The Development of Ceramic-Based Thermocouples
Rowan Technologies - October 2008

Rowan Technologies has been developing ceramic-based thermocouples for a number of years, beginning with a government-sponsored project in the mid 1990s. Several companies have shown interest in the technology, and provided funding, over this time. In the early stages of development, interest was of an exploratory nature but more recently substantial progress was made in using the technology as a direct replacement for high-accuracy type B thermocouples in the continuous casting of molten steel at around 1500-1600 ºC.

The technology is based on the use of electrically-conductive ceramics, rather than metals, as the two legs of a thermocouple assembly: the ceramics are in direct electrical contact at the 'hot junction' and metallic conductors are used at the 'cold' end of the ceramics to measure the resulting emf and compensate for the 'cold end' temperature. When used as discrete sensors - one leg of the thermocouple typically comprises a ceramic tube into which the second leg is inserted - forming a concentric rod and tube assembly. Either a general purpose data acquisition system, or dedicated electronics, can then be used to process the signals and output the temperature of the hot junction.

The technology has several potential benefits: ceramics can be very resistant to chemical attack and as such are especially appropriate in high temperature applications and in harsh (i.e. both oxidizing and reducing) environments. The materials are cost-effective when compared with precious metals such as platinum and rhodium. They may find application where metallic thermocouples are wholly inappropriate, in environments such as gas turbines and other high temperature plant, or as direct replacements for existing temperature measurement technology.

During the course of development, a better understanding of the ceramic materials' thermoelectric properties and improvements in appropriate calibration and measurement instrumentation, has meant that achievable accuracies have improved substantially to the point where high temperature measurements in the laboratory were generally accurate to within about 0.3%, whilst measurements in molten steel (for example) were often accurate to within 0.5% (compared with neighbouring type B thermocouples). Known thermoelectric inconsistencies within one of the ceramic materials used in the ceramic thermocouples has, to date, been the limiting factor to higher accuracies.

Steel Plants Trials

Several trials of our thermocouples have taken place in three separate steel plants in Germany, including the largest of the German plants - Bruckhausen.

Prior to the site tests, the ceramic thermocouples were tested and calibrated in a laboratory-based furnace. Typical results from a furnace temperature cycling test are shown in Figure (1): the furnace temperature was cycled between 1400 - 1600 ºC over a period of several hours. The figure shows the ceramic thermocouple tracking the signal from an adjacent type B thermocouple.

At the steel plants, the thermocouples were positioned in a tundish which is essentially a reservoir, or bath, of molten steel between the ladle and the continuous casting area - steel flows in a controlled fashion from the ladle into the tundish and then out from the bottom of the tundish to the casting area. Typical cast sequences last between 1-4 hours. The temperature of the steel has to be closely monitored in the tundish - if the temperature is too cold then the steel will solidify prematurely, if it is too hot then this wastes heating energy and may necessitate slowing of the casting process to allow the steel to cool sufficiently. Casting temperature may also effect steel quality.

In a tundish, the thermocouples are protected from direct contact with the steel using graphitised ceramic protection tubes. Figure (2) shows a thermocouple installed in a cradle and protection tube in a tundish. An insulating layer is put on top of the molten steel to minimise heat loss. Figure (3) shows a thermocouple within a protection sheath of a retractable arm, which has just been removed from the tundish, and a still-hot thermocouple is shown in Figure (4).

Typical results from the trials are given in Figure (5) and (6). In these graphs, the thermocouple output is compared with 'dip' measurements i.e. one-shot measurements of a disposable type B thermocouple which is 'dipped' into the molten steel with a lance. Figure (7) shows the ceramic thermocouple measurement in the foreground (calculated using dedicated electronics) with the dip measurement on a large display in the background.

Possible Applications

The ceramic-based thermocouples are particularly suited to harsh/corrosive high temperature environments. They may be constructed as discrete sensors, such as the application for molten steel described above, or as an integral part of a plant component in the form of ceramic coatings.

