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Through-Process Temperature Profiling for Heat-Treat Efficiency

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Fig. 2. Thru-process temperature-profiling system entering a gas carburizing furnace with integrated oil quench. The thermal barrier protecting the datalogger is safely contained within a product basket along with products being monitored. The system travels safely though the furnace and then the oil quench to provide a complete thermal profile of both the furnace and product.

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For anyone involved in industrial heating, a critical need of any heat-treatment process is the ability to measure and control both process and product temperature.

The temperature control of the heat-treatment application is critical to the metallurgical and physical characteristics of the final product and, hence, its ability to perform its intended function. Achieving the correct maximum product temperature, time at temperature (soak) and rate of change of temperature (quench) can be essential to not only product quality but the efficiency (energy use and productivity) of the process.

Despite the fact that modern furnaces now are supplied with sophisticated control systems, they are still not capable of truly giving an accurate picture of the heat-treatment process from a product perspective. Temperature sensors positioned along the furnace give only a snapshot of what the environmental temperature is at that specific point in the furnace. Furnace controllers, as the name suggests, can give confidence that heating is performed in a controlled manner but will never give an accurate view of what the actual product temperature is.

IR pyrometers and thermal imagers can provide surface temperature measurements but require line of sight and, therefore, limit the areas of the product that can be measured. Products loaded at the bottom of a basket, for example, may be impossible to measure accurately. Without sophisticated mathematical modeling, the surface temperature, although helpful, will not give core temperature information, which is the more critical in most situations.

As with air sensors being fixed, typically IR sensors only give information at that specific furnace location, which prevents accurate calculation of soak times at critical temperatures. Without additional information, soak times and temperatures may need to be extended well beyond the target to guarantee that the heat-treat process is completed with confidence but with an obvious compromise to throughput and energy conservation.

Product Temperature Profiling

To fully understand the operational characteristics of the heat-treat process, it is necessary to measure both the environment and product temperature continuously as it travels through the process. Such technique provides what is referred to as a "temperature profile," which is basically a thermal fingerprint for that product in that particular furnace process. This thermal fingerprint will be unique but will allow understanding, control, optimization and validation of the heat-treat process.

The measurement of the product temperature profile has

Fig. 1. Typical temperature datalogger (up to 20 thermocouple inputs) used in the thru-process system. Protected by a thermal barrier, the logger travels through the furnace with the product being monitored.

historically been performed by one of two methods. The more traditional, basic approach has been to apply the principle referred to as "trailing thermocouples." A very long thermocouple is attached to the product and manually fed through the furnace as the product travels through. The datalogger measuring the live temperature reading is kept external to the furnace. Although possible, this technique is limited in the information it provides and comes with many practical hurdles (Table 1).

An alternative approach to trailing thermocouples is the application of "thru-process temperature profiling." In contrast to trailing thermocouples, the datalogger travels with the product through the furnace. The datalogger (Fig. 1) is protected by an enclosure, referred to as a thermal barrier, which keeps the logger at a safe operating temperature (Fig. 2).

Temperature readings recorded by the datalogger from multiple short-length thermocouples can be retrieved post-run. Alternatively, the data can be read in real time as the system passes through the furnace using a two-way RF telemetry communication option, if feasible. The resulting temperature-profile graph (Fig. 3) provides a comprehensive picture of the thermal process.

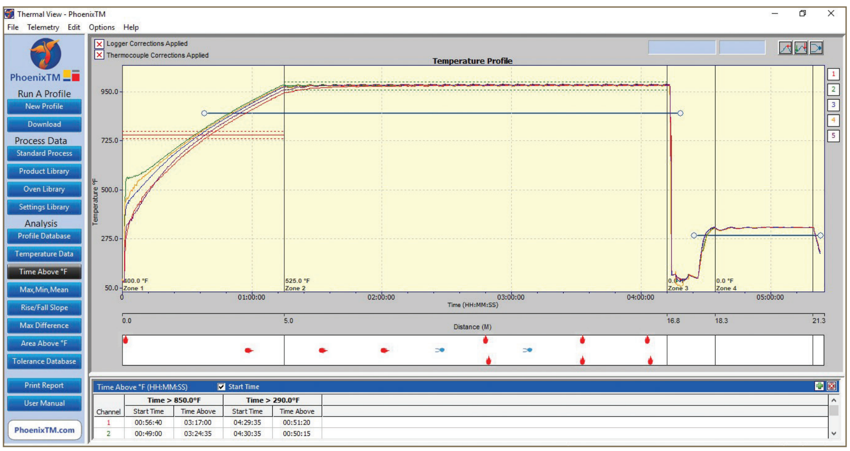

Fig. 3. Typical temperature profile obtained from the thru-process system. The temperature-versus-time graph shown is for a typical T6 solution heat-treatment process complete with water quench and age hardening.

Table 1. Benefits of thru-process temperature monitoring over traditional trailing-thermocouples methodology

	Trailing Thermocouples	Thru-Process
Number measurements	Limited to 1 or 2 safely	Up to 20
Operator needed during run	Essential to allow safe cable transfer through furnace	Not needed (system travels independently as if product)
Cable length	Furnace length minimum (cost/risk of damage)	Short (typically few feet)
Cable snagging/damage risk	Potential due to length. Automatic furnace doors may need to be overridden to prevent cable being trapped/damaged.	Minimal
Production stoppage	Yes, empty furnace needed (probe retrieval post-run)	No, used during production run
Representative of true production conditions	No, furnace may need to be empty	Yes, performed during production run
Robotic product loading	Not feasible	Possible (Fig. 4)
Multiple process steps (furnace, quench, etc.)	Difficult if possible at all	Possible (Fig. 3)
Safety	Operators close to furnace to feed thermocouples	No issues
Cost	Long thermocouples expensive to replace. Regular replacement risk.	Initial investment cost of system

The True Value of Furnace Thru-Process Temperature Profiling

Discovering the temperature profile of any heat-treat process provides the user with the potential to make a significant difference to the operational capabilities of his company as detailed here.

