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Department of Materials Science and Metallurgy

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Marmon Wire & Cable / Berkshire Hathaway Company

# Low drift Type K and N Mineral Insulated thermocouples for high temperature applications


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# Agenda

- Introduction to Low Drift thermocouples
- Thermocouple Life v Thermocouple Effective Life
- Summary of Cambridge tests and initial CCPI tests
- Latest CCPI tests on dual wall MI cable
- Other tests (EMPRESS)
- The next step: Alternative geometry

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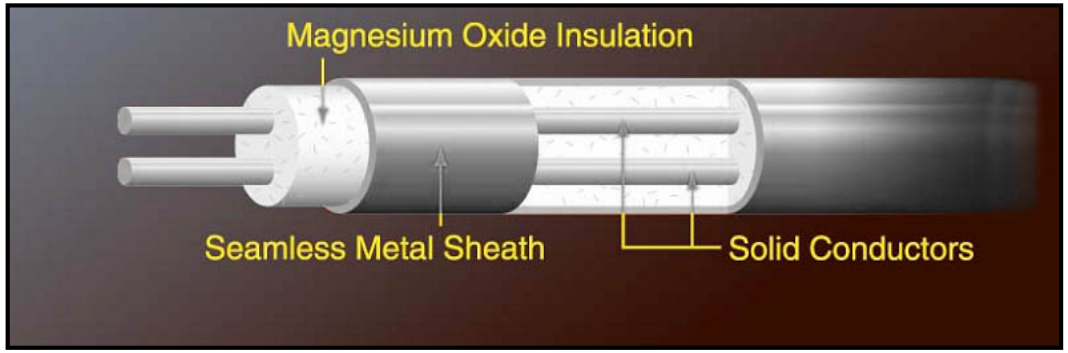
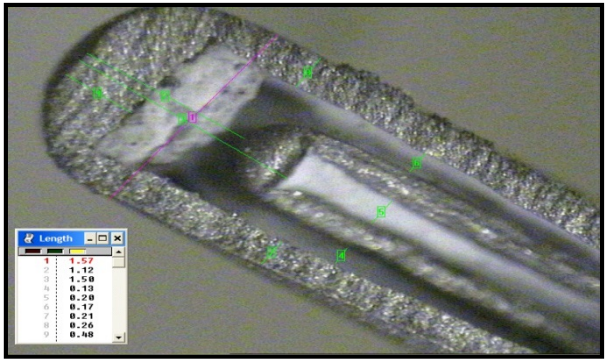
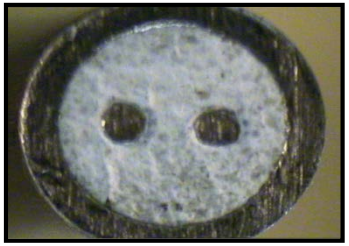
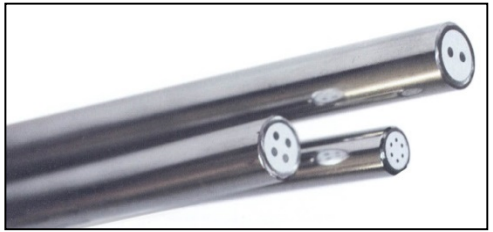
# Mineral Insulated Metal Sheathed (MIMS) thermocouples







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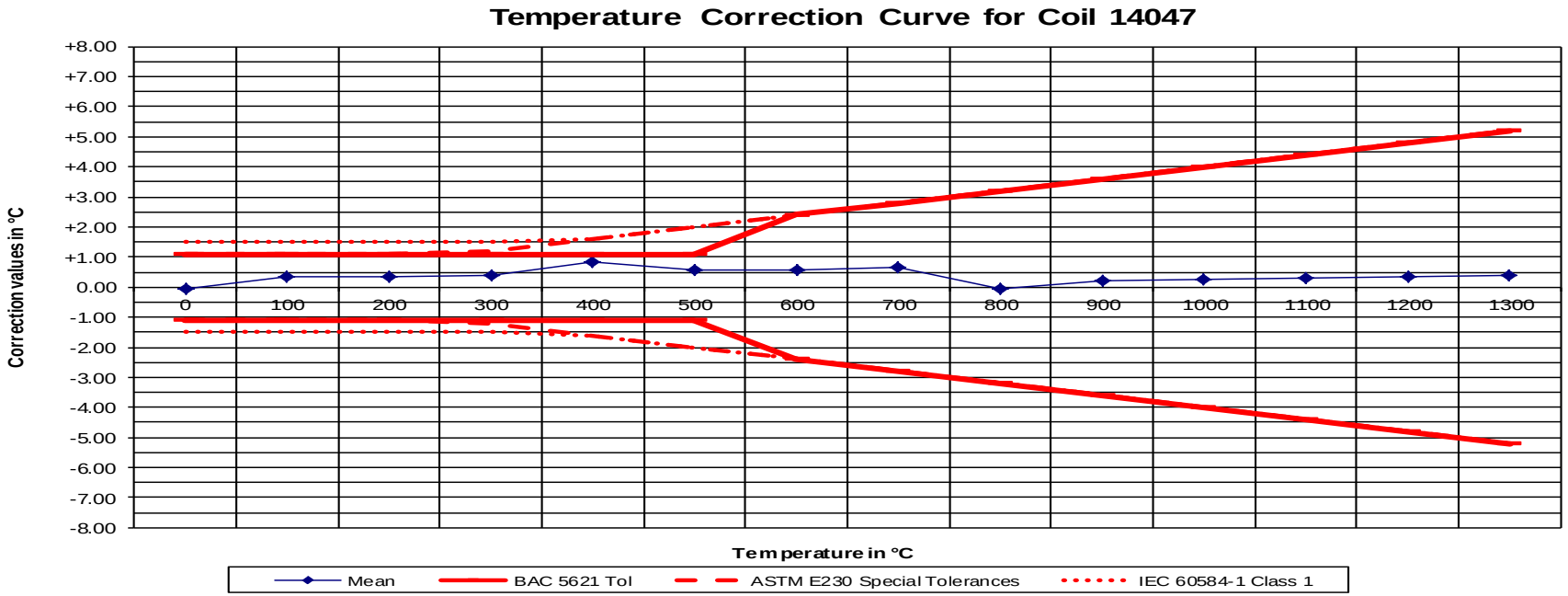
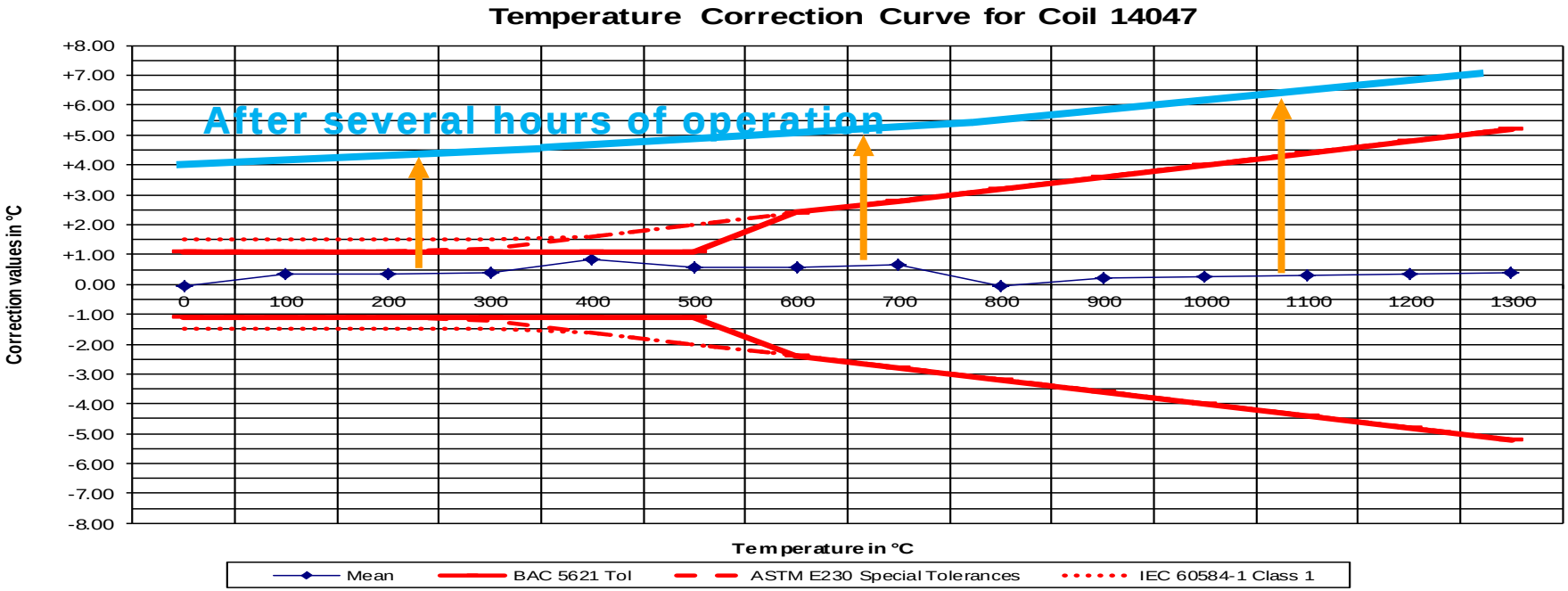
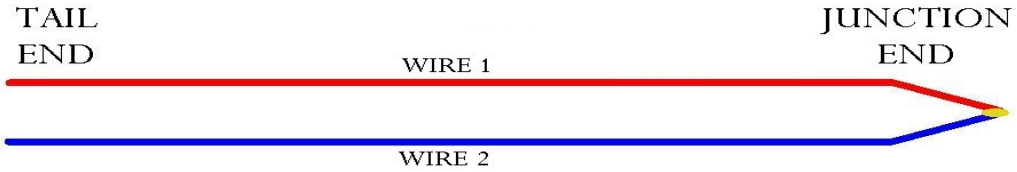
# An example of tolerance bands



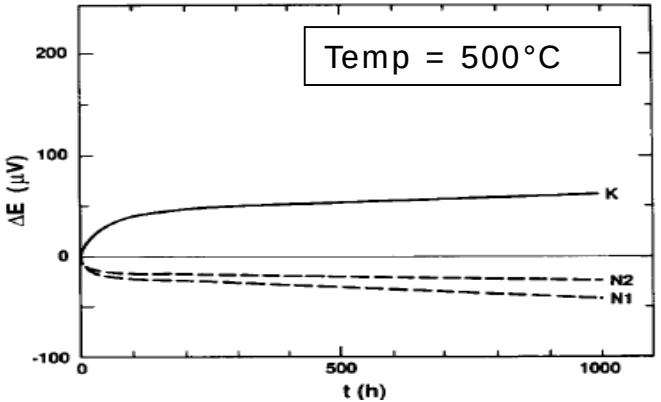
# Thermocouple Drift (1)



# Thermocouple Drift (2)




$$Emf = \int S \cdot \frac{dT}{dx} \cdot dx = E_0 + \Delta E_1 + \ldots + \Delta E_n$$




