Getting to the true core of the matter!

By Dr Steve Offley*

Thru-process temperature monitoring of aluminium slabs and ingots in continuous pusher furnace heat treat processes prior to rolling operations.

Introduction: Aluminium Flat Rolled Product Market

In today's manufacturing market, aluminium, being lighter, safer and more sustainable, is increasingly becoming the material of choice. A key player in this market is aluminium flat rolled products. These include sheet, plate and foil. The market size is estimated to be worth USD 114240 million in 2023 with a CAGR of 4.8% during the forecast period 2023-2030.

Aluminium flat rolled products are usually manufactured by rolling thick aluminium (slabs, ingots or billets) between rolls that reduce the thickness. Aluminium rolling can be performed cold (cold working), where the rolling process hardens and strengthens the material through changing the micro-structure, but this may leave the final product brittle. Hot rolling in contrast requires heating of the stock material (hot working) between 260 and 550°C (500 and 1022°F) before being processed through roller mills of decreasing thickness applying force to the top and bottom of the slab. Hot rolling prevents most, or all work hardening and allows the aluminium to remain ductile. The classification of the final rolled product is determined by thickness plate (<0.25 inches / 6.3 mm), sheet (0.008 inches / 0.2 mm to 0.25 inches / 6.3 mm) or foil (< 0.008 inches 0.2 mm).

Aluminium Slab/Ingot Reheat Processing Control

In the hot working of aluminium stock, the initial cast slab is passed through continuous pusher furnaces to reheat and homogenise at temperatures up to typically 550°C (1022°F). The actual set-point temperature and soak time employed in the process is obviously influenced by the stock characteristics including type of alloy and the physical dimensions of the slab, thickness, and overall thermal mass. Although modern furnaces incorporate sophisticated temperature control methods, often based on intelligent mathematical models, the success of the heat treat programs requires independent validation. The process engineer needs to understand how the furnace program characteristics, unique to each furnace (temperature and time) effect the temperature of the aluminium slab throughout the complete production heat treatment cycle (passage through the furnace) at different locations within

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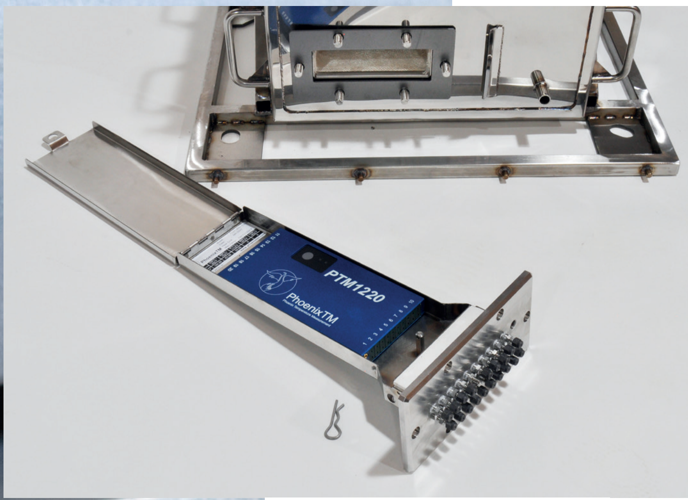


Fig 1. PhoenixTM PTM1220 20 Channel high temperature data logger shown in data logger barrier tray with IP67 thermocouple compression fittings ideal if water spray quenches are employed

