC PROCESSING: A DISRUPTIVE TECHNOLOGY

Aquil Ahmad, George Pfaffmann, Gail Ludtka, and Gerard Ludtka

Properties and performance of lower cost, simple alloy steels processed using induction coupled thermomagnetic processing can rival those of conventionally processed, expensive specialty alloys.
The same material can achieve a huge range of properties by exploiting heat treatment. Thus, steel can be made weaker than aluminum or stronger than millimeter-sized graphene or carbon nanotube samples. The properties of metals rely on size, shape, chemical composition, mechanical processing, and thermal treatment. The technologies available for thermal treatments are now astounding in their versatility. It is important therefore for engineers to appreciate some basic principles of heat treatment.

Heat treatment involves the motion of atoms. Because the extent to which atoms can move in the solid state depends exponentially on the inverse of temperature, and linearly with time, it follows that temperature has a much bigger effect than time. So an 80-ms heat treatment of steel at 600°C is about seven orders of magnitude more potent than holding a steel at 200°C for 10 days. On the other hand, very large components cannot be heat treated uniformly in short pulses of time. Thus, designing steel that transforms at low temperatures where the time scales required are long can be a positive advantage.

Concealed within this simple description of time and temperature is variety, because these two independent parameters can be varied suddenly, gently, or in complex combinations to affect the structure and properties of metals. For example, the Flash Bainite of Gary Cola relies on short time scales where the steel is not able to homogenize its carbon concentration even on a microscopic scale so that different regions transform to unexpected microstructures during rapid cooling. In contrast, the same phases require many days to evolve when very large chunks of steel are induced into a uniform nanocrystalline state.

Using fluids to cool metals during heat treatment is another fascinating technology. Red-hot forgings that are 300 tonnes in weight can now be quenched into violently flowing water without generating steam or bubbles of any sort! Likewise, minute regions of metal surfaces can be altered using pulsed lasers.

I hope that in these few words I have been able to convey the excitement of the subject. I recommend the proceedings of IFHTSE 2016, which includes articles that cover the plunging of red-hot swords into slaves and using ionic liquids as quenchants.

Sir Harry Bhadeshia
Tata Steel Professor of Metallurgy
Department of Materials Science & Metallurgy
University of Cambridge
CAI WINS 2016 HTS/BODYCOTE BEST PAPER IN HEAT TREATING AWARD

The winner of the 2016 HTS/Bodycote Best Paper in Heat Treating Award is entitled, “Microstructure Development in AISI 4140 Steels During Tempering,” by Xiaoqing Cai, a Ph.D. student in materials science and engineering at Worcester Polytechnic Institute (WPI). Cai received assistance from her advisor, Richard D. Sisson, FASM. She is currently working on a research project focused on furnace and induction tempering of steel. Cai has published three papers and given four presentations, and she plans to graduate in May 2017.

The award will be presented at WPI’s Center for Heat Treating Excellence in June. The ASM Heat Treating Society established the Best Paper award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or shows a clear advancement in managing the business of heat treating. The award includes a plaque and $2500 prize endowed by Bodycote Thermal Process-North America.

SISSON RECEIVES WPI AWARD

Richard D. Sisson, FASM, received Worcester Polytechnic Institute’s (WPI) 2016 Board of Trustees’ Award for Outstanding Research and Creative Scholarship. The award recognizes continuing excellence in research and scholarship by faculty members over a period of at least five years. Sisson is the George F. Fuller Professor of Mechanical Engineering, director of WPI’s Manufacturing and Materials Engineering Programs, and technical director of the WPI Center for Heat Treating Excellence. He is currently principal investigator for a multimillion-dollar, multi-institution project aimed at developing new metallurgical methods and new lightweight alloys to help the military build more effective and durable vehicles and systems.

