Advances in Quench Monitoring Using ‘Hot Box’ Systems

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Introduction

In heat treatment, the process of quenching i.e. cooling at a rate greater than under ambient conditions can be critical in the development of final material properties. Quenching is used to control or influence changes in structure by the use of forced or non ambient conditions which alter the way in which structures form on heating and cooling (figure 1).

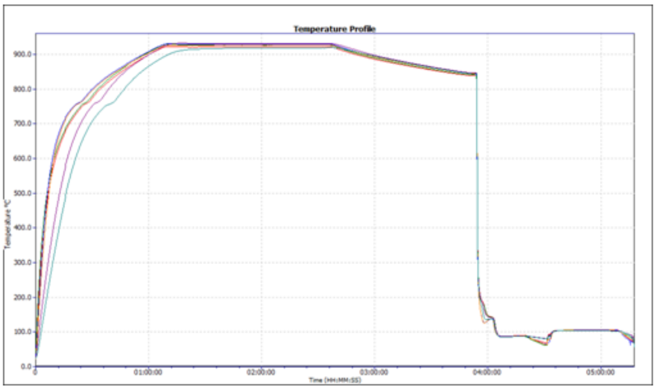

Figure 1: Complete carburizing process including oil quench

Monitoring the quench phase of the heat treatment process using ‘Hot Box’ systems has been a reality for over 20 years, with water and gas quenching being the first processes capable of being monitored by this method. In this paper we look at how the technology of ‘Hot Box’ monitoring systems has been developed to suit the different conditions in these processes, and how recent advances in technology have now made it possible to improve the reliability of equipment used in water and gas quenching. We also look at how these systems have been further developed to cope with the more difficult conditions of salt bath and oil quenching, and so cover the majority of quench processes that can be monitored.

How quench monitoring is carried out using the ‘hot box’ system.

Figure 2: A ‘Hot Box’ system is prepared for a trial in an aluminum foundry measuring cylinder head temperatures through a water quench

The principle of monitoring is the same for all processes, but the design of the system will change according to the process. In general thermocouples are set into dummy products which are placed in strategic positions around the product basket. The temperature data is fed back to the logger which is always protected by a thermal barrier. The system is placed in the product basket which will travel together with the parts being processed through the furnace and into the quench (see figure 2). After this the test basket will generally transfer into the processes downstream (further heat treatment ovens, wash processes, etc.), before arriving at a position where the data logger can be safely removed from the thermal barrier and the data downloaded to a PC where a detailed examination of the temperature profiles can be made.

Why monitor the quench?

In general, monitoring heat treatment processes and furnace surveying do not require monitoring throughout the quench. But in some instances it may be advantageous to monitor through the quench to determine specific information:

- To investigate the possible causes of part distortion in some gas carburizing processes, and how the physical shape of the part may affect this distortion.
- To monitor the rate of cooling within the quench when comparing the performance of various quench oils, liquid salts, or quench gases (and combinations of gases).
- To prove compliance to specification of precise time from furnace exit to full immersion in the quench (e.g. aluminum solution treatment - T6 processes).
- To monitor product temperature from furnace exit until full immersion into quench, ensuring temperatures in all areas of the product basket remain within specified limits.

Also, although temperature data during the quench may not be required, it may be advantageous to have a system that is able to travel through the oil quench if, for example, a furnace survey is required and physical removal of the 'hot box' system, prior to the quench is simply not possible.

Types of quench that can be monitored using a 'Hot Box' system

Liquid Quenches		
Quench media	Monitor with 'Hot Box'?	Notes
Water	Yes	Technology developed further to improve reliability (see below)
Aqueous Polymers	Yes	
Oil	Yes	System recently developed (see below).
Liquid salts	Yes	System recently developed (see below).
Fluidized bed	Possible	Possible with sealed system, but limited requirement
Gaseous quenches		
Fan assisted gas quench with high purity gases e.g. Nitrogen/Argon/Helium, etc.	Yes	Technology developed further to improve reliability (see below)
Gas quench without fan assistance	Yes	As above
Forced air cool	Yes	System developed for use in vacuum aluminum brazing processes

Specifics of quench monitoring using 'Hot Box' systems, and technological advances

