

HEAT TREATING IN 2020: WHAT ARE THE MOST CRITICAL ISSUES AND WHAT WILL THE FUTURE LOOK LIKE?

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ABSTRACT

Heat treating is an enormously important industrial technology which is often ignored and, in many cases, continues to be poorly understood. In nearly every survey taken to get a better insight into problems of greatest concern to the heat treatment industry, the following topics are often identified as the most important and of greatest interest:

1. Distortion and quality control
2. Energy costs
3. Implementation of modeling and simulation technologies
4. Problems with quenchant selection and use
5. Others

It is generally understood if these and related issues are not successfully dealt with, the ability of this vital industry to support industrial growth and improvement will be in serious trouble! However, there are a number of high-level and visible national research thrusts in progress to support this ailing industry. The objective of this lecture is to provide an overview of the various needs of the heat treating industry and to provide a vision of the future of this essential industry as it may exist in the year 2020.

INTRODUCTION

In the USA alone, heat treating is a \$US 15-20 billion a year business. It is a critical manufacturing technology in nearly every industrial market sector including: automotive, off-highway, railway, aerospace and others. In the USA, like many other industrialized countries, the heat treating market is composed of two primary sectors; captive (approximately 90%) and commercial (approximately 10%) [1]. In recent years, the commercial heat treating industry has seen slow growth as many captive industries downsize and sub-contract their heat treating business to commercial shops.

The heat treating industry is also a capital-intensive since it involves the use of specialized equipment requiring major capital investment. In addition, there are major operating costs since it is an energy-intensive industry. In view of these costs, it is understandable that heat treating may be a major fraction of the overall production costs of many components. Therefore, heat treating is a significant factor in the competitiveness and profitability of the manufacturing industry and to remain competitive in a global market environment, there are many technology areas where substantial innovations are required.

Recently, the Heat Treating Society of ASM International has developed a proposed research plan to address three primary technology needs that were identified by their membership which include [2]:

1. Heat Treating Equipment and Hardware Materials
 - Achieve zero emissions
 - Reduce process times by 50%
 - Reduce production costs by 75%
 - Increase furnace life 10 fold
 - Reduce the price of furnaces by 50%
2. Energy and the Environment.
 - Reduce energy consumption by 80%
 - Improve insulation (half needed for twice the capability)
3. Processes and Heat Treated Materials Technology Needs
 - Reduce process times by 50%
 - Reduce production costs by 75%
 - Achieve zero distortion and maximum uniformity in heat treated parts

Interestingly, the research focus is very similar to that established by Japan [3], Sweden [4] and Australia [5].

The primary focus of this lecture will be to discuss selected items in the ASM R&D Plan and to integrate many of these proposed technology thrusts with those that have been identified as critical technologies in other countries in Asia and Europe.

DISCUSSION

1. Heat Treating Equipment and Hardware Materials

Some of the needs that have been identified in this area. Selected examples will be briefly discussed.

Accelerated Heating – Rapid heating is defined as “any heating method that accelerates conventional furnace heating” [6]. Heat transfer rates of up to thirty (30) times those achieved in conventional convection furnaces are possible [7]. In the past rapid heating technology has been applied primarily to the forging industry where steel is heated to 1000 – 1250°C (1830 – 2280°F) and it is much less commonly encountered in the heat treating industry and is a targeted area of research in the ASM R&D Plan [2].

Real-Time Process Sensors – An area of continuing concern to the heat treating community is the development and availability of heat treating process sensors. Some of the more important which were identified in the ASM survey were [11]:

- Development of real-time case-carbon sensors
- Oxygen probes with improved resistance to carbon deposits (sooting)
- Development of real-time quenching sensors that provide process control by quantifying heat transfer.
- Development of sensors that provide system control with multiple chemical and physical property inputs.
- Development of algorithms to quantitatively integrate system inputs.
- Method to accurately, non-destructively and economically measure residual stress after heat treating.

Other Research Areas – Additional targeted research areas include [2]: nitriding process developments to reduce processing times, development of heat treatment processes that utilize lower cost alloys, development of significantly improved refractory materials, development of improved materials for higher operating temperatures, and increased understanding of the aging and tempering processes.

2. Energy and the Environment

The Center for Heat Treating Excellence (located at the Worcester Polytechnic Institute) has reported that the US Department of Energy (DOE) has invited the heat treating representative to join the IOF (Industries of the Future) initiative along with the aluminum, steel and metalworking industries. In addition to being a \$US 15-20 billion industry, it is an energy-intensive industry that consumes approximately 500 trillion BTU's per year which represents approximately 20% of the annual cost business cost [13].

Process Integration - One example of process integration that potentially may result in enormous energy savings is **Direct Forge Hardening** (also known as **Direct Forge Quenching** – DFQ) [9,10]. Various steels have been developed for direct heat treatment after forming or rolling which have provided substantial improvements in process efficiency, reduction in energy costs and improved properties. DFH that have been used for automotive part production include [9]:

- Quenching directly into water or aqueous polymer quenchant solutions (or oils) after hot forging.
- Direct cooling after forging in forced air which is optimized to yield the desired microstructure (Ferrite + Pearlite or Bainite).
- Use of microalloyed steels for crankshaft production to refine microstructure and strengthen ferrite.