HIGHLIGHTS FROM THE 23rd IFHTSE CONGRESS

Contributed by Scott MacKenzie, FASM

The 23rd IFHTSE Congress, held April 18-22 in Savannah, Ga., was very well attended with 20 countries and each continent represented. The conference attracted approximately 171 attendees and 20 exhibitors, and was sponsored by Houghton International and Linde Gas. The first keynote presenter was Prof. H.K.D.H. Bhadeshia, who was awarded the IFHTSE Medal and gave an interesting talk on “Very Short and Very Long Heat Treatments in the Processing of Steel.” It was an excellent presentation, sprinkled with humor, and showed a real connection with the audience. Bhadeshia’s talk was thought provoking and demonstrated some fundamental concepts in a unique manner. The second keynote was presented by Tobias Steiner, past winner of the Linde Tom Bell Young Author Award in Munich (2014). His presentation on “Alloying Element Nitride Development in Ferritic Fe-based Materials upon Nitriding” was intriguing and demonstrated fully why he was chosen for the Tom Bell Award. The final keynote was given by Prof. Dr.-Ing. habil. Rolf Zenker, Zenker Consult Mittweida, on “Surface Treatment by Electron Beam in Combination with Other Heat Treatment Technologies.”

Presentations on quenching, modeling, nitriding, and other advanced thermal processes were held throughout the conference. One interesting paper on extending the life of furnace and fixture alloys by surface engineering was discussed by Anbo Wang of Worcester Polytechnic Institute (student of Prof. Rick Sisson). This paper examined the practical benefits of prolonging the life of expensive, high nickel alloy fixtures.

The winner of the Linde Tom Bell Young Author Award for this Congress was Matteo Villa, Technical University of Denmark, for his talk “The Sub-Zero Celsius Treatment of Stainless Steels: Experiments and Perspective.”

A special symposium on residual stress prediction, control, and measurement was held in conjunction with the IFHTSE Congress. This symposium brought together many aerospace experts, including the USAF Materials Laboratory, Pratt & Whitney, Rolls-Royce, Lockheed Martin, and Boeing, as well as experts from IWT Bremen, including Prof. Hans-Werner Zoch, and others from the automotive industry. It was a very exciting symposium with an excellent idea exchange between very different industries. A great deal of networking was accomplished as well.
A special riverboat cruise on the Savannah River featuring a delicious dinner and perfect weather was a highlight of the conference. This IFHTSE Congress provided many opportunities for fellowship and networking. It was well organized and attendees from all over the globe enjoyed themselves. Special thanks goes to the domestic and international organizing committees, ASM staff including Jeanelle Harden and Lindy Good, and sponsors Houghton International Inc. and Linde Gas for a successful conference.

REGISTRATION NOW OPEN FOR HEAT TREAT MEXICO

The ASM Heat Treating Society will present a new global event, Heat Treat Mexico: Advanced Thermal Processing Technology Conference and Expo, scheduled for September 20-23 at the Fiesta Americana in Queretaro. The conference is designed for maintenance supervisors, metallurgists, and production engineers and will provide a bridge for relevant new technology for thermal processing and how it is applied to the production environment in Mexico. In addition to comprehensive technical programming, exhibitors will have the opportunity, in a classroom environment, to present the implementation of their technologies and products applicable to heat treating. Each presentation will be reviewed for technical merit and will include minimal sales-oriented content. For more information or to register, visit asminternational.org/web/htmexico.

CALL FOR PAPERS NOW OPEN FOR HEAT TREAT 2017

Heat Treat 2017, the biennial co-located show from the ASM Heat Treating Society and the American Gear Manufacturers Association, is now seeking papers. Conference organizers are looking for original, previously unpublished, noncommercial papers for both oral and poster presentations. Technical areas of interest include additive manufacturing, advanced processes, advances in heat treating, applied energy, atmosphere technology, automotive lightweighting, cryogenic treatment, induction heat treating, microstructure development, non-ferrous alloys, quenching and cooling, surface engineering, thermal mechanical processing, vacuum processes and technology, and more. Submit your abstract by December 30 to be considered for the Heat Treat 2017 technical program. For more information, visit asminternational.org/web/heat-treat-2017/cfp.

