

AISTech 2012 Conference and Exposition, Tuesday May 8, 11:00 AM

Session: Energy Savings Practical Applications (Energy & Utilities)

**Paper: ‘Ten Practical Tips for Ensuring Accurate Data
from Slab Reheat Profiling’**

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Keywords: slab reheat, thermocouple, data logger, mathematical model, system accuracy

INTRODUCTION

Mathematical modelling is used widely throughout the steel industry to control the transient times and drop out temperatures of steel slabs during the pre-rolling, reheat operation. Reheat furnaces are large dynamic entities and consume vast amounts of energy, so the efficiency of the operation depends on accurate control from the mathematical model. The model itself will take into account many parameters such as conduction in the slab, thermal radiation in the furnace, the effect of the furnace boundaries (walls, walking beams, etc.). But the mathematical model is essentially theoretical and requires verifying on a regular basis. This is achieved by the input of actual temperature data from a test slab which has thermocouples set at critical positions and depths, these feed temperature data back to recording instrument such as a data logger to log the temperature profile of these probed positions.



The test slab with thermocouples beneath the upturned angle iron protection. The data logging system is within the insulated package at the rear

The resulting data, normally in the form of a .csv file, is then compared to the predictions of the mathematical model, where adjustments can be made. The accuracy of the actual logged data from the test slab is therefore critical to the test and this paper

discusses not only the practical steps that can be taken to optimise this accuracy, but also the balance between the ideal testing conditions and the practical difficulties of achieving these conditions.

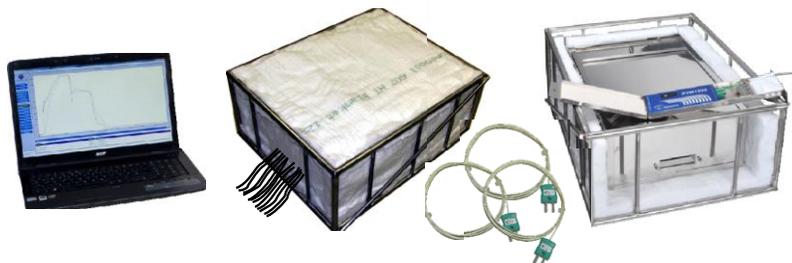
Slab reheat trials can involve days of preparation and are costly both in terms of the equipment used, and technicians time. Mistakes can mean lost data, or worst case, the destruction of an expensive monitoring system, so the preparation is vital. Safety however must be the first consideration as the recording instrument often has to be removed from test slab at high temperature, so basic safety considerations are also looked at.

DATA SOURCES

The information detailed in the ‘Tips’ below is based on the experience of carrying out trials and commissioning systems over the last twenty years. Many advances have been made in the instrumentation (data logger) and the insulating package or ‘thermal barrier’ that protects it during the trial in the furnace. The information is of a practical nature which is intended to help the technician in preparing and implementing accurate slab profiling trials.

BASIC ELEMENTS OF THE DATA COLLECTION SYSTEM

The basic data collection system consists of a data logger able to operate at temperatures of up to 110°C, a thermal barrier able to operate up to 1300°C for periods of up to 8 hours (in case of process interruptions), thermocouples, and software to analyse data and convert to .csv format.



From left to right: software, fully insulated thermal protection barrier, thermocouples, data logger on top of partially insulated barrier showing water barrier

