THRU-PROCESS TEMPERATURE PROFILING AND SURVEYING

Data obtained from thru-process profiling is used to calculate performance against specification, investigate process problems, and optimize the heat-treating process.

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"Thru-process" temperature profiling in the heat treatment industry has been around for over twenty years and the principle of operation of these systems is generally well known. A multi-channel data logger, protected by an insulated thermal barrier, travels through a furnace monitoring the products being heat treated (Fig. 1). At the end of the process the complete temperature profile can be examined, and critical calculations made using analysis software. This thermal fingerprint is unique and critical to the understanding, control, improvement, and validation of the heat treat process being undertaken.

BENEFITS OF THRU-PROCESS PROFILING

Prior to the development of these systems, long "trailing" thermocouples were often used to determine the actual product temperature profile through continuous furnaces. Feeding thermocouples through a continuous furnace had obvious disadvantages, mainly the difficulty of the operation itself, the limited number of thermocouples that could be used, disruption to production, and the accuracy of the data, given that products could not follow the test basket into the furnace (due to the trailing thermocouples), so the furnace loading decreased as the trial progressed.

As the thru-process method was adopted, the monitoring operation simplified, the disruption to production was minimized, and the measurement could always be carried out in a fully loaded furnace reproducing actual product conditions. Data obtained from thru-process profiling trials gives an accurate assessment of how long a product soaked at a specified temperature, the differences in product temperature around the product basket, quench rates, and more. This data is used to calculate performance against specification, investigate process problems, and optimize the process.

MONITORING CHALLENGES

Although the operating principle of these systems seems relatively straight forward, with the evolution of furnace technology and drive for automated systems, the design is often complex, as the thru-process system needs to meet the unique challenges that come with different heat treatment processes.

Thru-process temperature monitoring system loaded in a product basket traveling into and through a continuous sealed gas carburizing furnace.

When designing or selecting the most appropriate thru-process system the following criteria need careful consideration:

- Space or clearance in the furnace – Small enough to fit but with enough safe protection. Designed to either allow direct transfer by robot with or internally within the test product.
- Furnace temperature – Materials (metals and insulation) that will survive temperature maximums and rapid temperature changes and routine temperature cycling.
- Process duration – Protection to cover process delays whether anticipated or not.
- Atmosphere in the furnace – Systems capable of handling difficult atmospheres (such as hydrogen) which may make thermal protection more challenging due to increased heat transfer. Design of systems to eliminate contamination/poisoning of critical controlled atmospheres (such as aluminum brazing (CAB)).
- Quench within the process – Technology capable of handling not only heat but designed to allow safe

passage and monitoring through the quench process whether water, salt or oil.

The following case studies are examples of thru-process temperature monitoring surveys.

CASE 1: LOW-PRESSURE CARBURIZING

Carburizing has rapidly become one of the most critical heat treatment processes employed in the manufacture of automotive components. Also referred to as case hardening it provides necessary surface resistance to wear, while maintaining toughness and core strength essential for hardworking automotive parts.

The carburizing process is achieved by heat treating the product in a carbon rich environment, typically at a temperature of 900 to 1050°C (1652 to 1922°F). The temperature and process time significantly influence the depth of carbon diffusion and associated surface characteristics. The next step is critical to the process. Following diffusion, the product is rapidly quenched and the temperature is rapidly decreased to generate the microstructure, giving the enhanced surface hardness while maintaining a soft and tough product core.

An increasing trend in the carburizing market is the use of batch or semi-continuous batch low-pressure carburizing (LPC) furnaces. Following the diffusion, the product is transferred to a high-pressure gas quench chamber where the product is rapidly gas cooled using typically N_2 or helium at up to 20 bars.

The technical challenge is twofold. The thermal barrier must be capable of protecting against heat during the carburizing, and also against very rapid pressure and temperature changes inflicted by the gas quench.

To protect the thermal barrier in the LPC process with gas quench, the barrier construction needs to be able to withstand constant temperature cycling and high gas pressures. The design and construction features include:

- Metalwork – 310 stainless steel reduces distortion at high temperature combined with internal structural reinforcement.
- Insulation – Ultra-high temperature microporous insulation minimizes shrinkage problems.
- Rivets – Close pitched copper rivets reduce carbon pick up and maintain strength.
- Lid expansion plate – Reduces distortion during rapid temperature changes.
- Catches – Heavy duty catches eliminating thread seizure issues.
- Heat sink – Internal heat sink to provide additional thermal protection to data logger.