RESEARCH PROGRESS: NONDESTRUCTIVE MEASUREMENT TECHNIQUES

The Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI) in Massachusetts has spent the past three years working on a research project aimed at measuring surface hardness and case depth on carburized steels for process verification and control. CHTE is an alliance between the industrial sector and university researchers that addresses heat treating needs. The expectation is that project results will enable companies to improve the quality of heat treated products faster and more cost effectively.

According to lead researcher Richard Sisson, Jr., George F. Fuller Professor of Mechanical Engineering at WPI, and CHTE technical director, the heat treating industry needs accurate, rapid, and nondestructive techniques to measure surface hardness and case depth on carburized steels for process verification and control. “Current measurement methods require destructive testing with traveler specimens that cannot always represent the configurations of the production part, nor the associated subtleties of thermal history, carbon atmosphere, and geometry influenced diffusion. Our research will eliminate much of the guesswork,” says Sisson.

Another challenge with the traveler specimen measurement method is that it often requires periodic production part cut-ups to validate the hardness and case depth of parts after carburization, especially for critical shaft and gear teeth configurations. A key issue for researchers is to distinguish between hardness and residual stress, as most techniques currently used to measure case depth are not only sensitive to hardness distribution, but also residual stress.

Lei Zhang (left) and Rick Sisson (right) perform research aimed at measuring surface hardness and case depth on carburized steels.
CHTE UPDATE

**PROJECT STEPS**

The team analyzed several surface hardness and case depth measurement techniques, including eddy current, meandering winding magnetometer (MWM), and alternating current potential drop (ACPD), before concluding that Barkhausen noise testing and ACPD best support the project objectives. (Note: More work needs to be done on ACPD before insights can be shared.) Several widely used alloy steels including AISI 8620/9310/1018/5120 were carburized and fully characterized with destructive testing. Samples were also tempered. The concentration profile, hardness profile, and retained austenite percentage were experimentally determined. The team is now determining correlations among nondestructive test measurements and hardness and microstructure for standards, and then verifying the effectiveness of nondestructive test techniques in industry applications.

**THE PROCESS**

CHTE measured the properties of steel with Barkhausen testing and found a good correlation between surface hardness and the Barkhausen noise result. Magnetic parameter (MP) was measured with the Rollscan 350 unit from American Stress Technologies (AST). Carburized AISI 1018 samples were prepared using the surface removal method. Samples display different surface hardness due to the carbon concentration difference. MP is sensitive to hardness as shown in Fig. 1.

Due to the industry’s need for case depth evaluation, additional testing with Barkhausen noise is being conducted by CHTE, which includes the effects of grain size, tempering condition, and microstructure. Working with AST, researchers used the magnet voltage sweep method for case depth testing. The Rollscan 350 unit can measure the MP by scanning the exiting voltage from 0 to 18 Vpp. Data is collected with software and the maximum slope of the curve is recorded. With measurement from two different frequencies, properties of the sample from different depths can be evaluated. The slope ratio of the two frequencies is then correlated with case depth as presented in Fig 2. Completion of this CHTE research project is expected in December.

For more information: Visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson (sisson@wpi.edu) or Diran Apelian (dapelian@wpi.edu).

**ABOUT CHTE**

The CHTE collaborative is an alliance between the industrial sector and university researchers to address short-term and long-term needs of the heat-treating industry. Membership in CHTE is unique because members have a voice in selecting quality research projects that help them solve today’s business challenges.

Research projects are member driven. Each research project has a focus group comprising members who provide an industrial perspective. Members submit and vote on proposed ideas, and three to four projects are funded yearly. Companies also have the option of funding a sole-sponsored project. In addition, members own royalty-free intellectual property rights to precompetitive research and are trained on all research technology and software updates.

