Advances in Monitoring Internal Temperature of Aluminium Slabs or Ingots in Pusher Furnaces

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Introduction

In the aluminium plate and foil industry it has long been a goal to accurately measure the temperature of ingots or slabs (fig. 1) as they pass through continuous pusher furnaces to reheat and homogenise prior to hot rolling.


Figure 1. Aluminium slabs prior to rolling

The temperature profile inside a furnace is rigidly controlled so that rate of temperature increase / decrease; stabilisation times and temperatures; and the final slab 'drop out' temperature prior to rolling, can be optimised for the type of alloy being processed. An accurate measurement of slab temperatures throughout the reheat process can indicate how effective the set temperature profile is, and can show where further adjustments may improve the process.

Modern furnaces may also incorporate numerical model control. Verification of the model on a regular basis is desirable, and this means monitoring actual slab temperatures at multiple points throughout the reheat cycle.

The Heat Treatment Process

Cast aluminium slabs for hot rolling are reheated to a temperature of around 550°C, and then soaked at temperature for a time period dependent on the type of alloy, thickness of slab, etc. This operation is generally carried out in a pusher type furnace where the aluminium slabs are positioned horizontally as they approach the furnace, rotated through 90° as they travel through the furnace, then rotated a further 90° as they exit the furnace and are positioned onto the mill rolls (fig. 2)

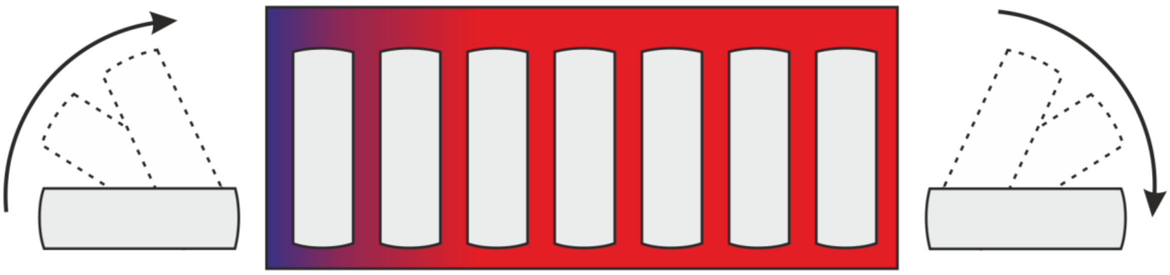
Figure 2. Aluminium slabs travel through 180° as they progress through the furnace

Slab Temperature Measurement

Prior to the development of 'hot box' systems, long 'trailing' thermocouples were fixed to the test slab and fed through the furnace. This method had major disadvantages:

- The number of temperature measurement points was limited due to cost and the difficulty of manoeuvring multiple thermocouples through the furnace
- Due to thermocouples trailing into the furnace it was often not possible to charge slabs behind the test piece, meaning that the trial was carried out in a half empty furnace.
- Opening and closing of furnace doors inhibited the use of long thermocouples.


Figure 3. 'Hot Box' system being prepared on aluminium slab

Today, temperature profiling is generally carried out using a 'Hot Box' system (fig. 3) where a high accuracy, multi channel data logger passes through the process attached to the test slab during normal production conditions, measuring the temperature of the test slab from thermocouples at up to 20 critical points. The data logger is protected from the heat of the furnace by using a highly efficient thermal barrier which keeps it at a safe operating temperature.

Technology of the 'Hot Box' System

The design of 'Hot Box' thermal barriers can differ depending on several critical factors:

- The maximum temperature of the process
- The duration of the process
- Space available within the furnace for the thermal barrier
- Movement of the product during the process
- Any atmosphere restrictions in the furnace

When space in the furnace is not limited and process durations are relatively short, it is possible to use a 'heat sink' design (fig. 4) where the data logger is housed in a 'heat sink' (a closed stainless steel container filled with a 'phase change material'), which in turn is protected from the heat of the furnace by a thick layer of microporous insulation. As the heat begins to penetrate the outer insulation layer, the temperature of the material in the heat sink (usually a type of eutectic salt) increases, and at a specific point (generally around 58°C) will change phase from solid to liquid. During this phase change period the temperature within the system will remain constant thus prolonging the time the data logger can remain in the furnace.


Figure 4. Two types of 'Hot Box' system. 'Heat sink' design - left, 'evaporative' design - right.

Where process durations are longer, and space on the slab may be limited, as is the case with slab reheating, then an 'evaporative' thermal barrier is normally used (fig. 4). With this type of system the data logger is surrounded by a container of water which is allowed to boil and evaporate into the furnace atmosphere as the system heats up. Again a thick layer of microporous insulation surrounds the water jacket to delay the boiling process and extend the time the system can remain in the furnace.

Size for size an 'evaporative' system is more efficient than a 'heat sink' system in terms of duration at temperature. The disadvantages of the evaporative barrier is that a) evaporation of a small amount of steam into a furnace atmosphere is sometimes not allowed, and b) if the evaporative system is not correctly designed, then water may escape from the barrier during entry and exit from the furnace when the slab rotates, decreasing its thermal capacity.