This technology is widely used in Asia but rarely used at the present time in North and South America.

Another example of process integration of foundry and heat treatment processes has recently been demonstrated by the placement of aluminum castings directly into the heat treatment furnace where three processes are combined: de-coring and sand removal, thermal sand reclamation and heat treatment [8]. Sand is collected in a “hopper-type” furnace bottom and is then thoroughly cleaned for reuse. This results in substantial

energy savings compared to reheating of the castings after solidification. In addition, the same furnace can be used for sand reclamation. Similar processes have been developed using fluidized bed furnaces [8]. Interestingly, quenching processes have also been integrated with the foundry/heat treatment process resulting in even greater savings [8].

Additional R&D needs to reduce energy reduction in the heat treating shop that we identified by ASM were [11]:

- Development of high heat transfer rate heating and cooling systems,
- Development of low-cost heat recovery and low-temperature heat utilization,
- Develop hybrid natural gas/electric heating systems to minimize energy cost.

To reduce environmental impact, the ASM R&D plan recommended [2,11]:

- Develop pollution prevention/control technologies,
- Develop alternatives to quench oil,
- Develop alternatives to NO_3 , NO_2 , CN and barium salts and solvent cleaners.

Recently, Ogino has provided an excellent integrated overview of all aspects of heat treating process technologies on both energy utilization and the environment as it related to automotive production [12].

An example of the development of an alternative technology that provides dramatic energy reduction and reduces environmental impact is intensive quenching [15]. Intensive quenching (IQ) refers to the process of quenching steel to provide MAXIMUM surface compressive stresses. IQ can be an alternative to, or used in conjunction with, either induction hardening or carburizing. When used to replace carburizing, the use of furnace gases and long diffusion times are avoided. Furthermore, the quenchant is typically water or a brine solution instead of quench oils which are commonly used.

Recently the Sandia National Laboratory has reported that the use of induction heating/hardening process, if properly designed, may provide up to 95% energy savings over furnace heating/hardening. To further capitalize on these enormous potential process and energy cost savings, a team has been formed to: 1. develop rigorous computational process models, 2. develop science-based sensors and closed-loop control algorithms applicable to a broad range of steels, processes, and geometries and 3. to utilize the data from (1) and (2) to develop components with optimal strength-to-weight ratios [14].

3. Processes and Heat Treated Materials Technology Needs

High Temperature Carburizing - High temperature carburizing is typically conducted at $>1850^\circ$ ($>1010^\circ\text{C}$) and it affords the possible reduction of carburizing cycle times. This is technology that is practiced in Japan and relatively rarely in the USA. Currently, there are a number of active research programs in this area. One program is underway at Northwestern University to develop a new computational materials design approach to integrate process and material optimization for fast high-temperature ($>1010^\circ\text{C}$) carburizing (which resists grain coarsening) and the creation of a new class of thermally stable case-hardened, ultra-durable tool and die steels with broad applications in

manufacturing processes. The target of this research is to reduce cycle times by 50% or more.

Process Modeling – ASM, and others, has identified the development of process modeling and numerical simulation as a critical core technology for the advancement of the heat treating process industry [16]. The ASM R&D plan has recommended the development of [2,11]:

- Microstructure response models based on alloy composition, atmosphere, temperature and time.
- Understanding of the thermochemical boundary conditions in furnaces.
- Models for the continuous cooling (CCT) and continuous heating (CHT) transformations in heat treatable steels.
- A database of thermal and mechanical properties up to and including heat treating temperatures.
- Models to predict residual stress and distortion profiles.
- User-friendly software for material and process selection that includes heat treating methods.
- Quenching property databases and empirical relationships for quenchant selection and performance prediction.
- Electromagnetic (E-M) models for 3-D analysis and databases for quantitative material selection.
- Mechanical models including: stress-strain databases and transformation plasticity data.

A general review of the current status of thermal process modeling was recently published that concluded that models such as those listed above provides the heat treating process engineer and designer with an invaluable tool for examination of important process parameters and their impact on the overall heat treating process. Excellent results have been obtained this far for relatively simple shapes for analysis of quenching, carburizing, induction heat treating and other processes [16]. However, before these models can be applied to more complex shapes, such as many production components, a database of high-temperature material properties must be available [3]. In addition, reliable heat transfer coefficients must be generated and boundary conditions identified. This will be the focus of heat treating process modeling in the near future.

New Materials – This is a very broad area and is outlined in some detail in Reference 2. A brief summary of research topics are identified here:

- Development of steels for carburization at high temperatures.
- Development of new steels for induction that permit even faster processing times.
- Development of structure-property relationships
- Development of quantitative data relating to the machinability and formability.
- Development of materials that are suitable for rapid heating technologies.

CONCLUSIONS

Based on this very brief and generalized review, it is clear that there is a great deal of work to be done if these goals are to be implemented by the year 2020. To achieve these

goals will require team building and leveraging of technical expertise nationally and the probability of success will be exponentially greater if increased international alliances can be formed to leverage the effort required to solve these challenging problems through collaboration. Currently, IFHTSE (International Federation for Heat Treatment and Surface Engineering), of which ABM is a member, is focusing its effort on foster key collaborations to facilitate the leveraging of work internationally that will be required if these goals are to be uniformly achieved by 2020.

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