CHTE is located in Worcester, Mass., on WPI’s New England campus. The university was founded 150 years ago this year. For more information about CHTE, its research projects, and member services, visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson at sisson@wpi.edu, or Diran Apelian at dapelian@wpi.edu.
Heat treatment is a critical part of the manufacturing process for a wide range of products, such as those used in consumer goods, power generation, automobiles, aerospace, and many others. The quality and safety of heat treated products is of utmost importance to both the companies that produce them and consumers. Maintaining global quality standards in heat treating not only helps ensure the highest quality of components used in aerospace applications, but also helps heat treaters continually improve and refine their processes to provide the best product quality for all applications. Aerospace Material Specification (AMS) standards and Nadcap (National Aerospace and Defense Contractors Accreditation Program) play key roles in ensuring that manufacturers performing heat treating and other special processes adhere to consistent, high-quality standards for producing aerospace products.

A series of articles, beginning with this one, will discuss questions and challenges that can arise about the Nadcap accreditation process, specifications involved, and other process considerations. Recommended best practices and steps from those who have undergone Nadcap accreditation are presented to help simplify the process, including:

- Tips on preparing for internal and official Nadcap audits, including networking with other suppliers and establishing an approved quality system.
- Where to locate key documents and specifications that help you prepare for the audit process.
- Review of common nonconformances (NCR) to better understand certain specifications and requirements.

While every heat treater’s Nadcap audit is unique (depending on processes, types of equipment, and specific customer specifications), a Nadcap accreditation process typically involves:

- Requesting and scheduling an audit
- Performing an internal audit
- Implementing corrective actions for findings from the internal audit
- Undergoing an official audit
- Reviewing and responding to NCR findings
- Applying corrective actions to resolve remaining issues
- Receiving Nadcap accreditation
- Whether participating in a Nadcap audit for the first time, or going through the reaccreditation process, many companies continually refine their audit process based on NCRs found during the internal and official audit.

**PREPARING FOR AN AUDIT**

The Nadcap audit process is lengthy and complex, but those who adequately prepare are able to make it through this endeavor without difficulty. Often, the biggest challenge is knowing where to start. Considering the following preparatory actions will help:

*Locating key documents and specifications.* To prepare for a quality audit, the first step is to know which documents

Overview of the typical Nadcap accreditation process, which often depends on specific primary contractor specifications, processes, equipment, and more. Courtesy of Ipsen.
During the process segment of the Nadcap audit, the auditor will spend a significant portion of time reviewing specification checklists and both historical and live jobs. Courtesy of Ipsen.

Sources commonly referenced during the audit process include the Heat Treating Task Group Audit Handbook and the Heat Treating Task Group Pyrometry Reference Guide. These materials provide useful information, including:

- Definitions
- Supplier guidelines for auditing to Nadcap audit criteria
- General heat treatment items (e.g., testing and inspection details, vacuum considerations)

Overall, the handbook and reference guide offer guidelines to help better understand and meet items listed on the audit checklist.

Audit checklists and customer requirements. Nadcap accreditation is available for a range of programs such as coatings, fasteners, heat treating, and materials testing laboratories. In the case of a Nadcap audit for heat treating, basic audit checklists that apply to all disciplines within the heat-treating category include:

- AC7102 Revision H – Nadcap Audit Criteria for Heat Treating
- AC7102/8 – Nadcap Audit Criteria for Heat Treating Pyrometry
- AC7102/S Revision F – Nadcap Supplemental Audit Criteria for Heat Treating

Additional checklists could apply depending on the specific process for which the company is seeking accreditation. A complete list of checklists for the heat-treating category can be found on eAuditNet.

Supplemental checklist AC7102/S provides additional requirements for companies seeking accreditation by specific aerospace primary contractors (primes). Primes are companies that take on the total responsibility for any given project and typically build the major elements of a product in their own plants (e.g., Boeing, UTC, Snecma). However, they often subcontract to other companies for various required parts and systems. Therefore, it is essential to be familiar with both common industry standards and the customer's requirements and specifications before moving forward in the audit process. It is also very important to be familiar with and adhere to these documents, as they are the standards by which the company will be audited.