TEN PRACTICAL TIPS

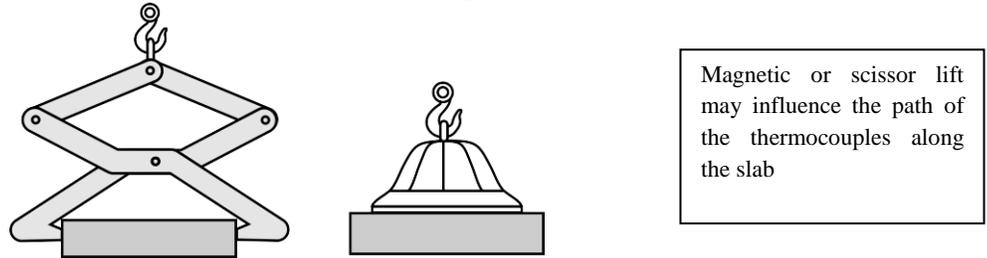
1. **Basics: Plan the measurements required.** How many thermocouple measuring points are required? Today a single data logger can record temperature information from up to twenty thermocouples, and there is a tendency to take full advantage of this to gather as much information as possible. However consideration should be given to the difficulties of manipulating twenty probes around the test slab and more importantly getting all the probes into the thermal barrier. So a balance should be struck between the optimum number of thermocouple points required to compare to the model, and the difficulty of practically setting these into position. Generally the critical points will include measurements at the surface, centre and base of the slab at various positions along its length. Additional data may also be required from probes set within the ‘shadow’ of the walking beam, or from positions marked as critical where a back up probe is required in case of failure.



Data loggers which can accept up to twenty channels are now obtainable. But the number of thermocouples must be balanced against the difficulties of manipulating these on the test slab, and into the thermal protection

To summarize, balance the optimum number of measuring points against the difficulties of manipulating the thermocouples into position.

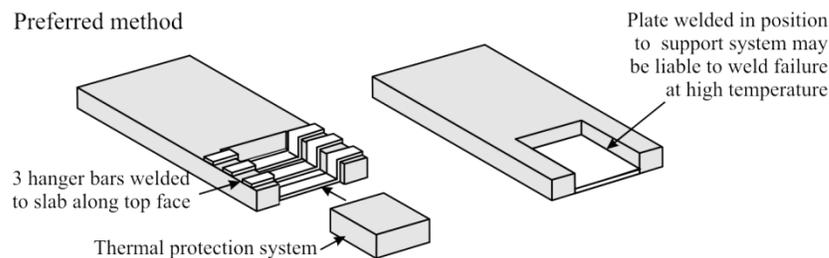
2. **Basics: Plan how to charge and discharge the test slab to and from the furnace.** This may not seem so important, but is vital, especially from a safety point of view. When charging the test slab consideration must be given to how it is transported to the furnace hearth. Setting thermocouples along the top of the slab may not be possible if a magnetic lifting device has to be used. Conversely thermocouples set along the side of the slab may cause problems if a 'scissor' lift is used.



When the slab exits the furnace it will need to be transported to a safe working area where the data logger can be quickly removed from the hot thermal barrier. It needs to be at a safe working height where the technician can easily remove the insulation (waist height is best). Placing the hot slab on top of a pile (4 or 5) of cold slabs is often a good temporary workplace. Ensure the area is cordoned off (for the safety of onlookers), and check that the surrounding area is cleared of all waste material etc. It is not a good idea to hold the slab 1 metre or so above a painted floor while the logger is removed as this could constitute a fire hazard! It is a good idea to have several pieces of cut blanket nearby to throw over the hot thermal protection barrier and so reduce the amount of heat being radiated from the working area.

Finally carefully check what is downstream of the test slab path. For example a de-scaler may impede the passage of the test slab, if so can the chains be removed and the water jets turned off? Most thermal barriers cannot be subjected to a water spray as the secondary insulation layers in the thermal protection box will be destroyed.

3. **Basics: Check and double check the clearance in the furnace.** This is especially important at the furnace entrance and exits to ensure the thermal protection barrier on the slab will pass through unimpeded. It should also be noted that clearance inside the furnace may be limited by a 'knuckle' or baffle between the hot zone and the pre-heat area. To reduce the overall height of the protection barrier on the test slab, the system is normally placed into a space machined from one end of the slab. This can reduce the overall height to 325mm to 350mm minimum, which is normally enough to pass through the entrance and exit doors of the furnace. However care must be taken in supporting the thermal barrier. Welded plate supports may be considered risky as at high temperature, the welded joints may fail with disastrous results. Today most plants will support the data logging system on 'hanger' bars which are forged from solid 25mm thick steel strip, welded to the test slab. Check also that the lift of the walking beam at the entrance of the furnace will allow the thermal barrier through without crushing the top layers of insulation.