**Ideal thermocouple output**

**Time dependent metallurgical modifications:**

- Oxidation
- Short range ordering
- Depletion/change in composition
- Other physical/chemical changes

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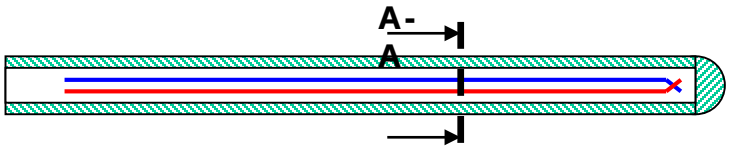
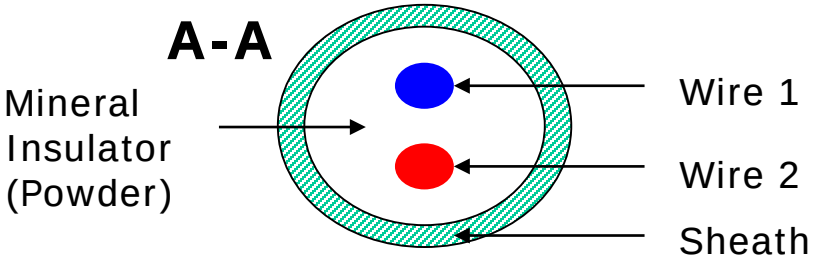
# Challenge to reduce Drift




- Conventional MIMS (Mineral Insulated Metal Sheathed) TCs experience significant drift above 1000 °C
- Improved temperature measurements are much needed for industrial applications: this led to a detailed investigation in to the specific causes of drift in mineral insulated thermocouples at the University of Cambridge.
- From this investigation a new design of thermocouple cable has been developed at the University of Cambridge

# The new thermocouple

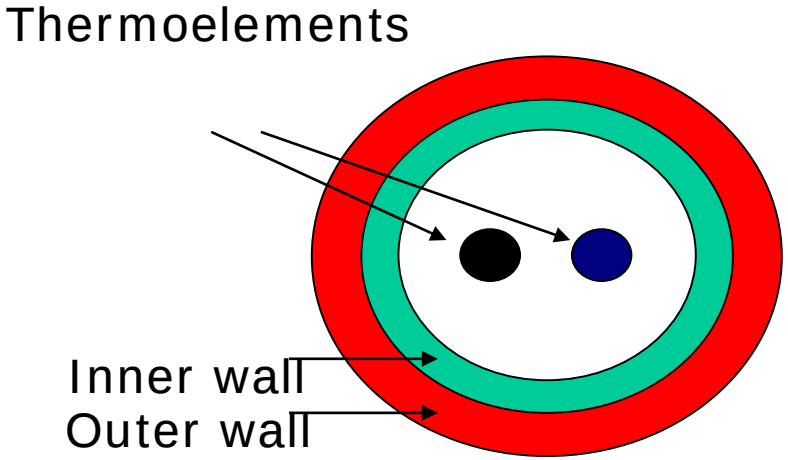
- Contamination from the sheath to the thermoelements is the major cause of drift in conventional MIMS

- The new sensor is based on new sheath

- **Minimise contamination from sheath to thermoelements**

- **Thermoelements**: flexibility to use type K, type N,...

- **Patent issued & pending**



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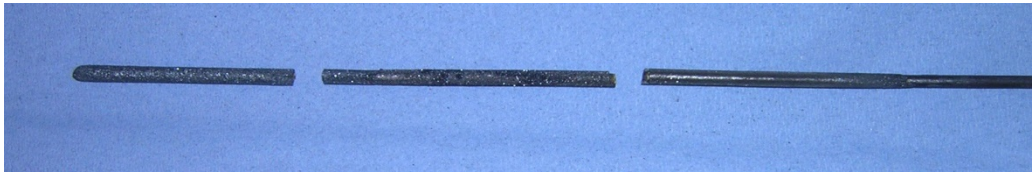
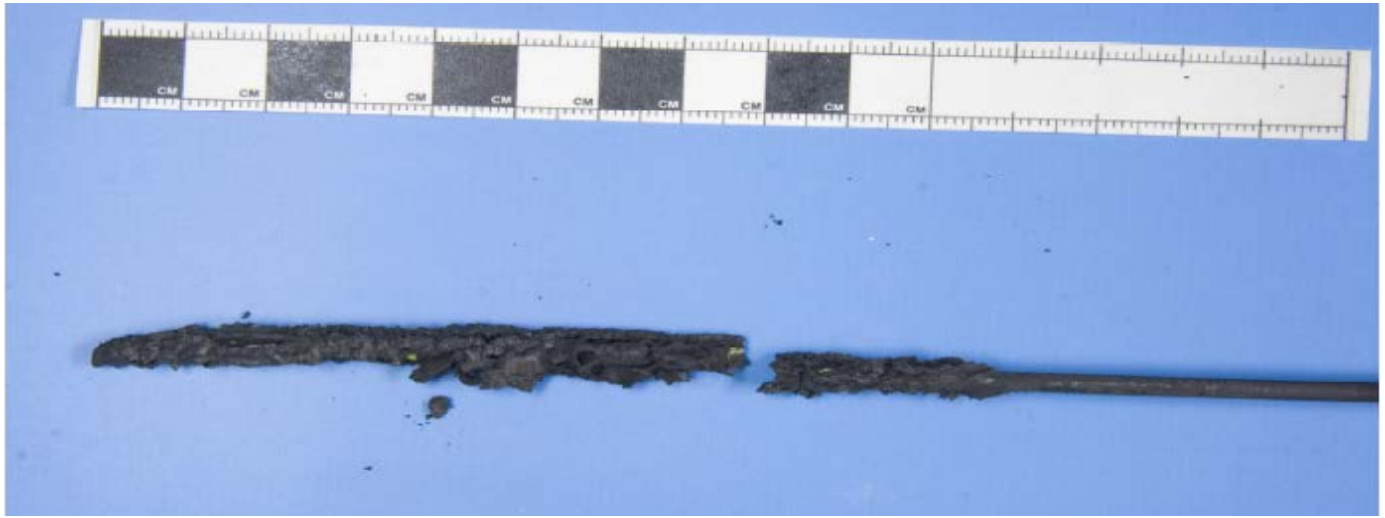
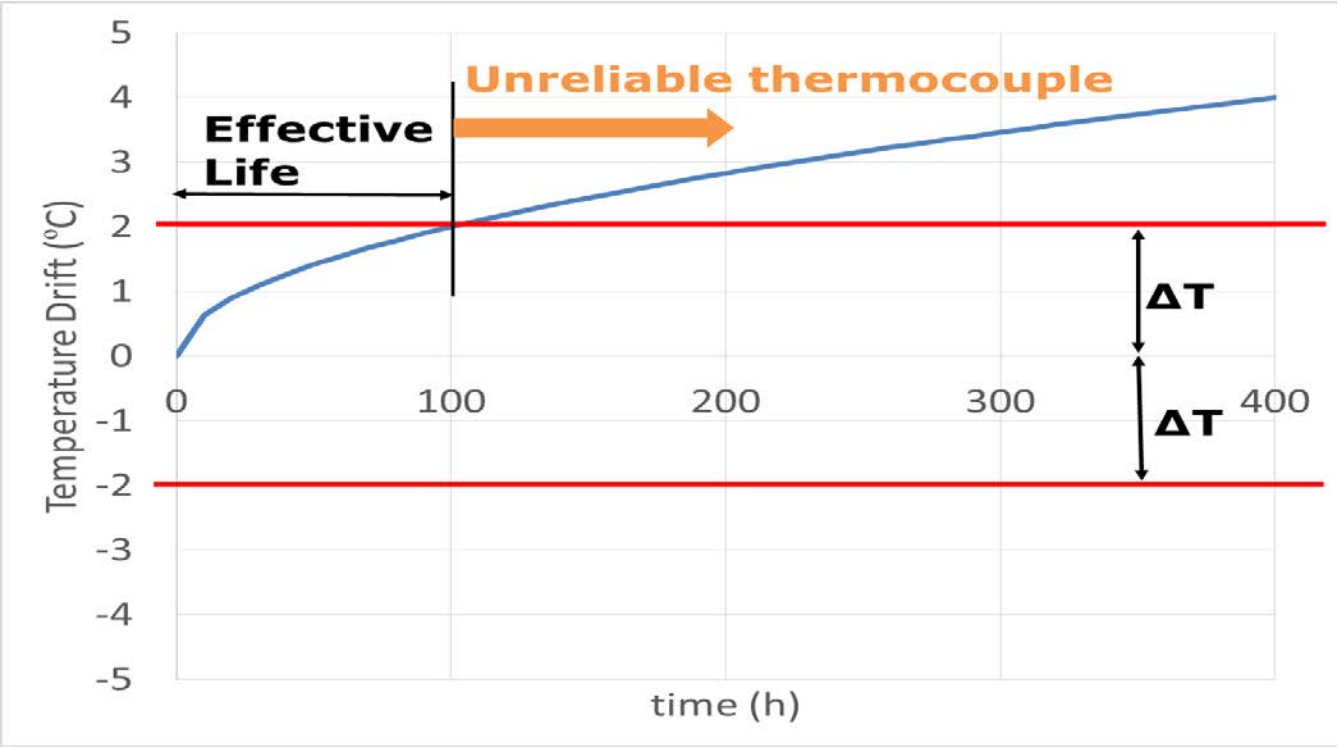
# The life of TCs