Consulting and networking with suppliers. In addition to becoming familiar with key documents and specifications, consulting and networking with other suppliers (companies that process components used by primes, calibration labs, furnace manufacturers) helps identify additional best practices to prepare for an audit. PRI holds three annual meetings that provide an opportunity to discuss audit experiences of other companies. These meetings also allow suppliers to discuss industry requirements directly with primes and gain clarification on checklist items. Notes from these meetings include information on what was discussed and conclusions on how to best handle certain issues and/or specifications; they can be reviewed on the eAuditNet website.

Discussions with other quality managers about their Nadcap audit experiences provide different points of view and help companies gain a better understanding of certain specifications. In addition, open discussions about best practices and recommended methods help companies better regulate themselves and ensure they consistently adhere to a global quality standard.

SCHEDULING A NADCAP AUDIT

Once a company reviews and understands the applicable checklists, reference materials, and customer requirements, and is confident they are fully prepared to perform an internal audit, it is time to schedule the official Nadcap audit through the eAuditNet website. It is important to know the answers to a few important questions before this step, including:

Q. Will you have either real parts for an aerospace customer, or have time to run sample aerospace parts during the scheduled audit?
A. It is recommended that you inform PRI in advance if you will be using sample aerospace parts.

Q. Do you know the scope of accreditation (i.e., processes and specifications) for which you want to be audited?
A. It is important to know the scope of accreditation beforehand, as you will be required to define the scope when scheduling the audit, as well as verify it at the beginning of the official audit.

Q. Do you already have quality system approval (e.g., AS/EN/JISQ 9100 and AS/EN 9110; ISO/IEC 17025)?
A. If you do not have an acceptable quality system approval, a standard audit process adds AC7004 (Aerospace Quality Systems) to the scope of accreditation. In this case, Nadcap auditors include a one-day quality system audit as part of the official audit process to verify that you adhere to this specification. If you already have acceptable quality system approval, you must provide evidence of such when scheduling, or at the start of the official audit. If you are unable to provide documentation, the auditor performs the quality system audit.

Q. Is there sufficient time between scheduling the audit and when the audit takes place to prepare for and perform an internal audit?
A. The accreditation process requires an internal audit (a form of self-assessment used to measure strengths and weaknesses against Nadcap audit requirements[1]) with results submitted at least 30 days prior to the official audit. However, it is recommended that the internal audit is conducted from three to six months prior to the official Nadcap audit. It is also important to factor in sufficient time to not only prepare for and conduct the internal audit, but to also identify the ultimate root cause and implement a corrective action for each NCR.

CONCLUSION
These are just a few helpful guidelines to consider before and during scheduling of an official audit. While this is just the initial step on the road to accreditation, the more prepared you are from the very beginning, the more successful you will be once the process is underway. Subsequent articles in this series will discuss details regarding the internal audit process, common NCRs, the official audit process, and auditor interactions.

Reference

For more information: Nathan Durham is an electrical solutions manager. For technical information, contact technical@ipsenusa.com or 844.464.7736 (select 1), Ipsen USA, 984 Ipsen Rd., Cherry Valley, IL 61016, ipsenusa.com.
INDUCTION COUPLED THERMOMAGNETIC PROCESSING: A DISRUPTIVE TECHNOLOGY

Properties and performance of lower cost “simple” alloy steels processed using induction coupled thermomagnetic processing can rival those of conventionally processed, expensive specialty alloys.

Aquil Ahmad,* (retired), Eaton Corp., Cleveland; George Pfaffmann, FASM,† Ajax Tocco Magnethermic, Madison Heights, Mich.; Gail Ludtka* (retired) and Gerard Ludtka, FASM,* Oak Ridge National Laboratory, Tenn.