4. **Accuracy: Selecting the correct type of thermocouple.** This can have an impact on the accuracy of results. The first question is what type of thermocouple is best? There is a debate about whether to use type N or type K thermocouples. It is generally accepted that type N are more stable at high temperature than type K and therefore have better accuracy, however type N thermocouples have an upper measuring limit of 1300°C (limitation is the 'look up' table), whereas type K has an upper limit of 1370°C. This may be critical when atmosphere temperatures around the slab are being monitored, as these can often exceed 1300°C. In slab reheat both N & K types are likely to be working in their upper range, whereas noble metal thermocouples, types S & R, would be within their capabilities. However cost, and the challenge of insulating this type of thermocouple generally prohibits their use.

5. **Accuracy: Size and construction of the thermocouple.** When a decision has been reached regarding whether to use type N or K thermocouples, the next decisions are thermocouple size and construction. The most common construction of thermocouples used for slab reheat monitoring is MI (Mineral Insulated). These are metal sheathed and the individual thermocouple wires ('Chromel' and 'Alumel' in the case of type K) are insulated from each other, and from the sheath, by compacted magnesium oxide. An alternative construction is to insulate the individual thermocouple wires with ceramic 'beading' or 'twin bore' ceramic tubing. However this is generally considered to be too prone to breakage during set up, with the risk of the insulation beads opening, the wires crossing over, and creating a hot junction at that point.

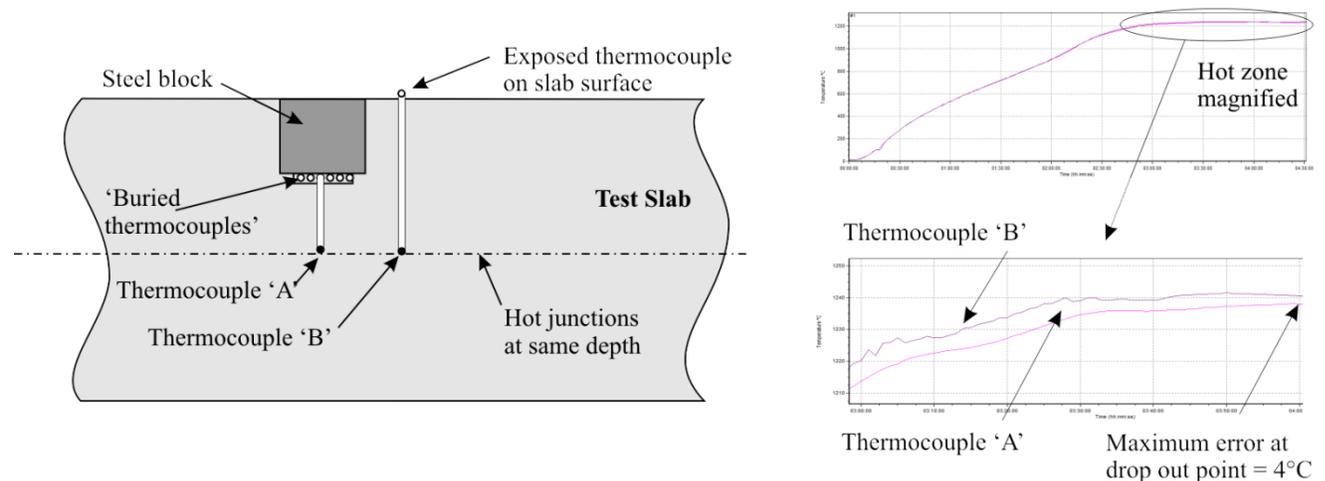


If mineral insulated (MI) thermocouples are selected, the next question is the size, or diameter, of the thermocouple itself. This is important as it can have a big effect on the accuracy of the readings. With small diameter MI probes the resistance of the magnesium oxide insulation can, at elevated temperatures, break down creating 'shunt impedance' errors. These errors are liable to occur when the thermocouple body (on the surface of the slab), is at a higher temperature than the hot junction, (in the centre of the slab). In an actual process these conditions can occur when the slab is entering the hot zone and the centre of the slab is 'colder' than the outside. There are two ways to minimise these errors:

- **By placing the body of the thermocouple at a similar level to the hot junction** or measuring point.
- **By increasing the MI sheath diameter** to increase the amount of insulation between the thermocouple wires and minimize the possibility of the insulation resistance breaking down.