Data loggers (fig. 5) for both types of systems have a slightly different design. For the 'heat sink' system standard alkaline batteries are used to power the logger as the internal temperature of the system is relatively low (normally less than 60°C). Where an 'evaporative' thermal barrier is used there may be some modification to the electronics, and lithium batteries are used so the data logger can withstand prolonged periods at high temperature (100°C). There is no difference in accuracy between the types of loggers, and both can support radio frequency (RF) transmission allowing the data not only to be stored in the logger, but also to be transmitted out of the furnace allowing the reheat process to be monitored in real time.

Figure 5. Typical multi-channel data logger capable of operating at temperatures up to 110°C

'Hot Box' System design

Generally there is limited clearance around the aluminium slab as it travels through the furnace so whichever type of system is used; the thermal barrier should ideally be kept within the boundaries of the test slab. This involves designing the system with a size and thermal capacity to cope with the process (and any unplanned stoppages), and machining the slab to accept the thermal barrier. Close cooperation between the system supplier and customer is vital at an early stage.

If the thermal barrier is evaporative, then it should be designed so that it does not shed any of the cooling water when rotating 180° from horizontal to vertical, and back to horizontal, as the slab enters and exits the furnace. The thermal capacity of the barrier is designed around having a specific quantity of water and any loss may seriously affect its performance in the furnace. Design of the system must also take into account fast removal of the data logger from the system in its final resting position after exit from the furnace.

The design should also take into account how the data logger is accessed from the thermal barrier before and especially after the trial, when the logger has to be removed from the hot slab.


Figure 6. System mounted in slab with stainless steel cover to protect from high velocity air flow in furnace

Finally it may be necessary to protect the thermal barrier from any high velocity flows of hot air from recirculation fans in the furnace (fig. 6) as this can have a detrimental effect on the thermal capacity of the system.

Fitting the 'Hot Box' system to the Test Slab

Generally a test slab is prepared by machining a portion out to accept the 'Hot Box' system with the thermal barrier positioned centrally and in a position where it will not impede any equipment used to load / unload the slab. Bolts securing the thermal barrier to the slab should be of a sufficient depth and diameter to ensure they don't break away from the hot aluminium as the slab rotates at the furnace exit.

Holes need to be drilled so thermocouples can measure temperature at the required positions, and correct depths within the slab. Depending on the type and diameter of thermocouple to be used, aluminium bushes may need to be used as guides. If a small diameter thermocouple is used, for example a 1.5mm diameter mineral insulated type, then it would be impractical to drill a small hole say 300mm deep to the measuring point. In this case a large diameter hole can be drilled, and bushes used (fig. 7).


Figure 7. From left: slot machined in slab, thermocouple in bush inserted into slab, steel plate fitted to hold thermocouple in position

It is essential that the thermocouples are firmly secured to the slab as they travel from the data logger to the measuring point, and that there is no possibility of 'snagging' within the furnace, or on charging / discharging the equipment.

Handling the Data

Software is an essential component of the system especially if calibrated thermocouples are to be used. Software incorporating thermocouple and data logger correction factors can correct inaccuracies and present highly accurate results (fig. 8). If a comparison of the results to a mathematical model prediction is required, then an essential component of the software is the ability to export the raw data directly to a spreadsheet.

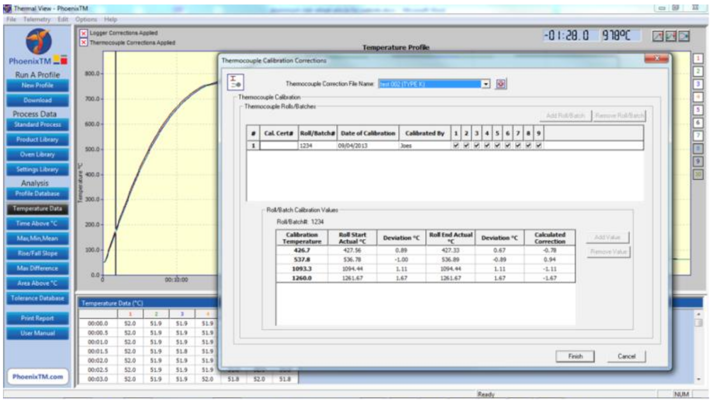

Figure 8. Software incorporating thermocouple correction factors and able to export data direct to a spreadsheet

During the trial data can be transmitted from the data logger inside the furnace via. RF to a PC situated externally. This is useful if the data is to be used to make adjustments to the furnace settings. Otherwise the data can be downloaded from the logger after the process is complete and an assessment made of the complete temperature profile.

Conclusion

Accurately measuring slab temperatures helps to ensure that the correct thermal balance is achieved efficiently throughout the product thickness. Non-homogeneous temperatures can cause variation in downstream processing and final product quality ultimately leading to energy wastage, higher costs and rejections.

Today it is possible to engineer a ‘Hot Box’ system which can be embedded in the slab during reheat, allowing the temperature profile at multiple points to be accurately monitored throughout the process on a regular basis without the inconvenience of long trailing thermocouples, and minimal production loss. Design of this type of system from the thermocouples, through to the Thermal Barrier is critical as this instrument must maintain a high degree of accuracy while resisting extremes of temperature and high velocity air flow over a long period of time.

In the aluminium industry many other heat treatment processes can be monitored using ‘Hot Box’ technology including aluminium log homogenisation, solution treatment of aluminium castings (cylinder heads, road wheels, etc), billet re-heat prior to extrusion, and brazing aluminium condensers and radiators.

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