1. **Water and Aqueous Polymer Quenches**.
    - **Specifics:** Historically this was the first quench process to be successfully monitored. 'Hot Box' systems are now used daily in T6 processes in aluminum foundries worldwide (cylinder heads, alloy wheels, brake callipers, etc.). In this application an 'Evaporative Hot Box' thermal barrier uses boiling water to keep a high temperature data logger at a working temperature of 100°C / 212°F. A layer of inexpensive fiber blanket insulation surrounds the sealed water container housing the data logger. The insulation is replaced after every run.
    - **Potential System Limitations:** Incorrect assembly of the thermal barrier, or failure of a water tight gasket, may lead to quench water entering the 'Hot Box' which may cause complete destruction of the data logger and subsequent loss of data. Even a small water leakage in the barrier will be exaggerated by the phenomenon known as 'low vacuum water ingress' where expanding air leaks out of the barrier (and data logger) during the process as it heats up, and on quenching, a partial vacuum is created which sucks quench water back in.
    - **Advances in Development:** The latest development is a fully waterproof data logger which is able to withstand 'low vacuum water ingress' (see figure 3). This is a 'last line of defense' if a failure occurs in the barrier during quenching and will save the replacement cost of a new logger.

Figure 3: Fully waterproof data logger

2. **Gaseous Quenches**
    - **Specifics:** These systems use a conventional 'heat sink' type of thermal barrier. This 'dry' barrier technology is often used in processes such as low pressure carburizing where evaporative barriers would not be suitable. The thermal barrier has to withstand temperatures sometimes in excess of 1000°C / 1830°F, followed by a high pressure gas quench of nitrogen etc. This type of system is commonly used in the auto and aerospace industry.
    - **Potential System Limitations:** distortion of the thermal barrier may occur over time due to the continuous cycle of heating and quenching at a high pressure (up to 20 bar / 290 lbf/in^2).

- **Advances in Development:** Initial developments involved reinforcing the casing of the 'heat sink' thermal barrier in multiple areas to minimise distortion. As quench pressures increased, further protection of the barrier was required and a gas quench 'deflector' has now been developed which shields the thermal barrier from the direct force of the quench gas (see figure 4). The latest technology incorporates a sturdy independent framework to support the deflection panels, but allows the quench gases to circulate around the barrier as well as the products. Advances in data logger design now allow the logger to operate in conditions which fluctuate between vacuum and high pressure routinely.

Figure 4: 'Hot Box' system with quench deflector carrying out a TUS in a vacuum furnace

3. Oil Quenches:

- **Specifics**: Quenching in oil is probably the most common type of quench in the heat treatment industry. It is widely used in integrated quench (IQ) and continuous gas carburizing furnaces in auto, aerospace and general heat treatment processes (See Figure 5).
- **Potential System Limitations:** Developing a commercial system able to withstand an oil quench has long been a goal of the industry, but also a major challenge as the thermal barrier needed to be completely air tight (i.e. to resist the ingress of the oil without leakage), and at the high temperatures involved in a carburizing process, air expansion inside the barrier, combined with the plasticity of the barrier casing, may cause distortion.

Figure 5: A 'Hot Box' oil quench system is discharged from a carburising furnace after passing through the oil quench

- **Advances in Development:** To overcome these conditions and protect the data logger, a combination of both the above designs of system were used. That is a system where the data logger is housed in a fully sealed inner thermal barrier which uses ‘dry’ heat sink technology. The inner barrier is further insulated with a sacrificial layer of high grade insulation which keeps temperatures in the inner barrier at a safe level. Although the outer insulation layer must be replaced after every run, design and engineering of these high grade insulation blocks keeps cost to a minimum and makes this a viable proposition.

4. **Liquid Salt Quenches**:
    - From a technological point of view, salt bath quenches are approached by the manufacturers of ‘Hot Box’ systems in a similar way to oil quenches. The difference being the construction of the outer insulation layers, and the balance between the insulating properties of the inner and outer barrier layers.

Figure 6: A ‘Hot Box’ system is charged into a roller hearth gas carburizing furnace terminating in a salt bath quench

Conclusion

Technological advances in thermal barrier design have made it possible to monitor temperature profiles through almost all types of quenches using ‘Hot Box’ systems. This not only allows important data collection which would not be otherwise available, but also offers the prospect of using ‘Hot Box’ systems in furnaces where there is no possibility of removing the system before the oil quench.

Acknowledgements: We are grateful to Bill Hewitt C.Eng MIMMM for his contribution to this paper

Further information: Website: www.phoenixtm.com

Video of water proof data logger: http://www.youtube.com/watch?v=OucGn2MncVo

Video of oil quench system: https://goo.gl/ewsCvm