Heat Treating Challenges for the Future

Where the industry should go from here.

Dr. A. H. Soni

The heat treating of gears presents a difficult challenge to both the heat treater and the gear manufacturer. The number and variety of variables involved in the manufacturing process itself and the subsequent heat treating cycle create a complex matrix of factors which need to be controlled in order to produce a quality product. A heat treater specializing in gears or a gear manufacturer doing his own heat treating must have a clear understanding of these issues in order to deliver a quality product and make a profit at the same time. The situation also presents a number of areas that could benefit greatly from continued research and development.

Critical Issues in Gear Heat Treating

Materials and Fabrication Methods. Materials, their chemical compositions and variations from one supplier to another present many challenges to the heat treater of gears. Complicating the issue is the specific gear geometry that must be retained after the heat treating process. The gear geometry parameters, such as number of teeth, involute profile, pressure angle and pitch diameter, are of critical importance, as are geometric alterations to them caused by heat treating.

Gears are fabricated a number of different ways, including hobbing, casting, forging, and powder forming. Heat treating process specifications must also consider the influence of these fabrication processes.

These heat treating issues may be resolved at the gear fabrication stage by cooperation between the gear designer and the heat treater in developing an SPC strategy. Using available predictive models, gear geometry may be purposely altered to account for part distortion after quenching. A controlled quenching process will compensate for such a predetermined alteration in the gear geometry, and the gears will then need few geometrical corrections. Processes such as die quenching should be avoided, for they set up unwarranted residual stresses. Again, a suitable application of control technology to rapid cooling may help obtain the desired result.

Hardening Methods. The heat treater must also address the question of whether the gears are to be surface- or bulk-hardened. Either induction or flame hardening can be used, although induction hardening is the preferred method for gears.

Another surface hardening method is the surface carbon-diffusion carburizing process. Gas carburizing of gear tooth surfaces to achieve the desired carbon content and the corresponding surface hardness is a more commonly accepted process for low-carbon or alloy steels.

Alternatives to surface carburizing are carbonitriding and nitriding. Since nitriding is done at a lower temperature than carburizing, gear distortion is not as severe.

Furnace Atmospheres. Controlling the furnace atmosphere for surface carburizing or nitriding is a critical issue in achieving the desired carbon or nitrogen surface penetration depth. For carburizing, the carbon depth is significant. In nitriding, the surface depth is only skin deep to achieve the desired wear properties. Both of these processes are associated with dimensional changes.

Furnace behavior and atmospheres in the furnaces may be controlled using expert systems, neural nets

This is the first of a series of articles on the future of various technologies that will influence gear design and manufacturing practice in the coming years. We will be bringing you the opinions of industry leaders, scholars and experts in these disciplines.

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and fuzzy logic integrated controllers. These tools address both the universal and local variables that dictate the quality of heat treated gears. The fuzzy logic controller is able to control the case depth very precisely, while maintaining a controlled furnace atmosphere. Also, since the fuzzy logic controller is able to track the energy input to the furnace, it can deliver carburized gears with optimum energy and cost savings.

These advances in computers and computer-integrated controls make it feasible for heat treaters to adopt such advanced technology. However, the U.S. heat treating industry is lagging behind in its application, which is much more common in Germany and Japan.

Quenching. Gear tooth hardness is achieved through a controlled cooling process called quenching. Quenching involves heating a gear to a desired temperature and cooling it at a rapid rate to achieve desired hardness. While the principles of the quenching process may be known with some degree of reliability, the actual practice in a heat treating shop is a closely guarded mystery.

The rate of cooling is dependent upon the type of quenchant, number of stages involved, agitation rate of the quenchant, gear location and orientation in the quench tank and quench contamination and degradation. The process has too many variables to control and produce uniformly consistent quality results for gear heat treating.

Unfortunately, heat treaters have learned to live with part distortion. Instead of developing a process control strategy, they have spent their resources, expensive equipment and technical talents straightening distorted parts. According to some estimates, the U.S. auto industry spends millions of dollars a year solving problems created during quenching.

Stress Relieving. Stress relieving quenched gears is normal practice in the industry. Controlling the stress pattern within the gear tooth and understanding the microstructures and grain size during heat treating is another matter. The role of the microstructures, grain size and residual stress distribution within heat treated gears is generally well understood by heat treaters; however, not much importance is given to these variables in practice. User-friendly technology to analyze the influence of these variables is much needed.

THE U.S. HEAT TREATING INDUSTRY IS LAGGING BEHIND IN THE APPLICATION OF ADVANCED TECHNOLOGY TO ITS PROCESSES.

Equipment. Heat treating equipment plays a significant role in developing heat treat processes and heat treat specifications for gears. Since the processes are dependent on the equipment, the technology is vendor-driven. Most commercial heat treat shops

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are limited in their resources; hence, they are unable to keep up with the capital investment required for implementation of new processes.

U.S. heat treaters eventually will have to face this fact and develop their own technology instead of depending upon the vendors, but this creates an additional burden on them. A reasonable solution is to develop a joint collaborative effort among the material suppliers, equipment vendors, process controllers and heat treaters to serve their clients. Professional groups such as the ASM Heat Treating Society are in an ideal position to serve this purpose.