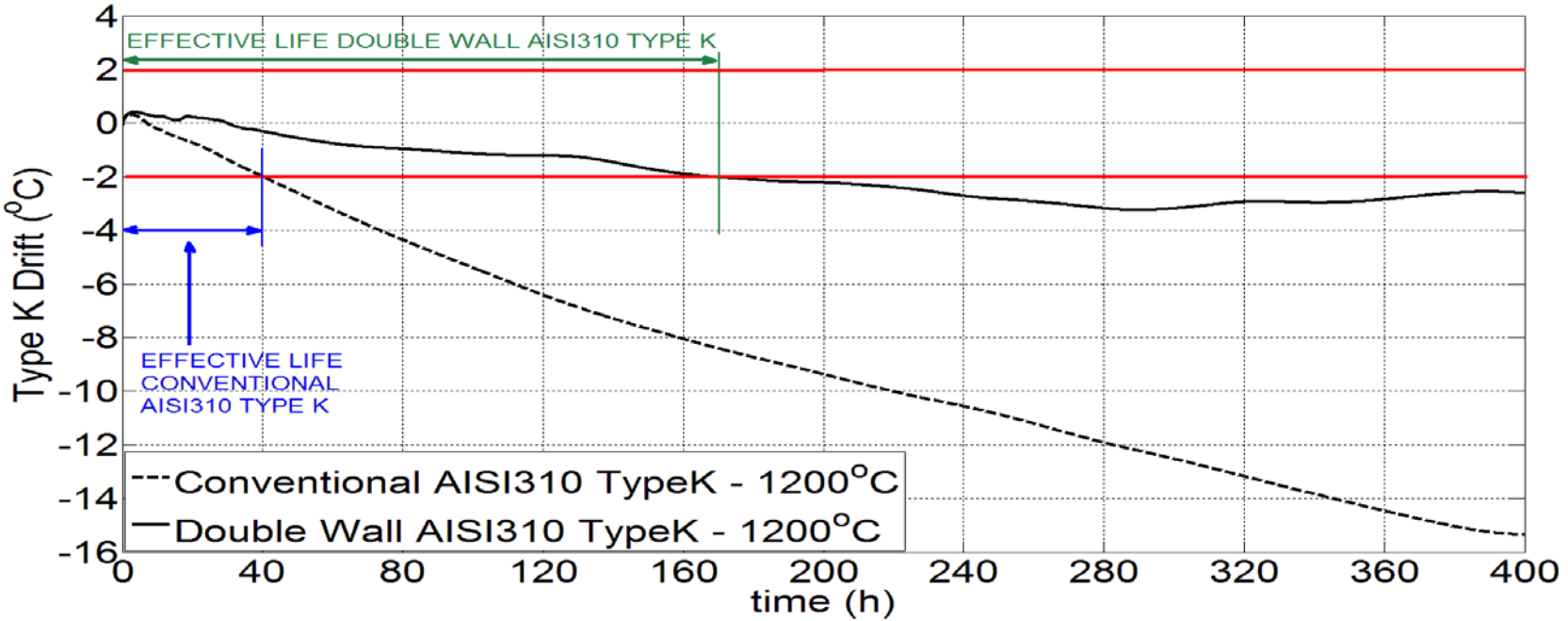




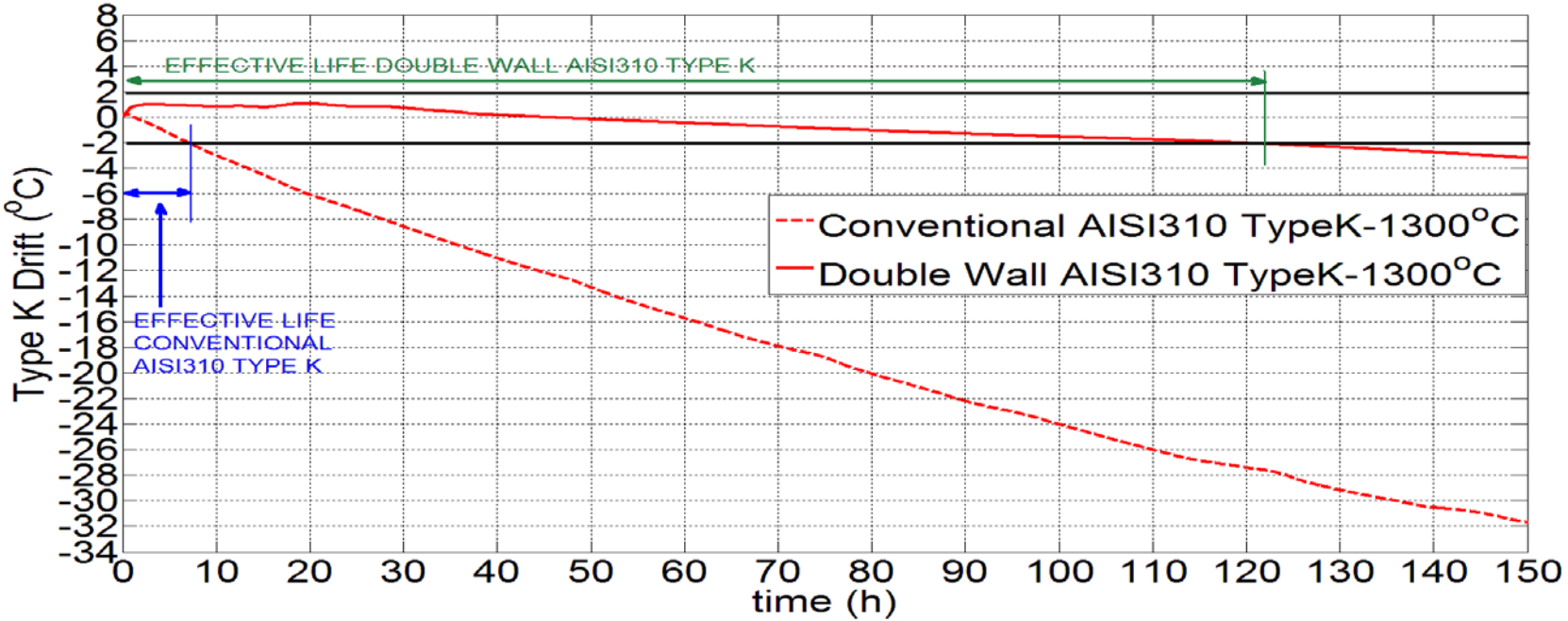
# The life of TCs: *Effective Life*



# Drift tests:AISI310 - 1200°C



# Drift tests:AISI310 - 1300°C



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# Drift tests AISI310: Summary

| | Total Drift |
|---|---|
| 1200°C – 400h (conventional TC) | **-15 °C** |
| 1200 °C – 400h (new TC) | **-2.5 °C** |
| 1300°C – 150h (conventional TC) | **-31 °C** |
| 1300 °C –150h (new TC) | **-2.5 °C** |

⇨ **1200 °C: Over 80 % drift reduction**

⇨ **1300 °C: Over 90 % drift reduction**

- Validation of the concept the new sensor is based on
- Path for reliable Ni based sensor working up to 1300 °C

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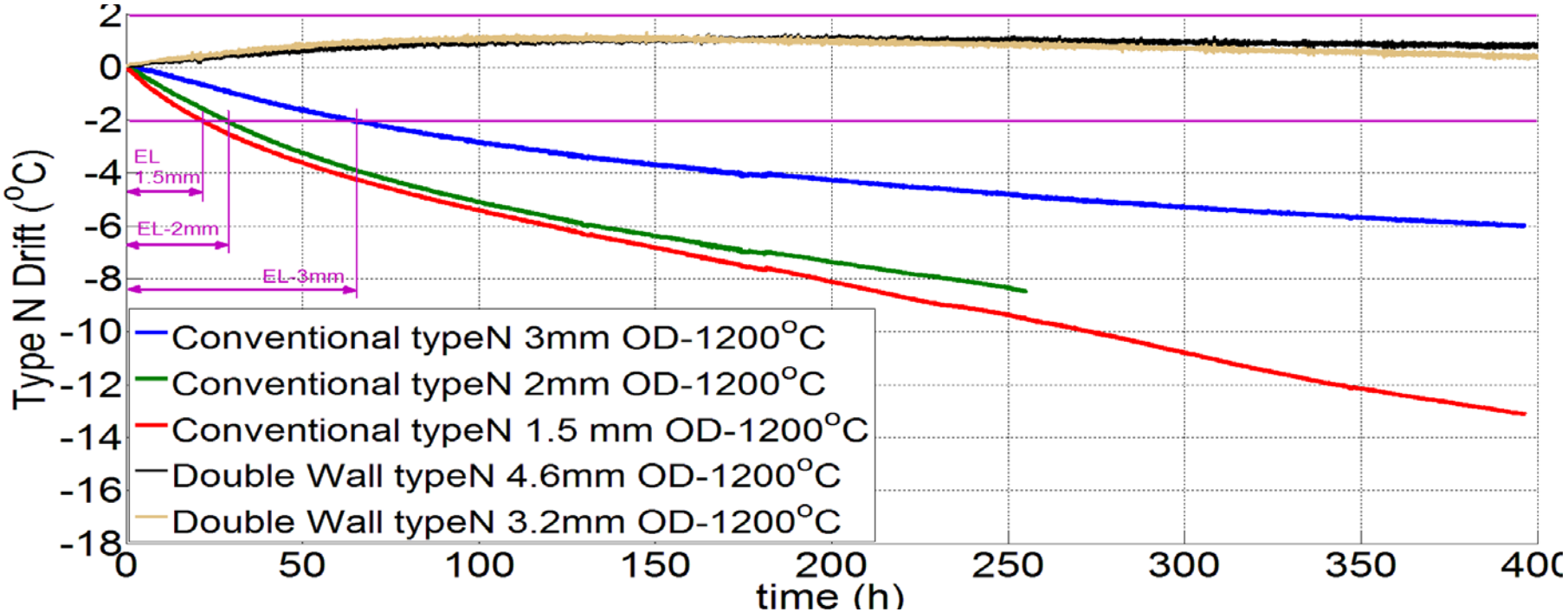
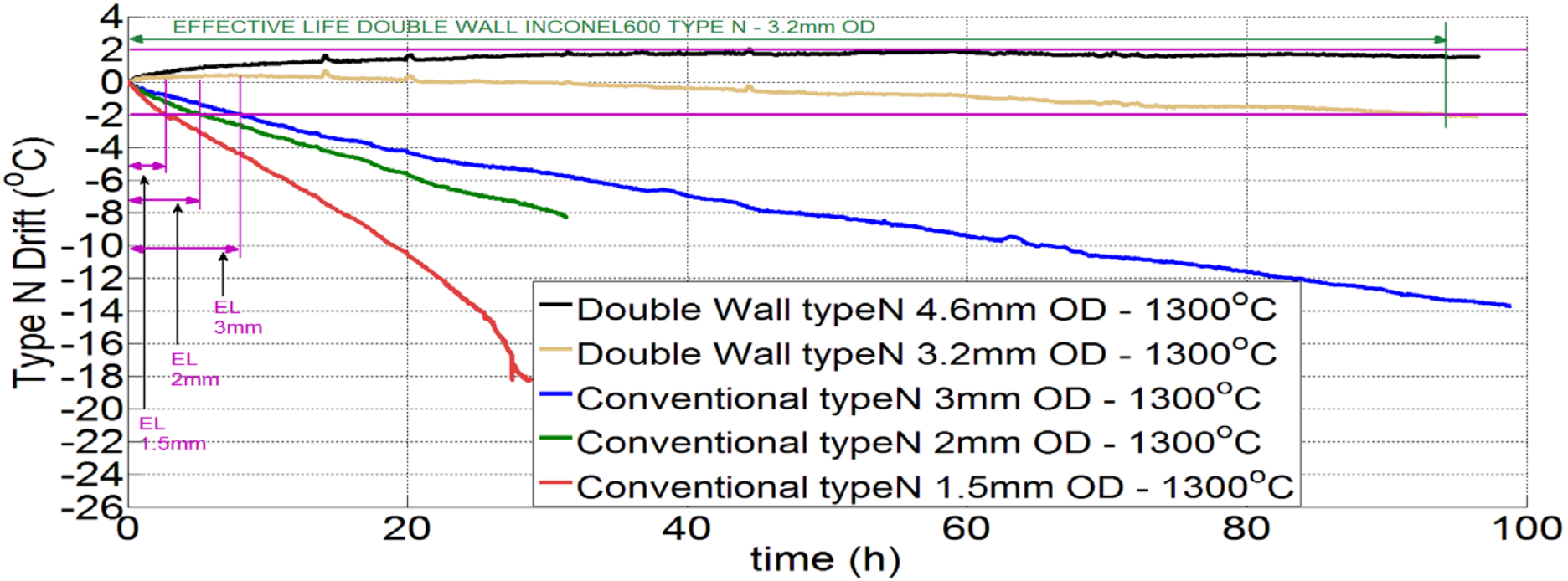
# Drift tests: INC600 - 1200°C