During the gas quench, the barrier needs to be protected from nitrogen N_2 or helium He gas pressures up to 20 bar. Such pressures on the flat top of the barrier would create excessive stress to the metalwork and internal insulation/logger. Therefore, to protect the barrier, a separate gas quench

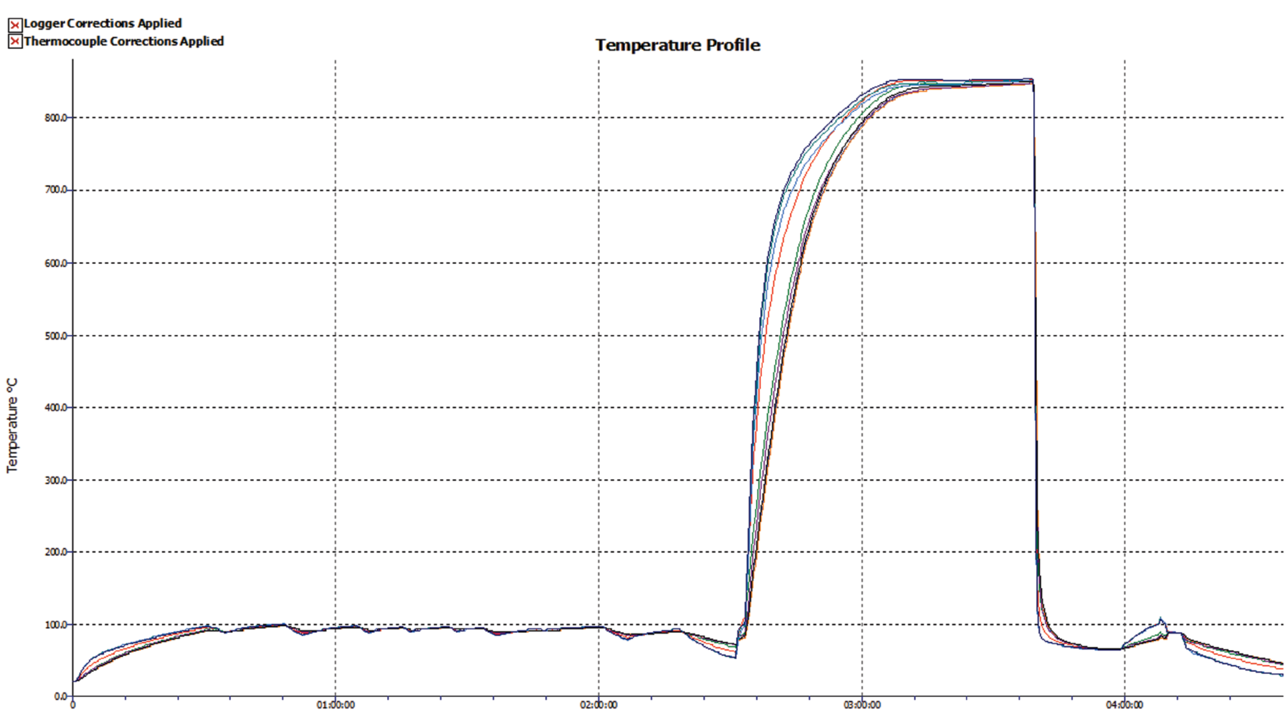

Fig. 1 — Typical thermal profile for thru-process temperature monitoring system through a continuous sealed gas carburizing furnace.

deflector is used (Fig. 2). The tapered top plate deflects the gas away from the barrier. The unique design means the plate is supported on either four or six support legs. As it is not in contact with the barrier, no force is applied directly to the barrier and the force is shared between the support legs.

Performing a temperature uniformity survey (TUS) to comply with AMS2750E/CQI-9 standards requires that the survey, analysis of data, and reporting, is performed in agreement with strict criteria. This can be tedious and lengthy unless using a customized TUS software analysis package such as the PhoenixTM Thermal View Survey software.