Both these solutions have advantages and disadvantages which are discussed below:

Placing the body of the thermocouple at a similar level to the hot junction or measuring point involves machining a 'groove' in the slab, for example 50mm deep where the thermocouples can run, then covering them with steel blocks which are welded into place. The machining of the slab can be costly and time consuming but the results are measurable. An experiment was recently carried out where two mineral insulated thermocouples from the same batch of wire were set to measure at the same point in the centre of the slab. One thermocouple was 'buried' beneath steel blocks, and the other was laid unprotected on the slab surface.



The test slab was subjected to a full process of 4.5 hours at a final process temperature of 1240°C. Results showed that at the entrance to the hot zone the difference between the two thermocouples was 7.5°C, and at the drop out point the difference was 4°C.

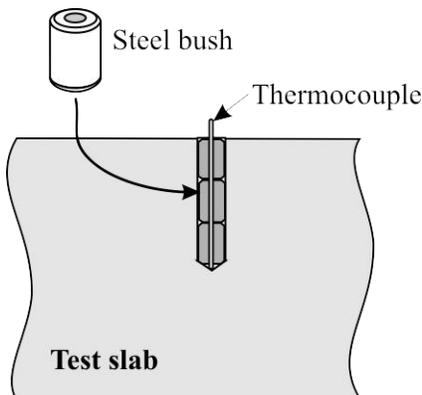
Increasing the diameter of the mineral insulated thermocouple can help to increase accuracy but a balance has to be struck between the highest achievable accuracy, flexibility when installing, and heat transfer back into the measuring system. Commercially, mineral insulated thermocouples for slab reheat applications are available in a range of diameters; 3.0mm, 4.5mm, & 6.0mm. Of these the latter, 6.0mm diameter, is considered too inflexible to manoeuvre around and into the data logging system, especially where 10 or more thermocouples are concerned. Ten 4.5mm diameter MI thermocouples may be just possible to fit onto the data logger and fit back in the thermal protection, but the heat transfer along the metallic sheath and back into the data logger cavity must be considered. The surface area of the sheath of a 4.5mm diameter MI thermocouple is approximately 50% greater than a 3.0mm diameter probe and would therefore conduct far more heat back into the system. The best compromise, for accuracy, flexibility, and minimum heat transfer, is the 3.0mm diameter MI thermocouple, and it is not surprisingly the most commonly used for these trials.

6. **Accuracy: Thermocouple lengths must be calculated carefully.** Thermocouples stretch from the measuring point (the ‘hot junction’) in the slab, back to the data logging system, and may exceed 7.0 metres in length. Enough extra length must also be included to allow for the logger to be inserted into the thermal barrier, but this additional length should be minimised to prevent too much of the thermocouple body being exposed to the direct heat of the furnace. When there is excessive thermocouple length, more of the thermocouple body is exposed to the atmosphere and therefore the greater the possibility that ‘false hot junctions’ could occur. The excess thermocouple length, should wherever possible, be protected from the direct heat of the furnace by covering it in high temperature insulating blanket.



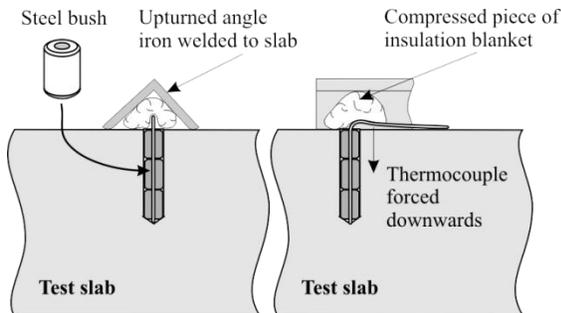
The excess length of thermocouples is carefully wound on top of the insulated thermal barrier and covered with extra insulating blanket to reduce heat.