# Drift tests: INC600 – 1300 °C



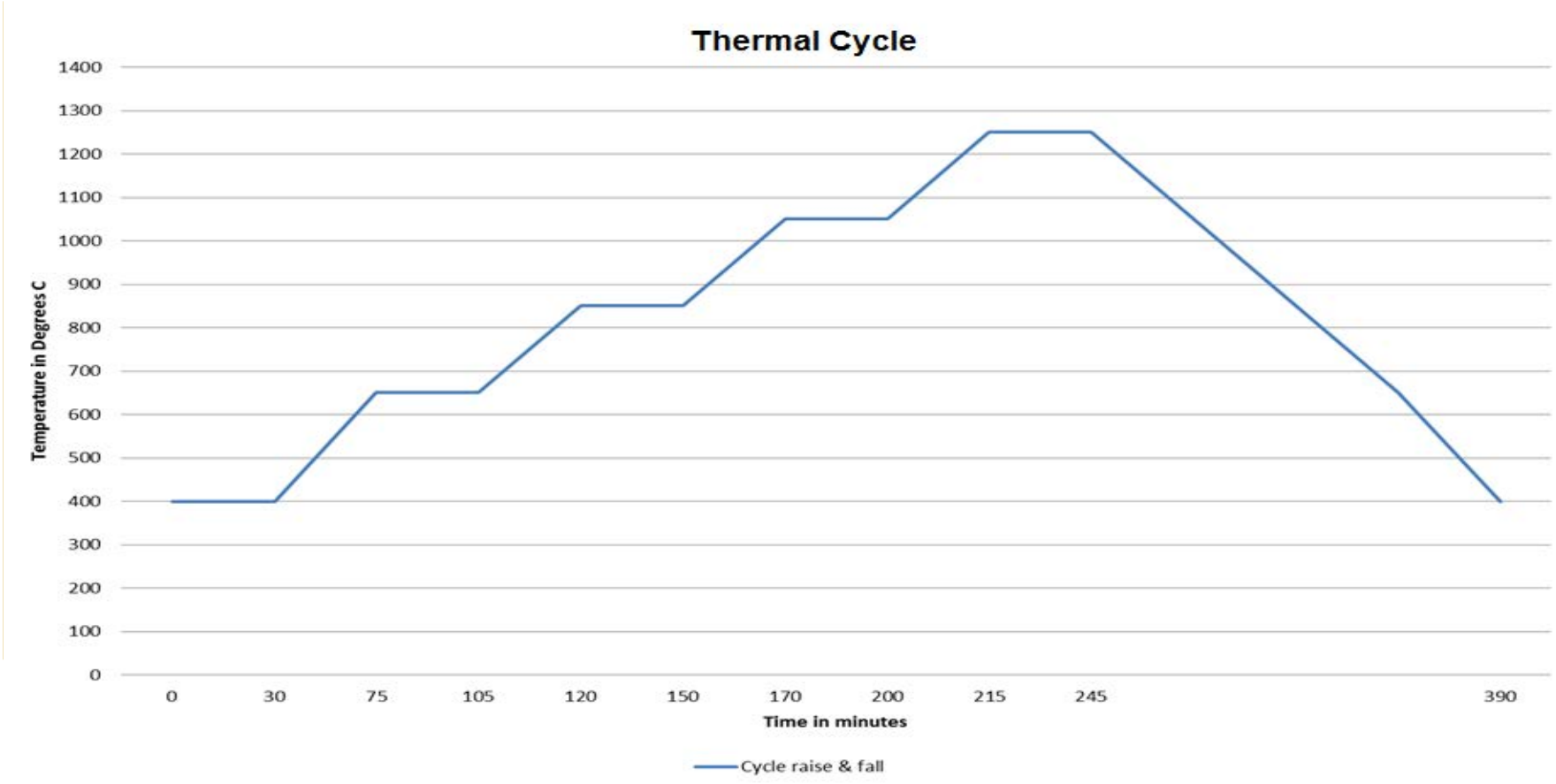
# Type N Drift tests: Summary

| | Total Drift |
|---|---|
| 1200 °C – 400h (conventional TC) | **-6 °C** |
| 1200 °C – 400h (new TC) | **Within +1°C** |
| 1300 °C – 100h (conventional TC) | **-2 °C** |
| 1300 °C –100h (new TC) | **-14 °C** |

**1200 °C: Over 80% drift reduction**

**1300 °C: Over 85% drift reduction**

- Validation of the concept the new sensor is based on
- No dependence on the diameter for the New thermocouple


Thermal Cycle
Temperature in Degrees C
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
30
75
105
120
150
170
200
215
245
390
Time in minutes
Cycle raise & fall

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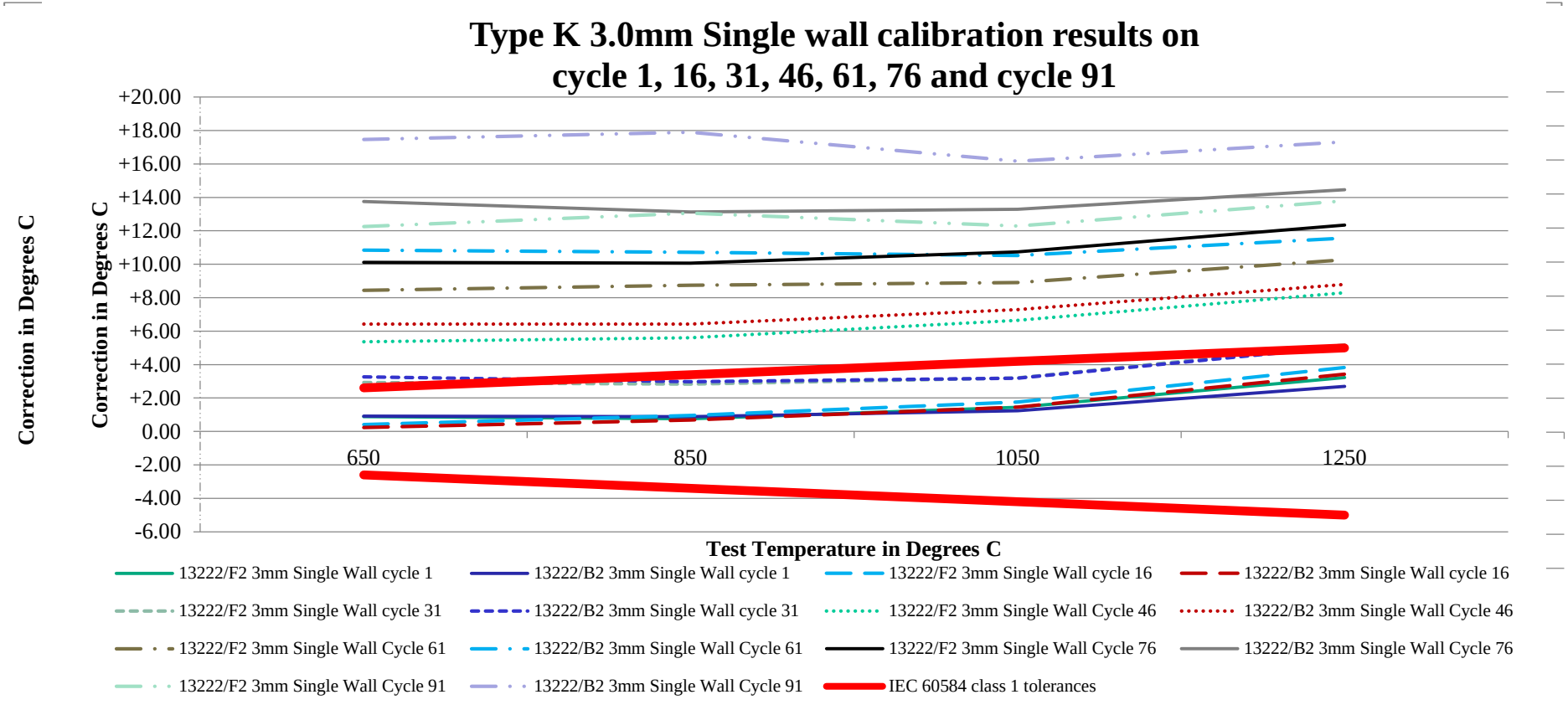
# Type K conventional results



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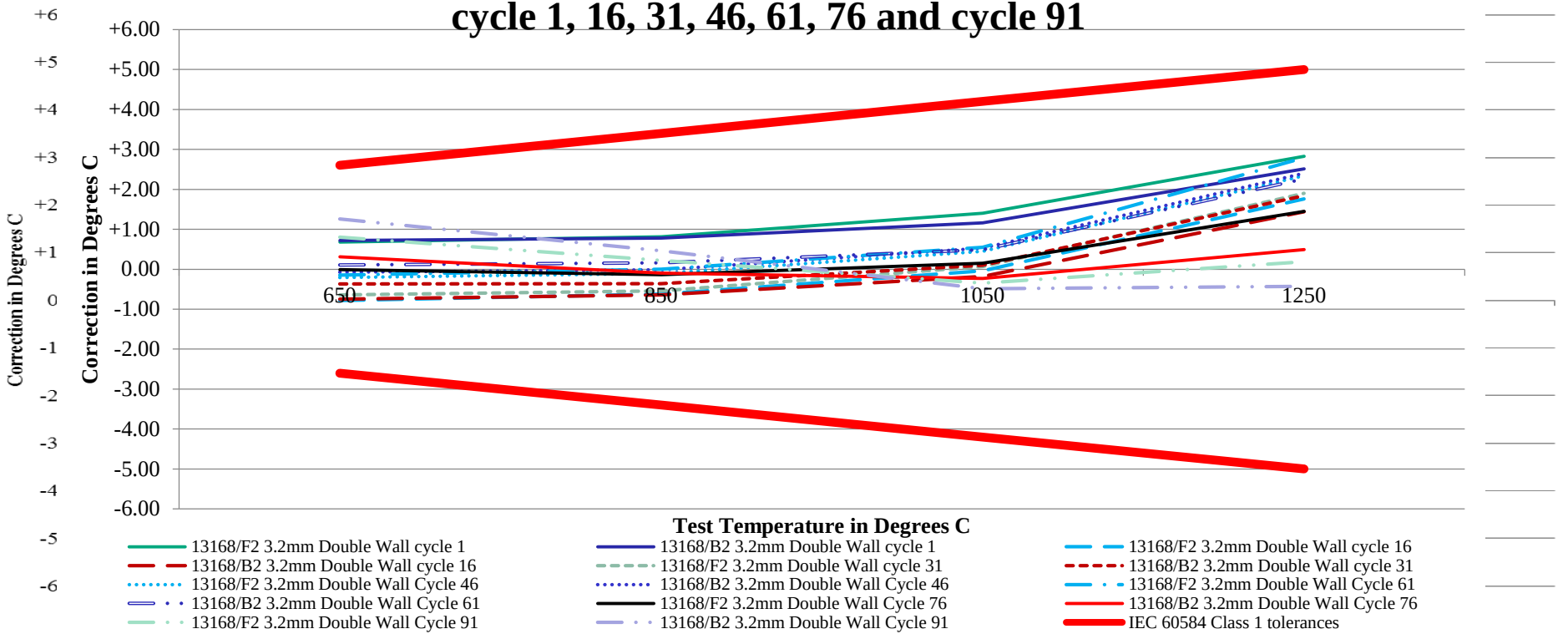
# Type K New Dual Wall results