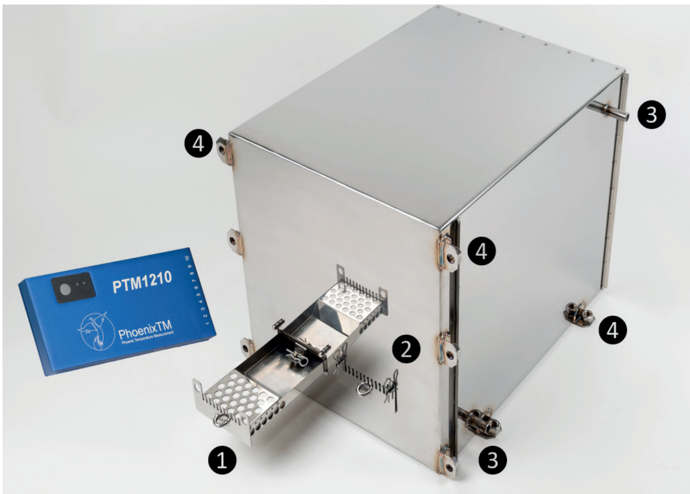


Fig 2. Aluminium slab thermal barrier showing (1 & 2) dual data logger tray within water tank and (3) filler and exhaust pipes and (4) slab mounting points

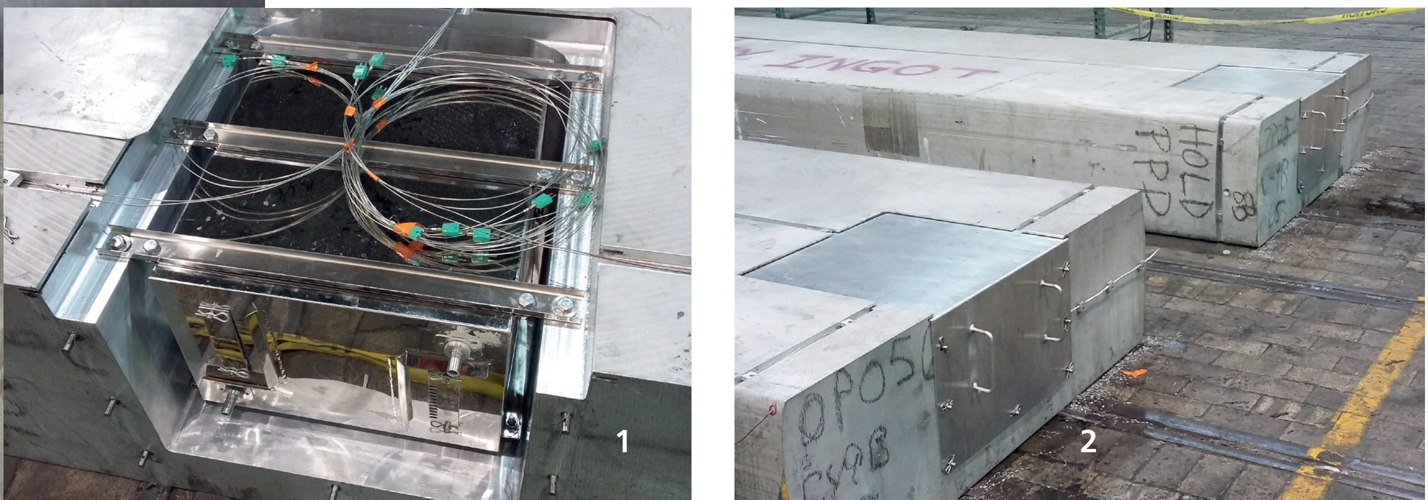


Fig 3. PhoenixTM System embedded in aluminium slab/Ingot (1) - stainless steel cover to protect from high velocity air flow in furnace (2)

the slab structure (length, width, and depth). Other techniques used for product temperature measurement in process, including furnace contact thermocouples and IR temperature measurement (spot, scanner, or camera) limit temperature to the slab surface and often are restricted to one face of the slab only. To achieve efficient hot rolling, it is critical the correct slab drop out temperature is achieved through the entire slab core.

Validation of Furnace Control Programs – Slab Temperature Profiling Challenge

To validate the performance of the heat treat process, a temperature profile of the slab temperature at different locations within the slab through the heat treat furnace is needed. Historically the temperature profile was achieved using the method of trailing thermocouples. An external data logger would collect temperature data from thermocouples attached to the slab fed through the furnace during the slab transfer. This measurement approach is not ideal for the following reasons;

- The number of temperature measurement points is limited due to cost and the difficulty of manoeuvring multiple long thermocouples through the furnace
- Due to thermocouples trailing into the furnace it is often not possible to charge slabs behind the test piece, meaning that the trial is carried out in a furnace that is not fully loaded. Temperature data is not therefore an accurate representation of true production conditions.
- Opening and closing of furnace doors may inhibit the use of long thermocouples.
- In the pusher furnace the slab is rotated 90 ° at entry and exit from furnace which creates damage or disconnection risks to the fitted trailing thermocouples.