Applying the thru-process monitoring technique there is no hardwired link between the monitoring system within the furnace and the outside world. To achieve real time measurement, as if using trailing thermocouples, the data measurements need to be transferred remotely. This is achieved using a high-performance two-way radio telemetry system. The temperature readings are transmitted as a RF signal from the data logger via external barrier antenna from inside the furnace to a receiver connected to the external monitoring PC. The two-way communication protocol allows not only live data collection for profiling or TUS work but also direct control of the data logger (reset/download) inside the furnace (Fig. 3).

CASE 2: SEALED GAS CARBURIZING WITH INTEGRAL OIL QUENCH

A common process in today's heat treatment industry is the carburizing of lower cost steel products for use in the automotive industry. To achieve this process a popular heat treatment technology used is a sealed gas carburizing furnace with an integral oil quench. For such furnace technology the historic limitation of thru-process temperature profiling has been the need to bypass the oil quench and wash stations. Obviously passing a conventional hot barrier through an oil quench creates potential risk of both system damage from oil ingress, barrier distortion, and general process safety.

In such carburizing processes the oil quench rate is critical to both the metallurgical composition of the metal and elimination of product distortion and quench cracks, so the need for a monitoring solution has been significant. Reg-

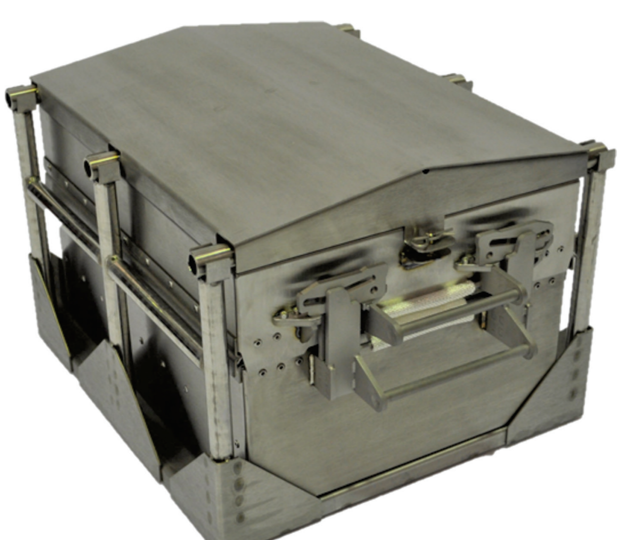

Fig.2 — Thermal barrier fitted with quench deflector designed specifically for surveying LPC batch furnaces with high pressure gas quenches.

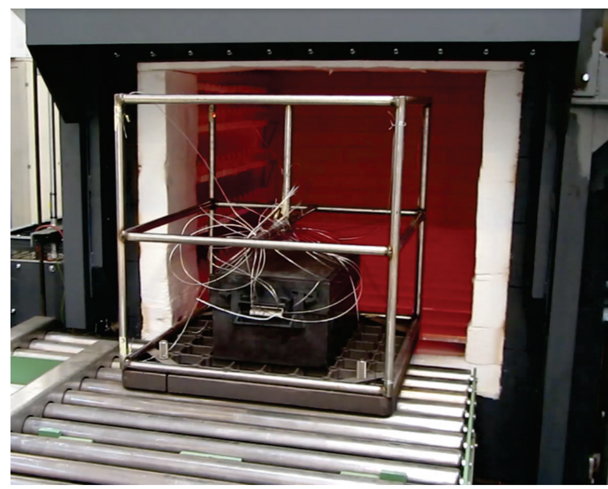

Fig. 3 — Thru-process temperature monitoring system loaded into a batch furnace with TUS frame to complete a temperature uniformity survey.

Fig. 4 — Thru-process temperature monitoring system for use in sealed carburizing furnace with integral oil quench. To the left is the inner sealed thermal barrier and data logger and on the right is the outer structural frame containing sacrificial insulation.

ular monitoring of the quench is important as aging of the oil results in decomposition, oxidation, and contamination of the oil, all degrading the heat transfer characteristics and quench efficiency.

To address these challenges a unique barrier design has been developed that both protects the data logger in the furnace (typically 3 hours @ 925°C (1697°F)) and also protects during transfer through the oil quench (typically 15 mins) and final wash station (Figs. 1 and 4).

The key to the barrier design is the encasement of a sealed inner barrier with its own thermal protection with blocks of high-grade sacrificial insulation contained in a robust outer structural frame. **~HTPro**

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