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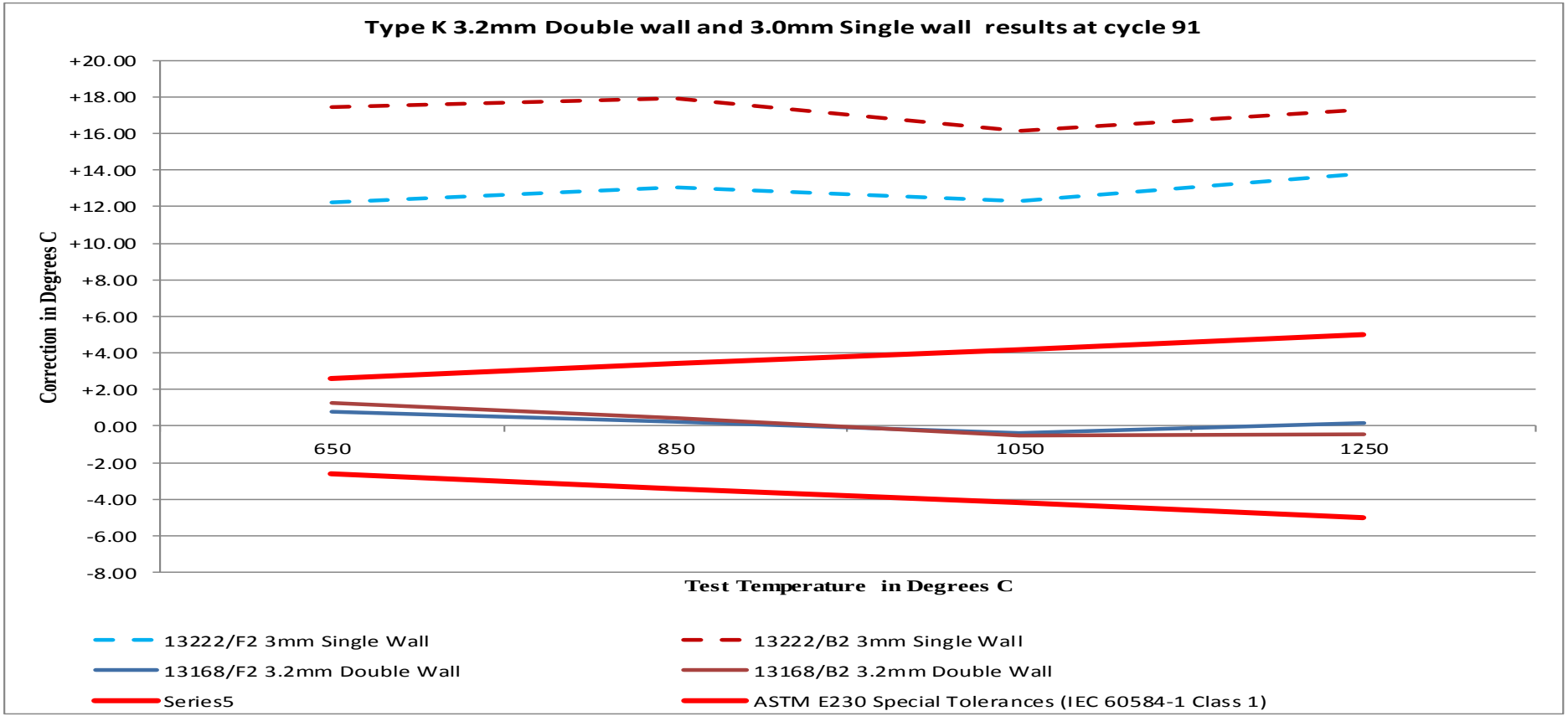
# Working within tolerances longer



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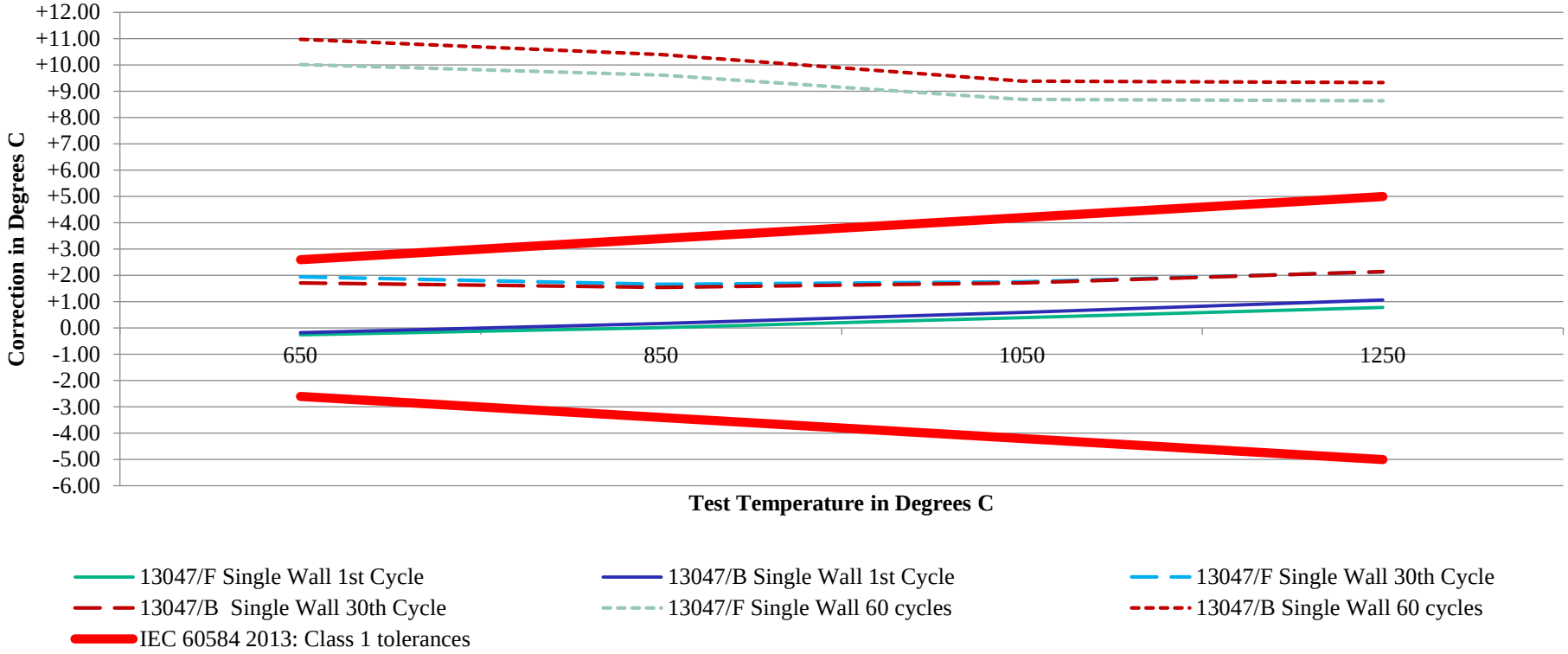
# Type N conventional results

## Type N 3mm Single wall calibration results on cycle 1, 30 and cycle 60



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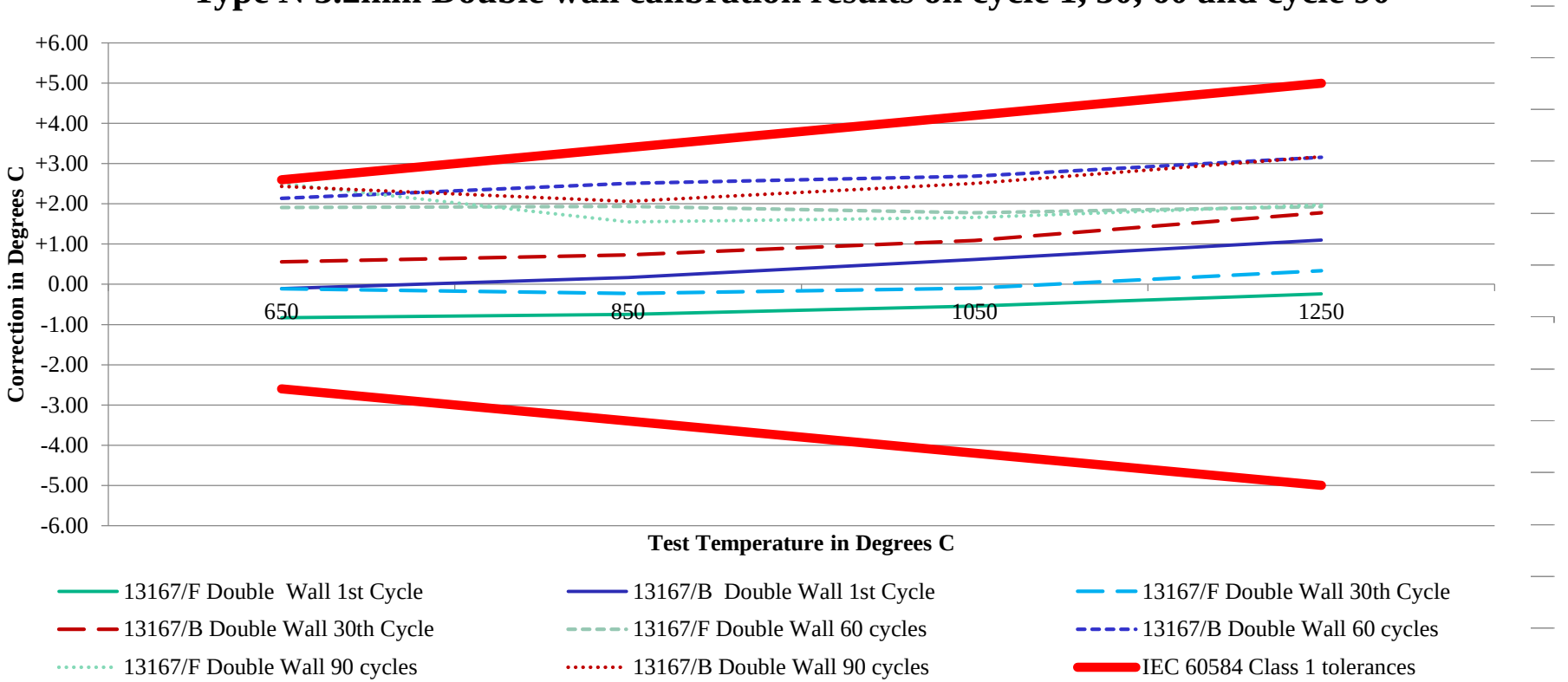
# Type N New Dual Wall results