To eliminate the inherent problems of the trailing thermocouple approach, the alternative method of thru-process temperature profiling is recommended. As its name suggests the measurement system (data logger) passes through the process attached to the test slab during normal production conditions, measuring the temperature of the test slab using short thermocouples at up to 20 critical points. The data logger is protected from the heat of the furnace by a highly efficient thermal barrier which keeps it at a safe operating temperature. As the monitoring system is self-contained within the test slab, the system is free to travel safely through the furnace without any of the inherent challenges of long trailing thermocouples as part of the standard production cycle within a fully loaded furnace.

Thru-process Temperature profiling system design

PhoenixTM Data logger Range

At the heart of the monitoring system is the data logger designed specifically for use in the hostile heat treat environment.

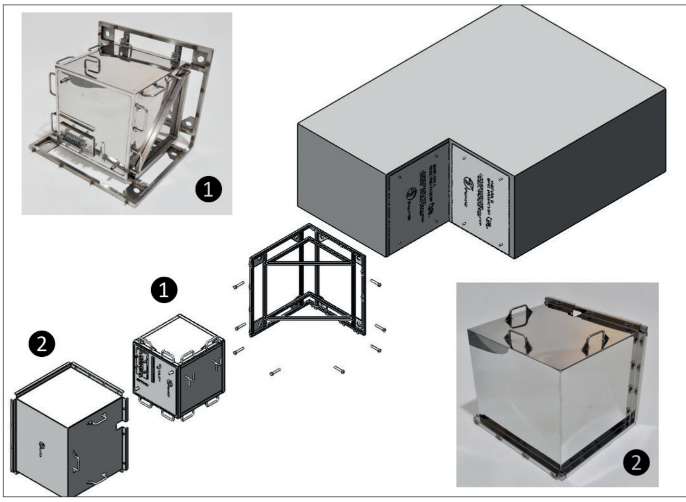


Fig 4. PhoenixTM System schematic showing exploded thermal barrier configuration with slab mounting frame (1) Thermal barrier photo positioned on frame (2) Thermal barrier with fitted protective high velocity air cover.

Data loggers can be provided in a variety of configurations to suit the specific demands of the process being monitored. Models ranging from 6 to 20 channels can be provided with a variety of thermocouple options (types K, N, R, S, B) to suit measurement temperature and accuracy demands (AMS2750 & CQI-9).

The loggers can be offered in either standard <80°C (176°F) or high temperature operating temperatures (Barrier Core Temperature <110°C (230°F) variants to allow use of either standard thermal barrier designs (Dual Phase - Heat Sink) or high performance (Phased Evaporation – Water Tank) as recommended for use in the demanding aluminium reheat pusher furnace monitoring application.

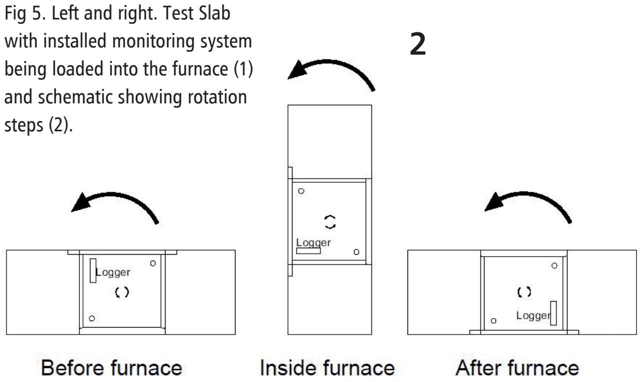
Although thermally protected by the thermal barrier, the operating temperature of the data logger during transfer through the furnace will increase up to the safe maximum operating conditions