Standards. Many heat treatment standards are available today, but with ever-increasing international competition, pressure is on heat treaters to learn to comply with ISO standards and practices. Accepting the ISO as a universal standard is a way to establish common ground for heat treaters to understand their client needs. The existing heat treatment standards will become the backbone of the ISO standards. Such integration of standards will create a win/win situation. Not only will everyone be speaking the same language, but when disputes about processing and legal liability arise, a heat treater would have the commonly accepted ISO standard to back him up.

In the meantime, the University of Cincinnati Center for Industrial Heat Treating Processes has a database-integrated expert system for PCs that permits a user to search for suitable heat treatment standards for a wide variety of materials. These standards (all in English) are from the U.S., Japan, France, Italy, Germany and other countries. Given a material designation or composition, one may search these standards and compare the differences in the various specifications.

Present environmental standards for the industry are another cause for concern. They are very restrictive. In some cases, meeting these standards can put a heat treater out of business. Some kind of common ground will have to be developed to allow heat treaters a reasonable profit margin while still protecting the environment.

Training. Training of personnel to keep up with technical advances is a critical issue for the captive and commercial heat treaters. Most educational organizations do not offer a practice-oriented education training program on heat treating. The practice in industry is labor-intensive and still relies very heavily on local experience. This is another area in which much work needs to be done.

MEETING PRESENT RESTRICTIVE ENVIRONMENTAL STANDARDS CAN PUT A HEAT TREATER OUT OF BUSINESS. SOME COMMON GROUND WILL HAVE TO BE ESTABLISHED TO ALLOW HEAT TREATERS A REASONABLE PROFIT WHILE STILL PROTECTING THE ENVIRONMENT.

Advances in Heat Treating Science, Technology and Its Practice

We have briefly discussed the issues which influence the way heat treating is done today. How the industry addresses these issues will determine what the industry will look like in the future.

New technology and approaches are now available for the heat treating industry if it will only take advantage of them. They include:

• Process development and its control,

• Networking to share common resources and problems,

• Material handling to bring automation to the captive heat treating auto industry,

• Development of production schedules to reduce cycle times,

• Implementation of real-time process control,

• Training of personnel to learn and implement new heat treating technology.

Because of a large number of variables that affect the outcome of heat treated gears, heat treaters should develop their own process control strategies to deliver quality in their work. While the typical methodologies remain the same in developing such process control strategies, the approach has to be individualized by each heat treating enterprise. The Taguchi method to identify the significantly contributing parameters, statistical process control, quality control, PID control and fuzzy-logic-based control are some of the technologies that one may apply, depending upon the process and the required degree of control.

Networking of heat treaters, equipment vendors and material suppliers is an alternate approach to gaining the knowledge needed to develop a process control. The ASM Heat Treating Society, Ohio's Heat Treat Network, the Metal Treating Institute and the University of Cincinnati's Heat Treating Research Center, among others, provide avenues for heat treaters and the users of their services to link up.

Material handling is a key to automation and is very much needed in the heat treating industry. Because of smaller batch sizes and part and material variation, heat treaters should look into developing flexible heat treating work cells. Adaptation of such new technology will significantly improve serviceability, productivity and profit.

With a suitable development of flexible heat treating work cells, a heat treater is in an ideal position to develop a production schedule and optimize his resources to give the best turnaround.

Real time process control is needed in gas carburizing, nitriding and quenching. However, much work remains to be done in this area beyond integrating the sensors in the furnaces to control the furnace atmosphere.

Training of the personnel is a key to developing a quality heat treating process. However, because of the limited number of resources available to the heat treaters and to the educational institutions, this issue has not been addressed at a satisfactory level. Plenty of room for progress remains.

New Materials and Processes

New materials that will provide some challenges to gear heat treating industries are the composite materials. Metal matrix composites in particular are expected to change the way we will fabricate gears with a desired degree of hardness and other mechanical properties.

The nitriding process has gained significant acceptance in the heat treating industry. With some modification, it may replace the popular gas carburizing process, which is very time-consuming, costly and creates severe metallurgical problems. The induction hardening process may get replaced by a patented gas heat treating process under development that is as fast as induction heating. Since the heating cost is considerably less in this process, the fast heating gas furnaces show promise for the industry. Much development is needed, however, before this fast-heating gas fired furnace's integrated process is commercialized.

Cutting Edge in Heat Treating Research

Some of the important issues that need to be addressed now include:

- An affordable, user-friendly computer simulation model for predicting gear distortion as a result.
- An affordable, user-friendly computer simulation model for predicting residual stresses in heat treated gears.
- An affordable, user-friendly computer model for the quenching process to achieve the desired hardness and microstructures.
- Real-time process control methodology for heat treaters.
- Design and implementation of flexible gear heat treating systems.

Using the finite element technique, The Center for Industrial Heat Treating Processes has developed models for predicting part distortion and residual stresses in gears that are made from plain carbon and alloy steels. The Marathon Monitor has developed a model for the gas carburizing process. The National Center for Manufacturing Science (NCMS) through its CRADA agreement with the national government laboratories is developing a quenching model for heat treating processes.

While a significant amount of new technology is being developed and may be available to the user, the industry is still pursuing a pragmatic, best-compromise approach to delivering the quality heat treating service. The ideal of a 100% guaranteed, completely controllable and predictable process that is affordable for the customer and profitable for the provider is still a long way away. ○

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