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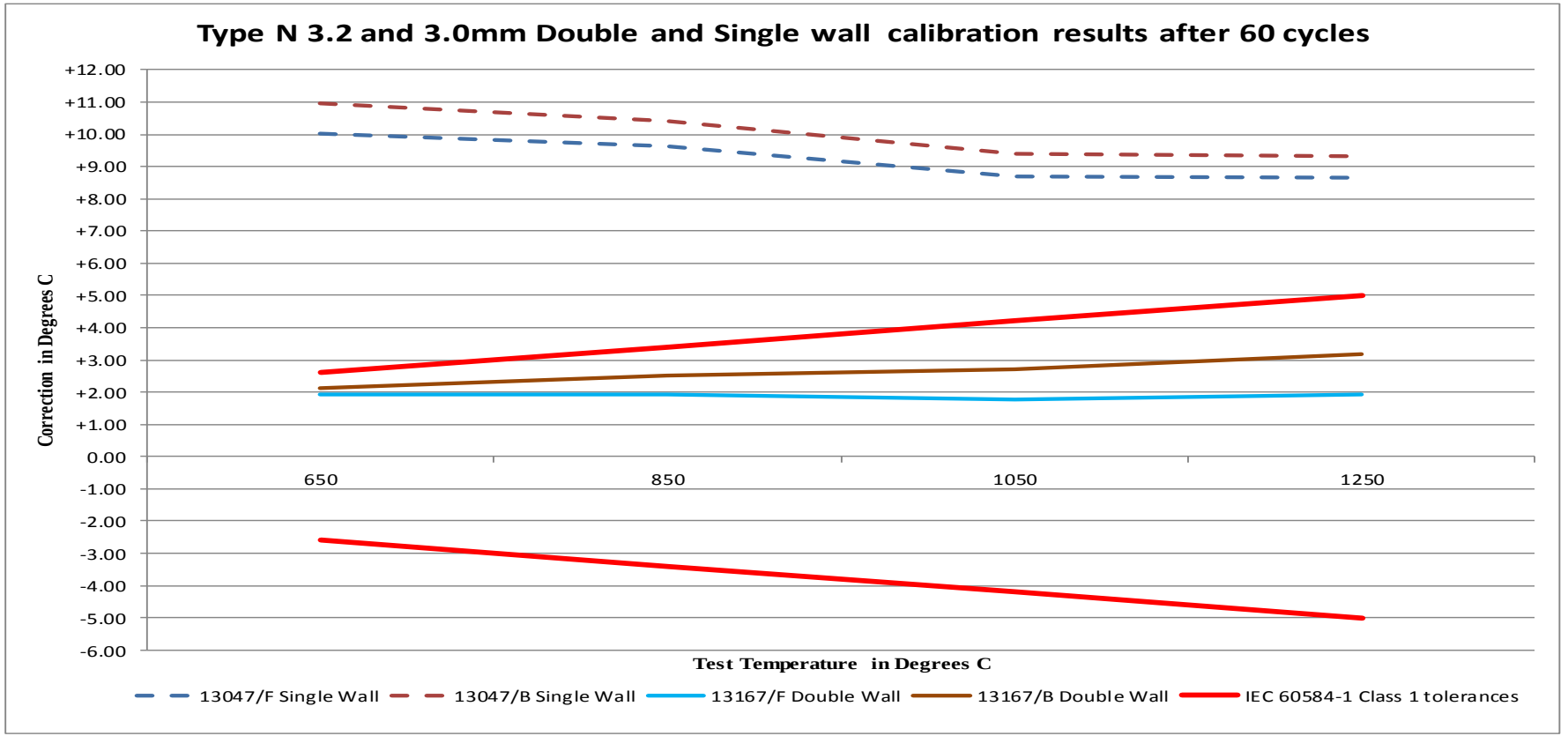
# Working within tolerances longer



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# Latest CCPI tests on dual wall MI cable

# Latest test data on dual wall MI cable

- Initial tests on the dual wall MI cables have mainly been focused on the sizes recommended for higher temperatures.

  *-- 3mm to 6mm diameter*

- In practise MI cable of different diameters are used in industry and often the smaller sizes are used in the high temperature region above 1100 °C

- So to conduct this latest set of tests we manufactured a range of different MI cable diameter's in the dual wall configuration.

  - *Type K 1.5mm*
  - *Type N 2mm and 1.5mm*

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# Latest test data on dual wall MI cable

- These latest set of tests were designed to see the short term performance of the varying smaller diameters and thermocouple types under cyclic, high temperature and mid temperature conditions.
- All tests were conducted in the CCPI Europe ISO 17025 accredited calibration laboratory.
- The tests conducted were comparative tests in which the test dual wall thermocouples were matched or compared with conventional design MI cables which had been manufactured from the same original batch materials for both the thermocouple conductors and outer sheathing.
- The results are shown in the form of difference graphs indicating the change in output in Degrees Celsius.

# Latest test data on dual wall MI cable

- The next set of result we are going to be looking at are **high temperature** range **(650 to 1250 °C)** for :-
- Type K 1.5mm and type N 2mm and 1.5mm diameter constructions
- For this test we measured the output of :-

  *-- 1.5mm diameter Inconel sheathed conventional type K MI construction against 1.5mm Inconel sheathed type K dual wall constructions*

  *&*

  *-- 2mm diameter Inconel sheathed conventional type N MI construction against 2mm Inconel sheathed type N dual wall constructions.*

  *&*

  *-- 1.5mm diameter Inconel sheathed conventional type N MI construction against 1.5mm Inconel sheathed type N dual wall constructions*
- The test thermocouples were tested over 20 cycles and the following results show the measured difference in Degrees Celsius between the 1st and 20th cycles.
- Immersion depth for test thermocouples was 500mm

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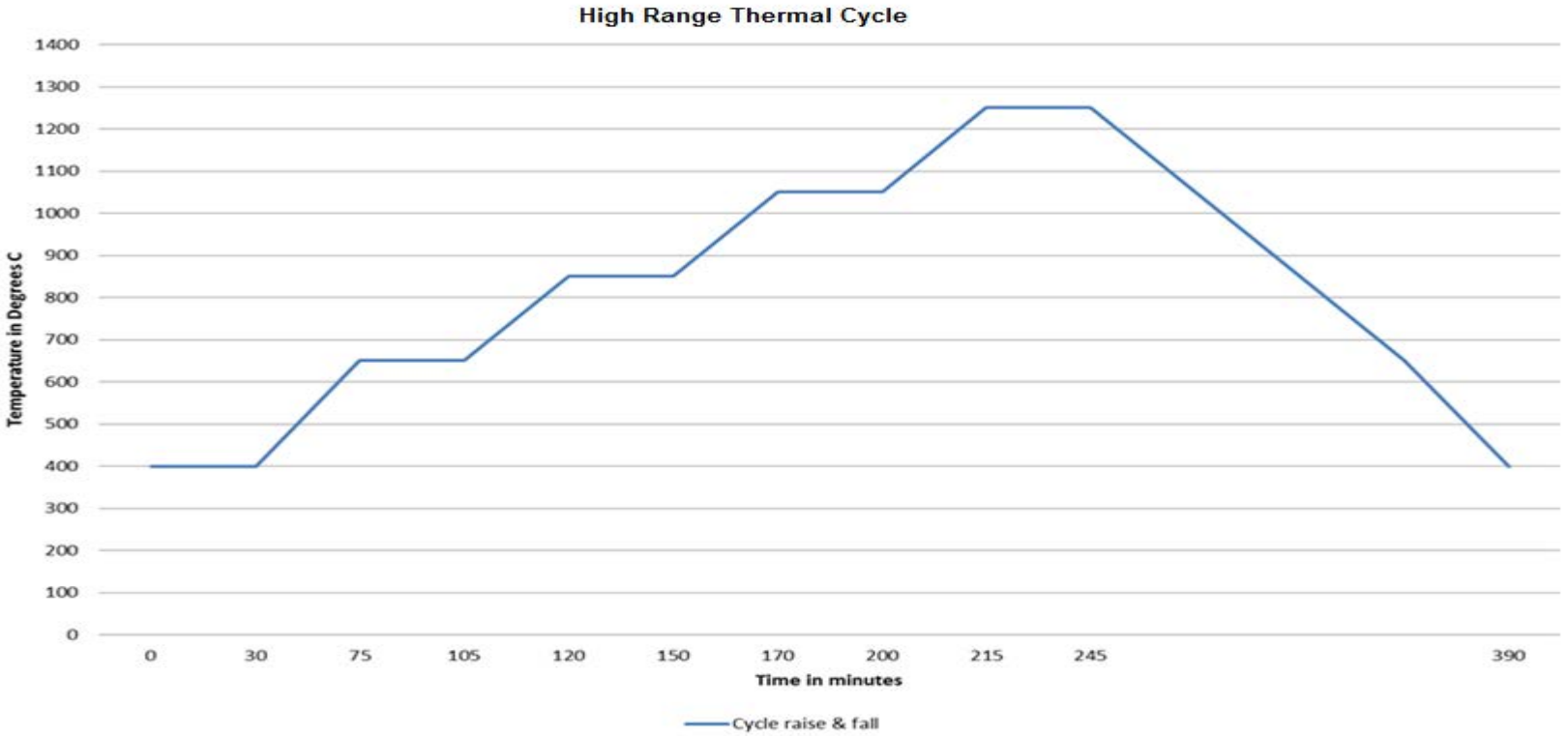
# Latest test data on dual wall MI cable