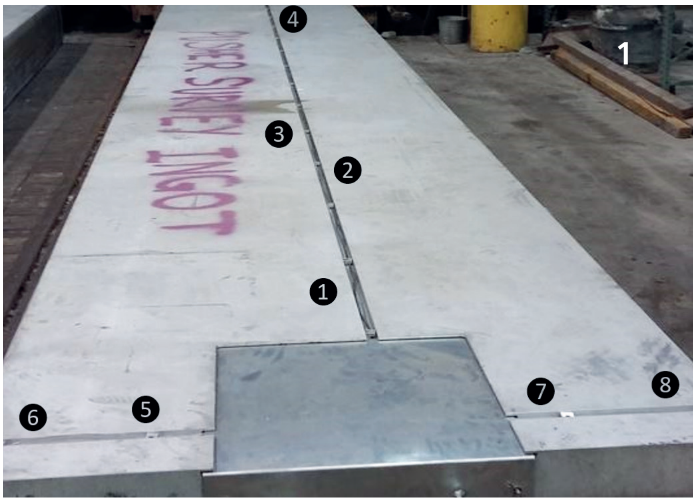
(100°C (212°F) in evaporative water barrier). The data logger temperature change, which would normally affect the thermocouple reading, is automatically compensated for using an accurate internal temperature compensation feature protecting the measurement accuracy in process.

Built to cope with hostile industrial environments the IP67 logger is capable of managing even the most demanding processes where water spray quenching may be necessary.

Provided with Bluetooth wireless connection for short range localised download and reset (direct from within the barrier) the logger memory of 3.8M allows even the longest slab reheat processes (20 hours) to be measured with highest resolution to deliver the detail you need. An optional unique 2-way telemetry package offers live real time logger control and process monitoring with the benefits detailed in the later following section. **Fig 1 and 7.**

Fig 5. Left and right. Test Slab with installed monitoring system being loaded into the furnace (1) and schematic showing rotation steps (2).





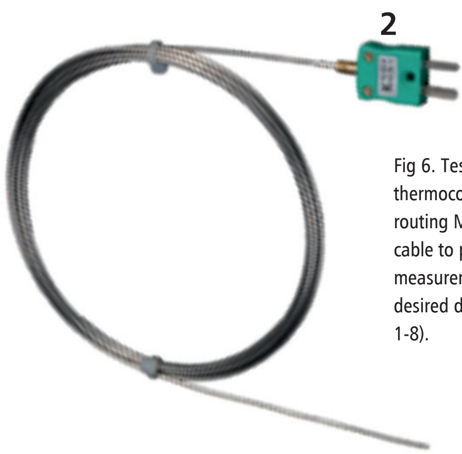
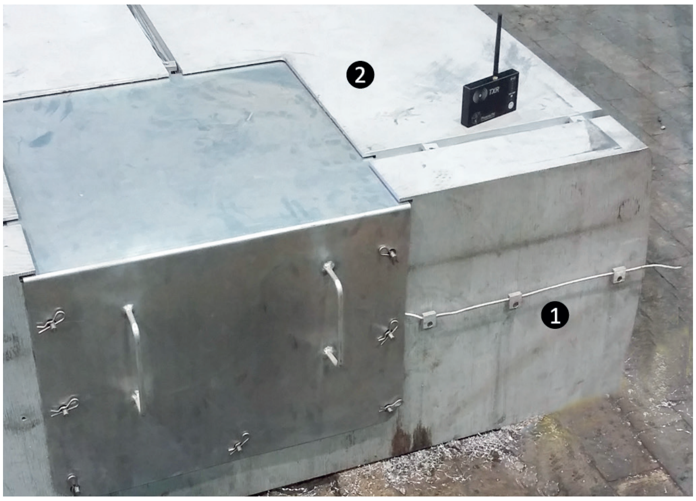


Fig 6. Test Slab with thermocouple channels routing MI thermocouple cable to point of measurement at the desired depth (channel 1-8).