Product Quality

Confirm accurately that the product achieves the correct temperature conditions required to perform the heat-treatment process (homogenizing, carburizing, tempering, etc.). Verify the physical characteristics of the material for its intended use. Prevent costly rejects or rework incurring wasted energy from a labor and furnace fuel-consumption perspective.

Problem Solving

When process problems occur, and they do, have the means to identify furnace problems quickly and efficiently. Collect accurate data to identify the root cause and allow confident corrective action. Prove the success of any process correction strategies. How much does one hour of lost production cost you?

Process Optimization

Maximize the productivity and efficiency of your process. Fine-tune setpoint temperatures and soak times with confidence. Consider what a 10˚F reduction in furnace setpoint temperature or reduction of soak time of 10% could make to your annual energy bill and line productivity.

Regulatory Compliance

Provide the necessary process-validation certification (product profile or TUS) to prove compliance to CQI-9, AMS2750E or other quality standards. Prove to your customers the product quality you offer.

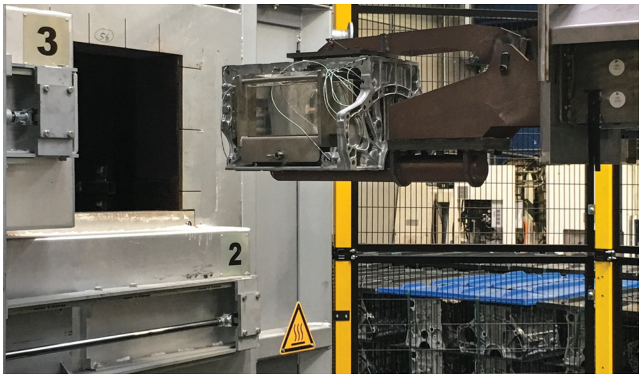

Fig. 4. Robot loading combined thru-process system and engine block into a BSN rotary T6 furnace. The thermal barrier is designed with a combination of thermal insulation technology capable of fitting in the engine-block cavity. With a thermal-protection capability of 550°C (1022°F) for several hours, the system has the ability to monitor the complete T6 process including solution reheat, water quench and aging *(courtesy BSN Thermoprozesstechnik GmbH Germany).*

Fig. 5. Thru-process profile system installed ready to run through the reheat furnace. Thermal barrier provides 3.2 hours protection at 1300°C (2372°F). It is loaded on a cast-steel beam blank, which is reheated prior to rolling into structural metalwork for buildings/skyscrapers. The datalogger at the core of the system stores data measured by the thermocouples inserted into the blank at varying depths along its length.

Temperature-Profiling Techniques – Pros and Cons

To highlight the benefits of "thru-process" temperature profiling over trailing thermocouples, refer to Table 1.

Thru-Process System Solutions for Heat-Treat Challenges

Rotary-Hearth Furnace with Robot Loading – T6 Solution Reheat of Aluminum Engine Block

In modern rotary-hearth furnaces such as that shown in Figure 4, temperature profiling using trailing thermocouples is impossible because the cables would wind up in the furnace transfer mechanism. Due to the central robot loading and unloading and the elimination of charging racks/baskets (the grippers place the component directly into the furnace opening), the use of a conventional thru-process system is also a challenge.

To overcome the loading restrictions, PhoenixTM developed a unique thermal barrier small enough to fit within the cavity of the engine block and allow automated loading of the complete combined monitoring system and product. The system allowed BSN Thermoprozesstechnik GmbH in Germany to commission the furnace accurately and efficiently and thereby optimize settings to not only achieve product quality but ensure energy-efficient, cost-effective production.

Slab and Billet Reheat Furnace Controller Mathematical Model Validation

Although modern slab and billet reheat furnaces have sophisticated controllers, it is critical that their mathematical models are validated with accurate real product temperature-profile data.

Thru-process systems are available to provide such data, offering up to 20 thermocouple inputs. This allows temperatures to be measured at the surface, center and base of the product at various positions along its length. The resulting temperature-profile data can be imported directly into the furnace controller model to validate correct selection of process parameters and assumptions applied.

Passing through the reheat furnace reaching temperatures of up to 1300˚C (2372˚F), the datalogger requires significant thermal protection. Such protection is provided by the specially designed thermal barrier. Manufactured using graded insulation layers and an evaporative inner water tank, the phased evaporation of water maintains the logger temperature at a safe 100˚C (212˚F).

Applying accurate profile data to mathematical models, targeted roughing-mill exit temperatures can be set to obtain a desired furnace dropout temperature throughout the product thickness. Accurate control of such variables allows a successful rolling operation with minimal scale buildup, which maximizes mill yields, saves energy and maximizes production throughput.

It is claimed that using thru-process temperature profile data to optimize furnace operation results in energy savings in the region of 5%. Such levels of energy saving provide a return on investment for the profiling system of a few weeks if not days.

Summary

Thru-process temperature profiling provides today's heat treater with a safe, efficient means to accurately measure both the furnace and product temperature throughout the whole thermal-treatment process. With such information, the engineer can understand, control, optimize and validate the process being undertaken with confidence. Not only can the engineer ensure product quality and drive productivity improvements, they can also perform accurate fine-tuning of the furnace parameters to achieve potential energy savings.

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