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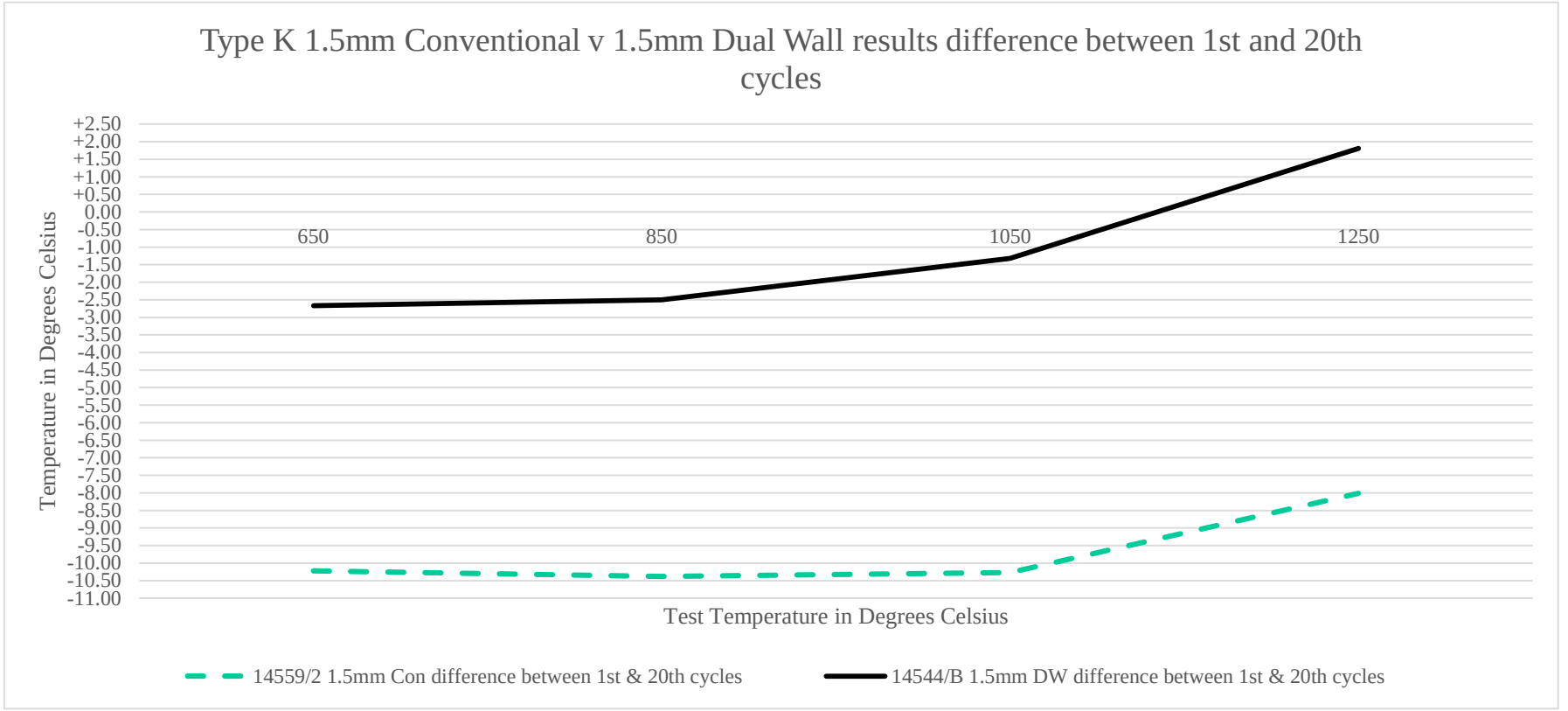
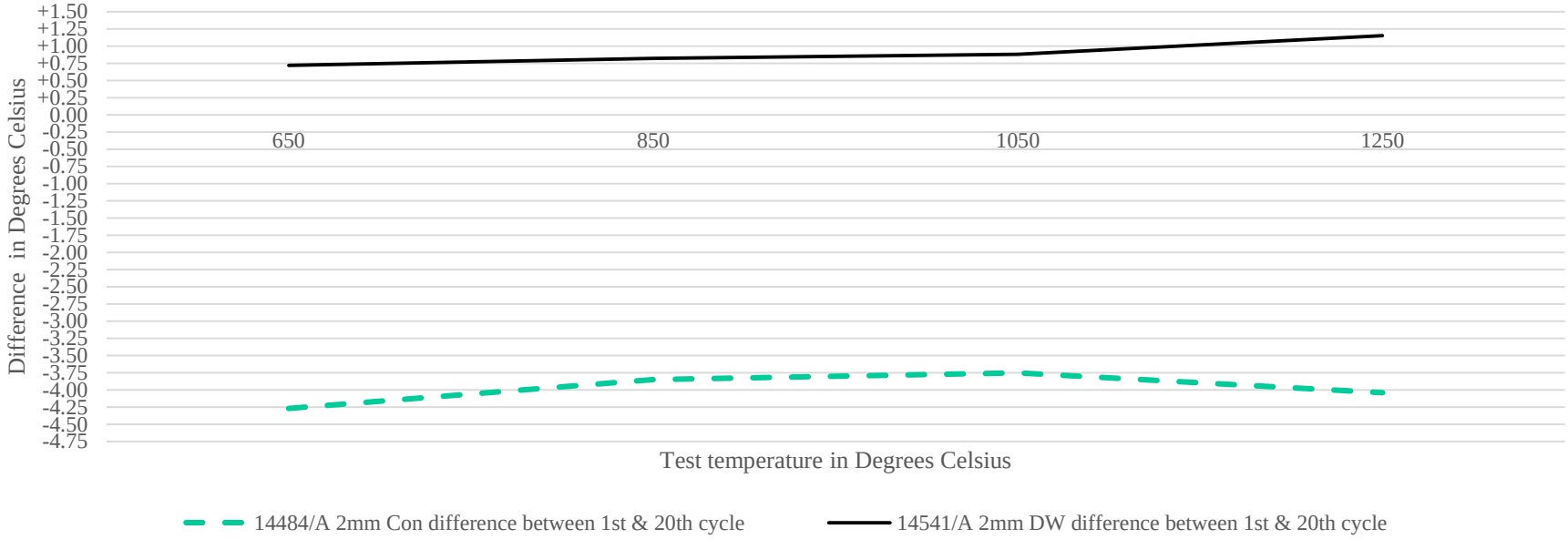
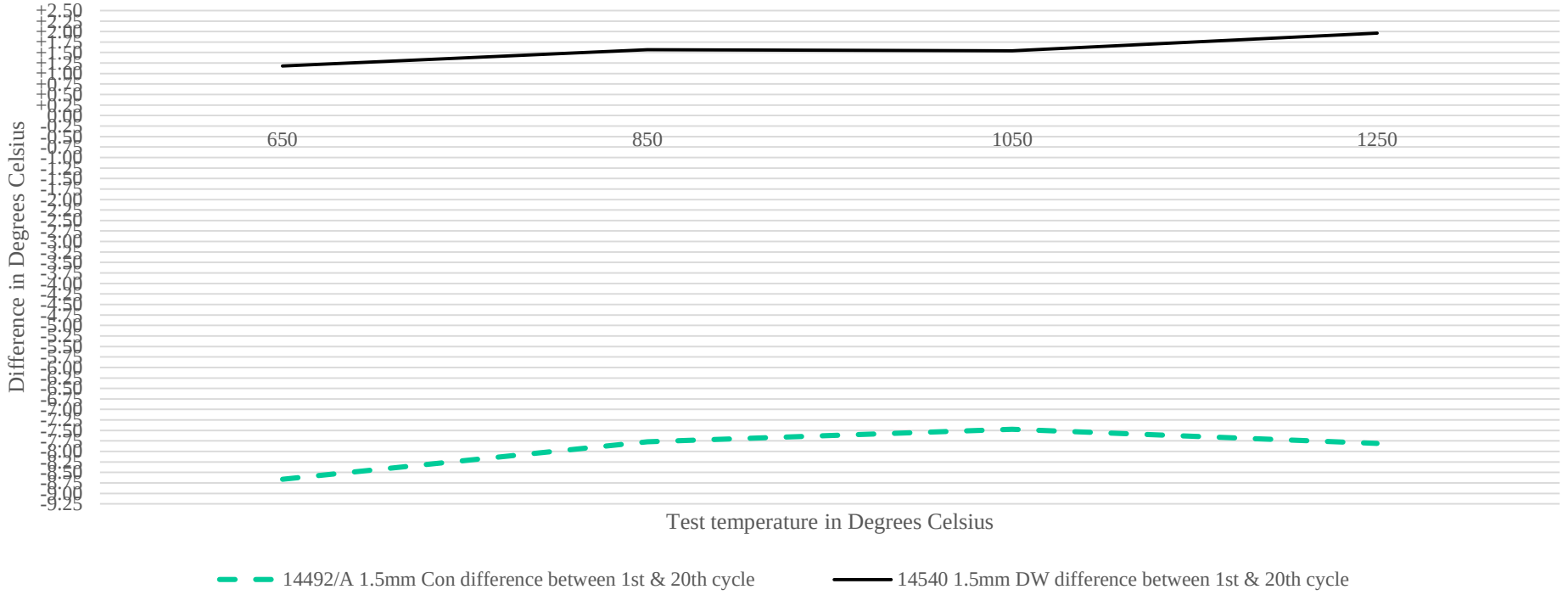


# Type N 2mm Conventional v 2mm Dual Wall results difference between 1st and 20th cycles



# Type N 1.5mm Conventional v 1.5mm Dual Wall results difference between 1st and 20th cycles



# Latest test data on dual wall MI cable

- The next set of result we are going to be looking at are **mid temperature** range **(400 to 1000 °C)** for :-

- Type K and type N 1.5mm diameter only with short immersion (200mm)

For this test we measured the output of :-

*-- 1.5mm diameter Inconel sheathed conventional type N MI construction against 1.5mm Inconel sheathed type N dual wall constructions.*

*&*

*-- 1.5mm diameter Inconel sheathed conventional type K MI construction against 1.5mm Inconel sheathed type K dual wall constructions*

- The type N and K thermocouple were tested this time over 30 thermal cycles and the following results show the measured differences in Degrees Celsius between the 1st and 30th cycles of the test.

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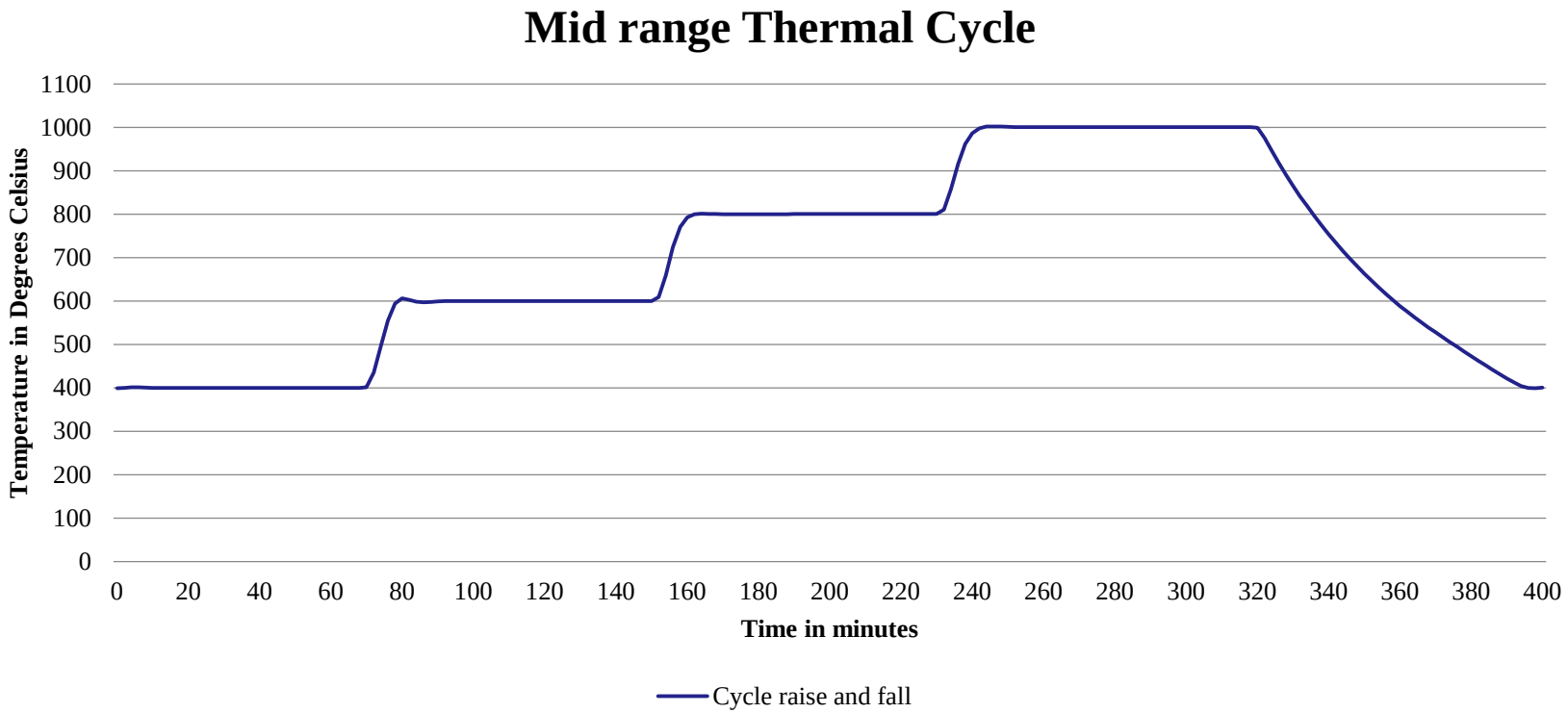
# Latest test data on dual wall MI cable