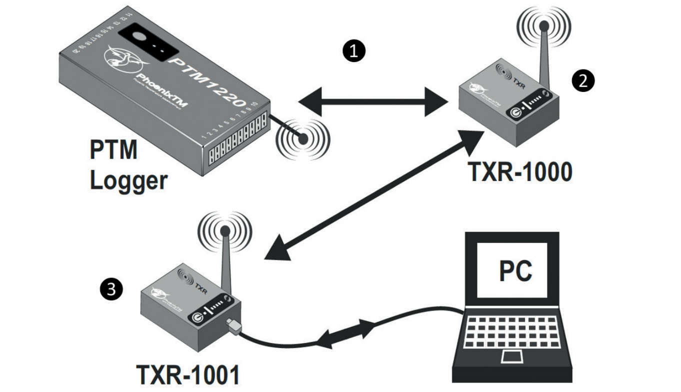


Fig 7. Left and right. Installed system on slab showing (1) RF telemetry Antenna and (2) portable RF repeater unit transferring live temperature data direct from furnace back to (3) RF coordinator linked to the monitoring PC

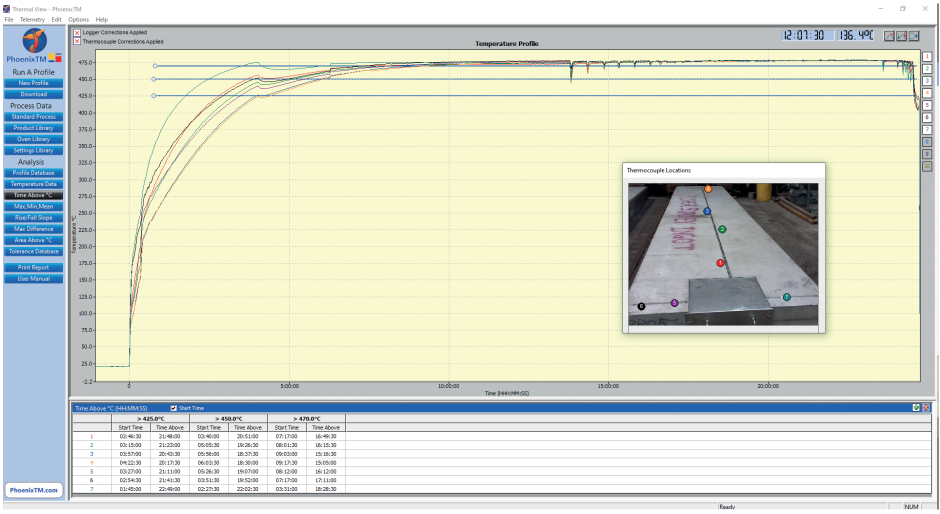


Fig 8: Temperature profile graph showing the temperature variations within the aluminium slab core over the entire heat treat process. Soak times at critical temperatures can be accurately calculated to ensure that drop out temperatures and rolling operations are performed correctly.

Thermal Barrier Design

Heat treating a 30 tonne 600 mm / 24 inch thick aluminium slab requires significant heat to achieve homogeneity. Processes are typically therefore up to 20 hours at 500°C / 932°F and as such the thermal barrier used to protect the data logger needs to be very efficient but at the same time be compact enough to allow safe installation within the slab.

For such process the recommended thermal barrier design is based on a dual phased evaporation technology. The high temperature data logger operating safely at temperatures up to 110°C / 230°F is housed within the dry cavity of a water tank. Data logger sealing options within the thermal barrier are available including IP67 compression fittings, recommended if water spray quench steps are employed in process (**Fig 1**). During transfer through the furnace, the water heats up to its boiling point at 100°C / 212°F and then maintains the temperature as water phase changes from liquid to gas (steam). The rate by which the water temperature in the tank rises is further controlled by an outer skin of microporous insulation, which helps reduce rapid temperature changes and associated risk of distortion problems for the thermal barrier structure.