7. **Accuracy: Placing thermocouples into slab.** The importance of this is often overlooked; the mechanics are that a 3mm diameter thermocouple has to be inserted up to 200mm deep into a slab (if base temperatures are to be measured). It is very difficult to drill a 3mm clearance hole to this depth and generally a much larger hole is drilled (say 20mm diameter) for the probe. However to maximise accuracy of the temperature measurement, filling the void between the internal wall of the drilled hole and the external sheath of the MI thermocouple should be considered. Insulating blanket or air setting liquid ceramic cement is often used as a filler material to try to insulate the thermocouple. The best method found, which maximises accuracy, is to manufacture steel bushes which are a close fit around the thermocouple and to the inside of the drilled hole. These bushes should have similar heat transfer characteristics to the slab material.



Steel ‘bushes’ guide the thermocouple down to its measurement point. These have heat transfer characteristics to the slab material

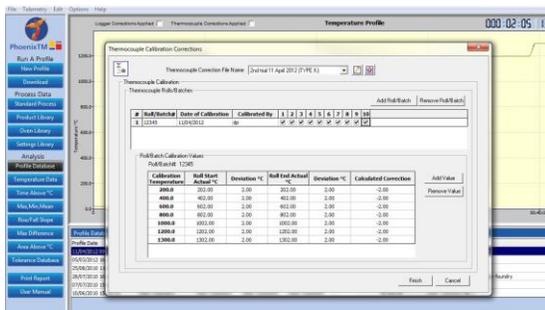
8. **Accuracy: Ensure good thermocouple contact at the measurement point.** Mineral insulated thermocouples initially have a residual ‘springiness’ and need to be held in contact with the steel at the base of the hole (where the measurement is required). If this contact is not made, or is intermittent, the hot junction of the thermocouple will measure atmosphere temperature, rather than actual stock temperature. To prevent this the thermocouples should be held in position by packing insulating blanket beneath a piece of upturned angle iron and ‘tack welding’ this to the slab surface. This forces the thermocouple down into place. The angle iron should cover the whole thermocouple to prevent direct flame impingement from burners etc.



Compressed fibre insulation maintains a downward pressure on the thermocouple keeping it in contact with the bottom of the hole (where the measurement is required).

9. **Accuracy: Selecting the correct type of data logger.** There are a range of data loggers that can be used to monitor temperature, but the environment the data logger operates in will be very testing. The requirements for an instrument that will deliver consistently accurate readings are:

- Ability to operate for long periods at high temperature (100°C to 110°C). This is because most thermal protection devices use water as a phase change medium to keep the data logger at a safe working temperature and during the process the water will reach boiling point and will stay at this temperature for a period of hours.
- Ability to consistently maintain a high accuracy (+/- 0.5°C or better) at high temperature.
- Data loggers need to be rugged due to the testing environment they operate in. instruments with plastic casing and LCD displays are unlikely to last or meet the accuracy requirements for this type of operation.



Software with ability to enter instrument and thermocouple correction factors (left), and data logger capable of high temperature operation.

10. **Accuracy: Software with the ability to add or subtract correction factors.** Most mineral insulated thermocouples can be calibrated at specified temperature points and supplied with a certificate detailing the deviations. These data can be entered into specialised software packages and will display the corrected temperature data. It is only possible to use these correction factors on new thermocouples, as once they have been subjected to reheat temperatures; the correction factors will no longer be valid. Software should also have the ability to apply correction factors from the instrument (data logger), and be able to export the corrected data in .csv format.

CONCLUSION

A high degree of accuracy is achievable in slab reheat trials if careful consideration is given to the selection of the instrumentation, software, and especially the thermocouples. It is worth making the investment in good quality, calibrated thermocouples, even though they will only be used for the one trial. Accuracy also depends on the care and attention given to setting up the test slab with emphasis on the protection of the thermocouples during the trial.