One of the major goals of the U.S. Department of Energy (DoE) is to achieve energy savings with a corresponding reduction in the carbon footprint. With this in mind, the DoE sponsored the Induction Coupled Thermomagnetic Processing (ITMP) project with major partners Eaton Corp., Ajax Tocco Magnethermic, and Oak Ridge National Laboratory (ORNL) to evaluate the viability of processing metals in a strong magnetic field. Processing materials in such a manner is a novel, game changing concept[1]. Applying a strong magnetic field with controlled-frequency induction heat treatment to metals results in properties not achievable using conventional processing techniques. The magnetic field produces a change in thermodynamics that alters conventional phase diagrams resulting in new phase equilibria and solute solubilities. This provides opportunities to develop alloys with novel microstructures and improved physical and mechanical properties. In addition, phase transformation kinetics, especially for tempering, are dramatically accelerated. This results in improved processing efficiency and refined microstructural features, such as finer martensite-lath populations and large amounts of finer carbides after tempering.

The use of a coupled induction heat treatment with high magnetic field heat treatment enables the development of metals with improved performance using faster processing times and less energy. The technology allows substituting lower cost alloys for more expensive alloys[2] while achieving greater combinations of strength and ductility. In addition, microstructures can be tailored for improved magnetic properties, wear resistance, and mechanical performance. Processing lower cost, simple alloy steels under a strong magnetic field achieves properties comparable to those achieved in highly alloyed steels processed using conventional techniques. In addition, the enhanced strength and toughness in ITMP materials improves power density in a significant number of industrial mechanical components.

This article discusses some of the demonstrated improved mechanical properties achieved for steels in the ITMP project. The technology can also be applied to forging operations resulting in lower temperature formability, thus reducing energy consumption while improving mechanical properties. These results would be beneficial in components such as gears, shafts, net-shape forged valves, and forging dies. The technology is also applicable to non-ferrous alloys. For example, ITMP reduces solution heat treating and aging times by 80% for precipitation hardening aluminum alloys.

MAGNETIC PROCESSING DEFINED

Earth’s magnetic field is 60 micro-tesla (µT) at the surface. By comparison, the industrial prototype superconducting magnet system at ORNL is capable of 9 T, 150,000 stronger than the earth’s magnetic field. Application of a 9-T magnetic field in heat treat processing achieves properties in low cost alloy steels that rival properties achieved in more expensive higher alloy steels. Figure 1 shows the potential for improvement in steel performance versus cost per pound. The trend line indicates that the potential of thermomagnetic technology is unlimited.

BENEFITS OF ITMP

A strong magnetic field significantly affects the iron-iron carbide (Fe-Fe₃C) phase diagram, as well as the kinetic behaviors of continuous cooling and isothermal transformation. Benefits of ITMP include:

- Accelerated transformation kinetics
- Refined microstructure
- Fine carbide dispersion
- Minimum grain boundary segregation
- Mitigation of segregation banding
- Reduced volume fraction of retained austenite
- Improved mechanical properties including tensile and yield strengths, and ductility (elongation and reduction in area)

Rotating beam bending fatigue was evaluated using R.R. Moore type test equipment according to ASTM E466 “Standard Practice for Conducting Force Controlled Con-

*Member of ASM International; George Pfaffmann is recently deceased.
stant Amplitude Axial Fatigue Tests of Metallic Materials."

Figure 2 shows an improvement of 6.4 times for ITMP samples over baseline carburized samples at a stress of 150 ksi (sample size: 6 in. long with 2 in. taper section; 0.75 in. diam.; 0.375 in. minor diam.).

Evaluation of reverse torsion fatigue in torsion shafts was not completed due to incompatibility of sample size and processing equipment. With the availability of a new industrial prototype thermomagnetic processing facility (Fig. 3), further studies were conducted on gear tooth bending fatigue.

**Reverse idler gear single-tooth fatigue.** Gears were processed in an 8-in. diameter superconducting magnet system incorporating a 10-30 kHz, 200-kW induction heating power supply with an integral 75 gpm polymer quench capability. Heat treated gears were shot peened to the same parameters as baseline gears. The goal was to improve single tooth bending fatigue by 200%. Technical challenges included developing a fine microstructure-scale understanding of ITMP and performing finite element analysis (FEA) and modeling calculations.