For example, some preliminary work has been undertaken using thin coatings of ceramic material applied to metallic surfaces - the 'legs' of the thermocouple are fabricated in such a way that they are electrically insulated from the metal, and each other, except at the hot junction. One possible application might be within gas turbines to measure, for example, the turbine inlet temperature. Ceramic thermocouples can potentially operate up to about 1900 ^{o}C.

Future Work

To achieve accuracies as good as existing metallic thermocouples, further work is still required to optimise the electrical 'consistency' of the ceramic materials. This may well require some degree of collaboration with relevant ceramic manufacturers.

For thin-coating thermocouples, although some preliminary tests have already taken place, further fundamental research is still needed on the electrical behaviour of the ceramic coatings before field tests can begin.

Rowan Technologies is looking for collaborators to fund the commercial development of the ceramic thermocouples and to exploit its market potential. Further information can be obtained by contacting Dr. David Farrell at mail@rowantechnologies.co.uk.

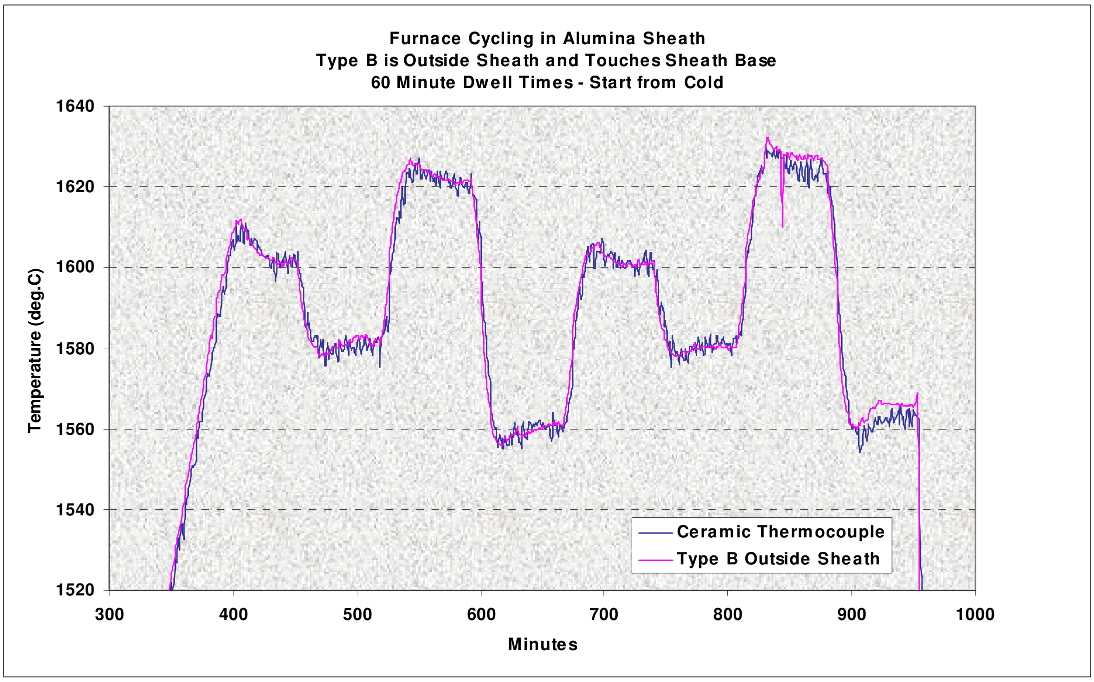


Figure 1 - Typical Laboratory Furnace Cycling Tests

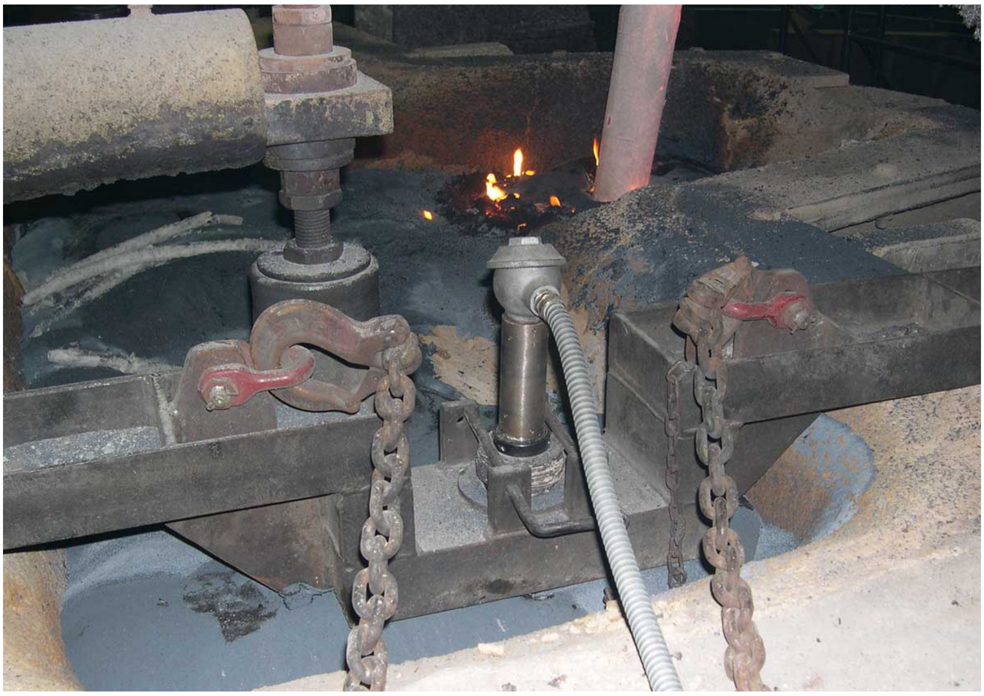


Figure 2 - Cradle-Mounted Ceramic Thermocouple
within Steel Plant Tundish

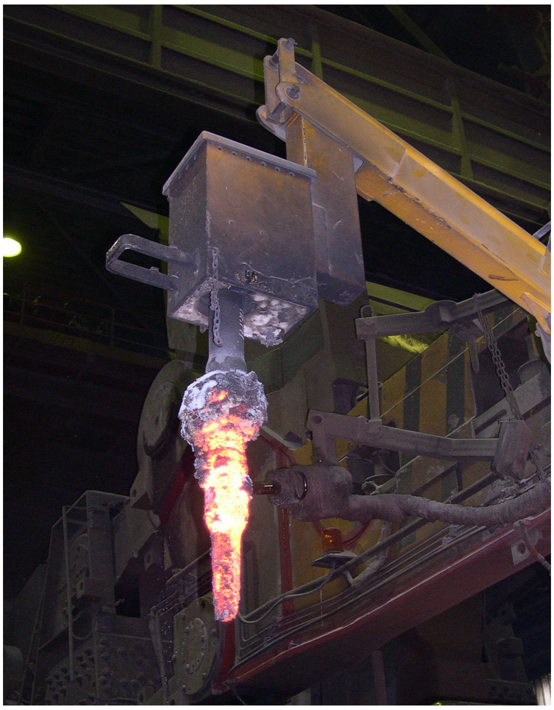


Figure 3 - Thermocouple within Protection Sheath of a Tundish Retractable Arm

Figure 4 - Thermocouple just Removed from Tundish Cradle and Protection Sheath