The exact thermal barrier protection is governed by the capacity of the water tank. When specifying the correct thermal barrier design often there is a fine balance between maximising the size of the water tank and volume of water available to the outer dimensions of the thermal barrier suiting the size of the slab being monitored.

A feature of the pusher furnace design is that the slab is rotated at the entrance and exit of the furnace to maximise loading capacity. The rotation of the slab (**Fig 5**) and therefore also thermal barrier could create problems with water loss and deterioration in thermal capacity. The water tank construction is designed therefore in a unique way to orientate water filler and steam exhaust pipes to minimise water loss during any rotation step.

Fitting the monitoring system to the test slab

Generally, a test slab is prepared by machining a portion out to accept the monitoring system with the thermal barrier often positioned centrally and in a position where it will not impede any equipment used to load / unload the slab (**Fig 3**). 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.

The assembled monitoring system fitted within the slab cavity is covered with an external metal shield (**Fig 3**). The shield has two purposes to firstly protect the thermal barrier from high levels of heat transfer from high velocity hot air convection and maintain air flow patterns over the slab itself to maintain normal production heating conditions.

Thermocouple Placement

Temperatures within the slab are measured from the tip of the mineral insulated thermocouple as shown in figure 6. To position the tip at the exact location / depth within the slab pilot holes need to be drilled in 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 1/16 inch diameter mineral insulated type, then it would be impractical to drill a small hole say 300mm / 11.8 inches deep to the measuring point. In this case a large diameter hole can be drilled, and bushes used. It is essential that the thermocouples are firmly secured to the slab as they travel from the data logger to the measuring point. Often the thermocouples are channelled along groves in the slab surface so that the cables are confined within the slab eliminating snagging risks in the furnace, or on charging / discharging the equipment.

Real Time Communication

Conventionally profile data collected during the test is downloaded to a PC running analysis software post run. Alternatively, it is possible to collect data in real time live utilising an RF telemetry option. The data logger is available with a unique 2-way RF system option allowing live monitoring of temperatures as the system travels with the product through the furnace. Furthermore, if necessary using the RF system it is possible to communicate with the logger, installed in the barrier, to reset/download at any point pre, during and post-run.

Provided with a high performance 'Lwmesh' networking protocol, the RF signal can be transmitted through a series of routers linked back to the main coordinator connected to the monitoring PC (**Fig 7**). The routers being wirelessly connected are located at convenient points in the process to capture all live data without any inconvenience of routing communication cables as needed on other commercial RF systems. The operator from the convenience and comfort of his control room / office can see what is happening in the process live. For a 20 hour slab reheat process, such live data gives the operator confidence that process is working in real time, without that nervous wait with a non-RF system to download from the logger at the end of the run.

In many processes, there will be locations where it is physically impossible to get a RF signal out of the furnace. With conventional systems this results in process data gaps. For the PhoenixTM system this is prevented using a unique fully automatic 'catch up' feature. Any data that is missed will be sent when the RF signal is re-established ensuring in most applications 100% in-process data review.

Handling the Data

The result of the thru-process monitoring step is the invaluable temperature profile graph (**Fig 8**). The profile graph represents a thermal fingerprint of what temperatures the aluminium slab achieved through the process at the selected locations over the slab foot print and at specified depths within its core. The profile data can be interrogated in detail to fully understand the heat treat operation at the critical product level and be used to control, optimise and validate the furnace operation. Such data is essential to accurately set-up and verify mathematical model predictions used to control the furnace operation and ensure that the process is run efficiently to save energy, improve productivity and reduce carbon emissions.

Conclusion

Thru-process product temperature profiling is an accurate and efficient method to measure aluminium slab internal core temperatures in pusher furnaces prior to hot rolling operations. Product temperature information gleaned helps to ensure that the correct thermal balance is achieved efficiently throughout the product thickness. Non-homogeneous temperature conditions can be prevented that would potentially cause variation in downstream processing and compromised final product quality, ultimately leading to energy wastage, higher costs, and rejections. ■

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