The first of two sets of experimental runs fell short of expectations and processing time and temperature parameters were revised for the second series of experiments. The new parameters for rapid heat up and hold time at temperature were based on Ajax Tocco calculations for achieving appropriate solid solution of carbon in the austenite phase, determined from results of joint research by Colorado School of Mines, ORNL, and Torrington[1]. FEA work was conducted such that the targeted carbon content in austenite before rapid quenching was achieved in the gear root without overheating the gear tip. (Note: Hot root, cool tip, and cold core.)

Single-tooth bending-fatigue test results for the second batch of gears showed an improvement of 2.5 to 5 times that of baseline gears (Fig. 4). Probability analysis clearly demonstrates the mean shift in the curve for 202 ksi and 215 ksi. Results are as follows:

<table>
<thead>
<tr>
<th>Stress level, ksi</th>
<th>Mean cycles Baseline</th>
<th>Mean cycles ITMP</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>174</td>
<td>70,751</td>
<td>360,658</td>
<td>5.1x</td>
</tr>
<tr>
<td>202</td>
<td>23,822</td>
<td>75,626</td>
<td>3.17x</td>
</tr>
<tr>
<td>215</td>
<td>16,344</td>
<td>40,950</td>
<td>2.5x</td>
</tr>
</tbody>
</table>

Hardness and case depth of ITMP and as-carburized gears are comparable. ITMP dramatically accelerates the tempering process resulting in significant energy efficiency improvements, as well as reducing the carbon footprint. For example, tempering as-carburized gears at 350°F via ITMP required only 10 minutes compared with two hours using conventional processing.

ITMP gears have a refined microstructure with a fine dispersion of carbides and negligible segregation at the grain boundaries compared with the microstructure of baseline gears (Fig. 5). The thermodynamic effect of the strong magnetic field raises the martensite start temperature ($M_s$), resulting in a reduced volume of retained austenite. Induction hardening alone does not have this fundamental driving force. The lower volume percent of retained austenite and fine dispersion of carbides compared with the baseline microstructure leads to improved properties plus higher wear resistance.

**CONCLUSIONS**

- ITMP modified processing parameters on the reverse idler gears demonstrated major improvement in fatigue life (~3x) at very high stress levels.
- Tempering parts for 10 minutes in a magnetic field provides improved fatigue life properties compared with the conventional tempering for two hours at 350°F.
Fig. 3 — ORNL industrial prototype magnetic processing equipment includes 8-in. diam. vertical warm-bore superconducting magnet system and Ajax Tocco Magnethermic 200-kW dual-frequency induction heating system with 75-gpm polymer-water quench.

Fig. 4 — Improvement in single-tooth bending fatigue life of ITMP gears over baseline properties.

Acknowledgment

This report is based on research supported by the U.S. DOE under Award No. DE-FG36-08GO18131 with Eaton Corp. as the primary lead, using the Thermomagnetic Processing Facilities at ORNL, supported by the Office of Energy Efficiency and Renewable Energy.

This manuscript has been authored by UT-Battelle LLC under Contract No. DE-AC05-00OR22725 with the DOE. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for Government purposes. The DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (energy.gov/downloads/doe-public-access-plan).

References


For more information: Aquil Ahmad is retired from Eaton Corp., Cleveland. He can be reached at ahmadaquil@sbcglobal.net.

From a sustainability perspective, an 85% reduction in energy use is estimated when using ITMP versus conventional processing for the gears.

As presented in Fig. 1, low cost steels can rival exotic costly alloys in properties and performance when using ITMP.
Imagine a tool that allows you to anticipate disruption. A tool that gives you the power to optimize equipment performance and production efficiency. A tool that connects your team to critical information they need to make your business more agile, more competitive.

That's the power of the PdMetrics™ software platform for predictive maintenance.

Watch the video:
scan the QR code or visit www.IpsenUSA.com/PdMetrics