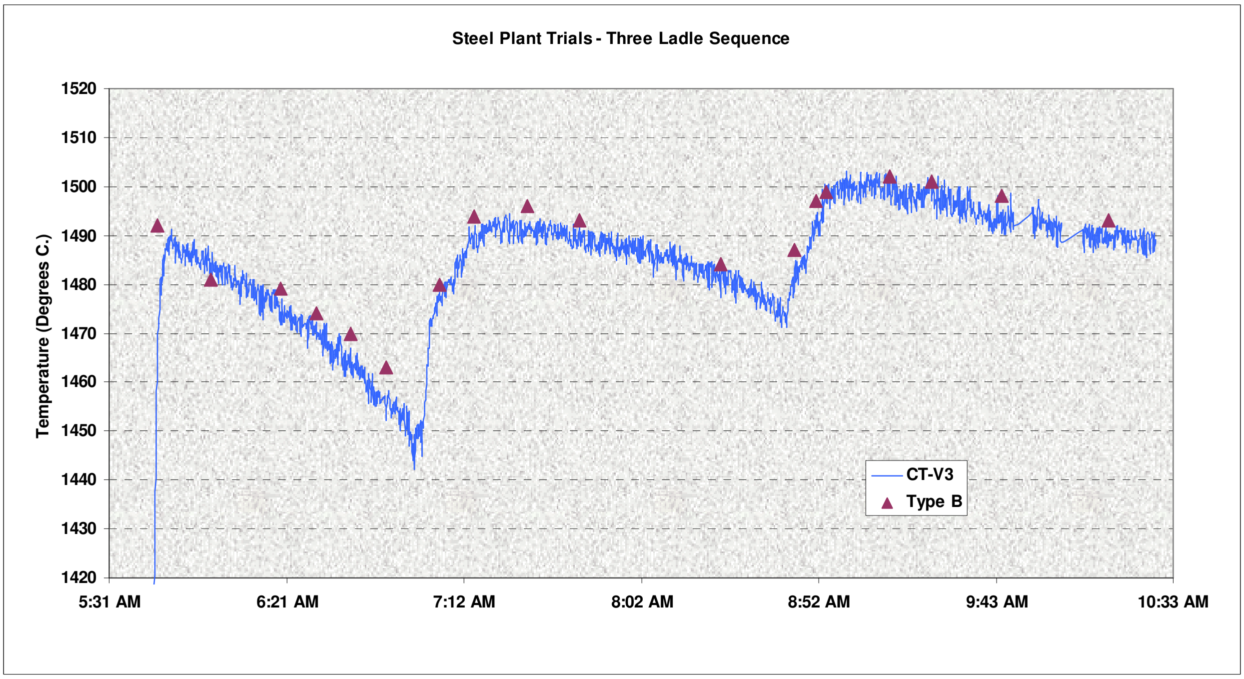
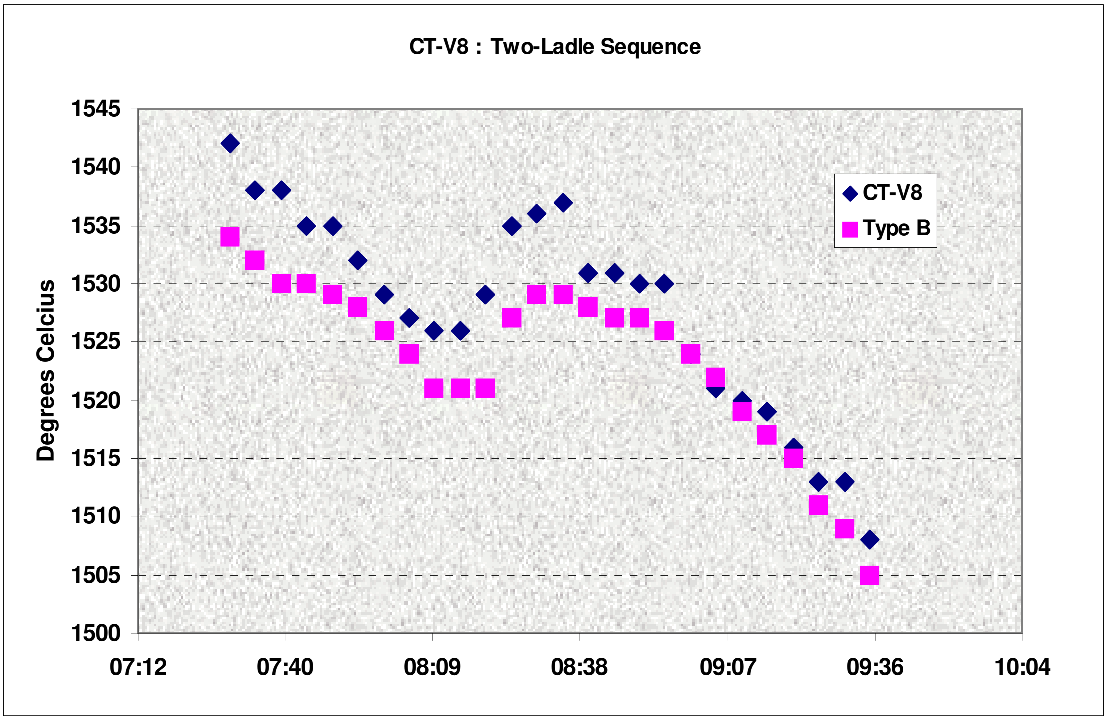
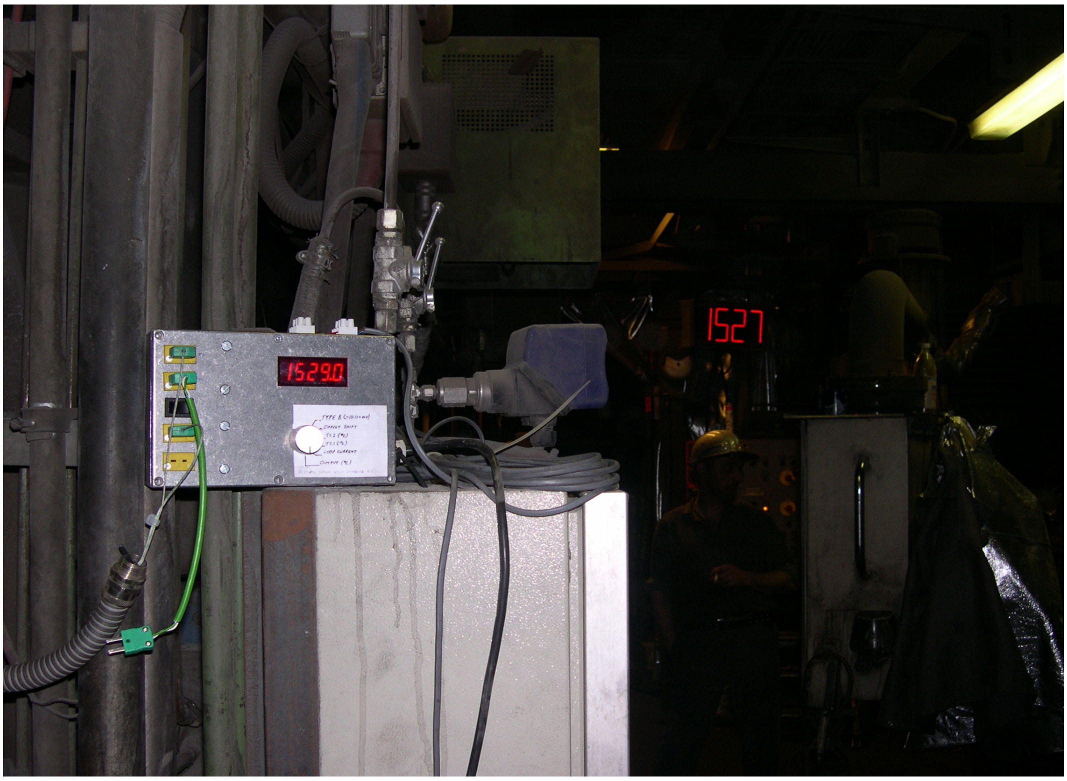


Figure 5 - Typical Molten Steel Casting Sequence: 3-Ladle Cast
The Ceramic Thermocouple is Compared with a Type B





Figures 6 and 7 - Two ladle Casting Sequence: The Ceramic Thermocouple is Compared with a Type B. The Output from the Ceramic Thermocouple is Shown on the Dedicated Electronics in the Foreground, and the Type B Output in the Background of the Photograph.