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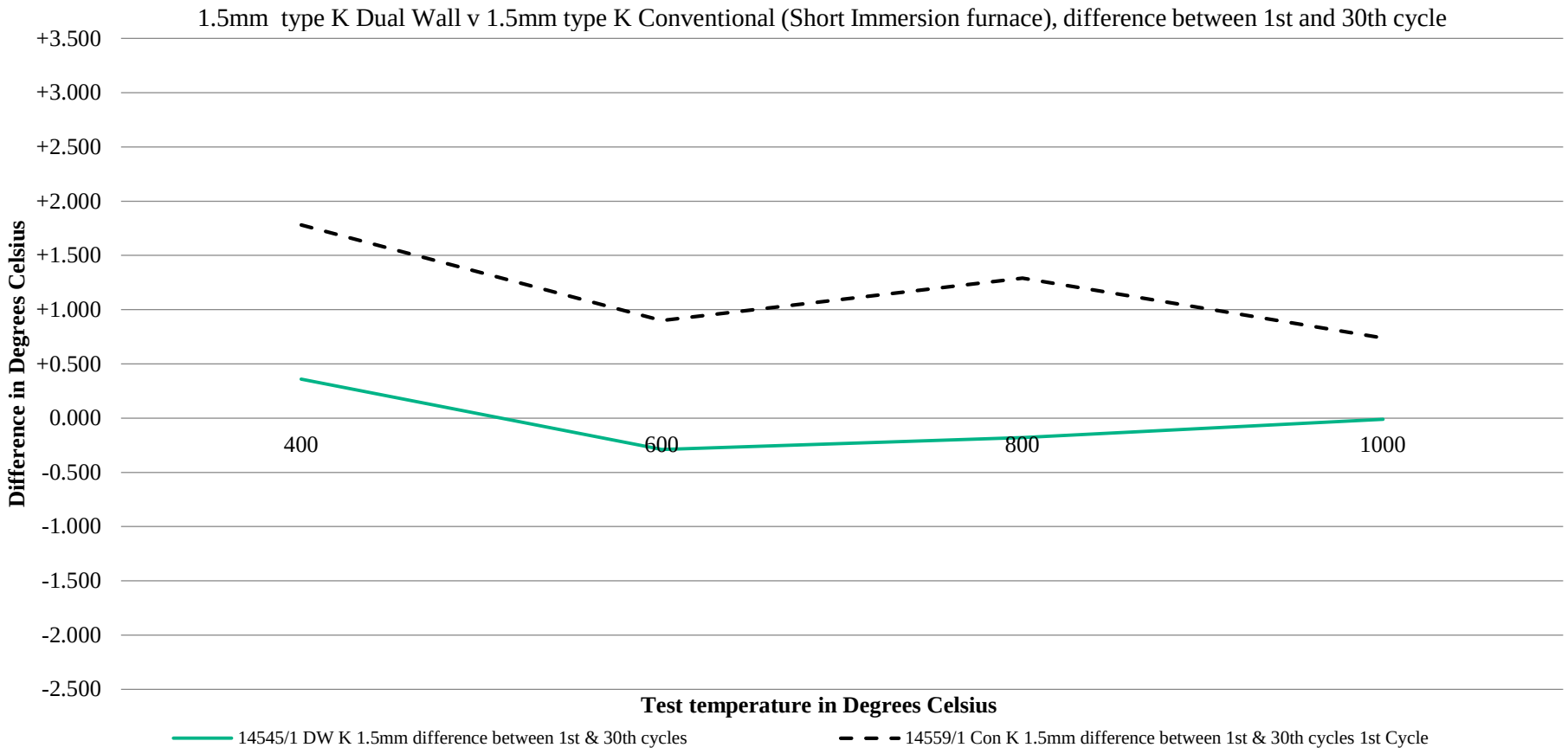

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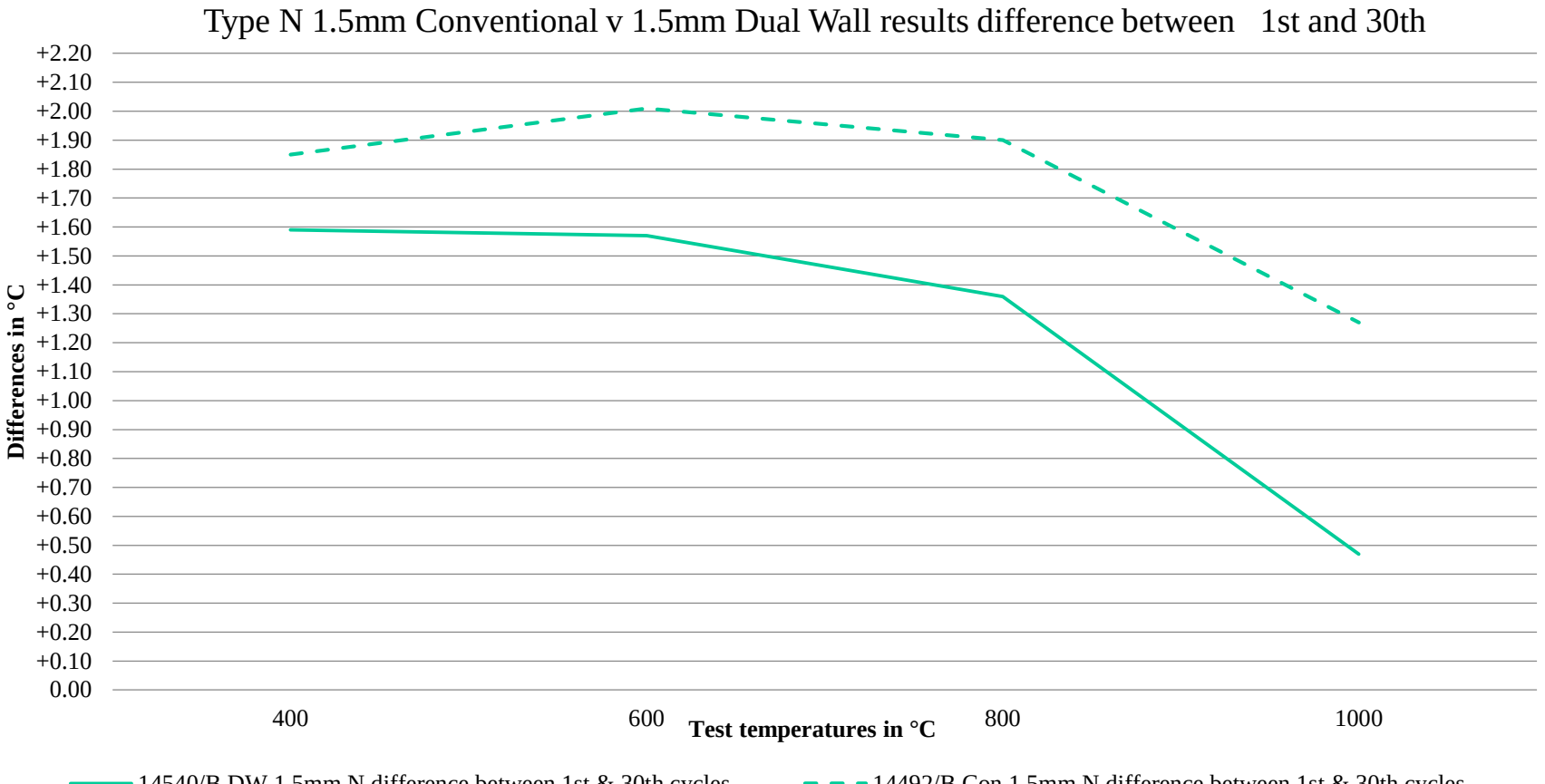


# Other tests (EMPRESS)

- Currently under a European funded program (EMPRESS) aimed at enhancing process efficiency through improved temperature measurement. A number of addition tests on this dual wall MI thermocouple cable are being conducted.

- The bulk of the laboratory test under the EMPRESS project on the dual wall MI cable will be conducted under the direction of the University of Cambridge.

- In addition a number of field trial will be conducted, these are currently underway, at industrial sites.

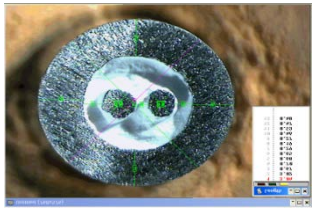
- Two in particular are being conducted at Bodycote heat treatment sites in the UK and Europe. These will involve dual wall MI thermocouples being used as the operational measurement sensors at high temperature under real life operational industrial conditions.

- The results are expected by late 2017.

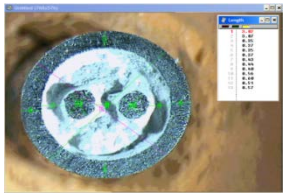
# Different cable geometry

- The test data we have been looking at so far has been all from the larger wall dual wall configuration.
- The dual wall configuration is a much more flexible design compared to single wall conventional thermocouples: by changing the inner wall to outer wall thickness ratio it is possible to tweak or control the drift performance of the double wall thermocouples and their mechanical properties.
- As a result dual wall thermocouples with a wide variety of performance can be designed to suit different and varying applications.
- CCPI is currently working on different inner wall thicknesses as part of the development and optimisation of the dual wall thermocouples. In particular, a reduced wall or thin wall geometry is currently under test.

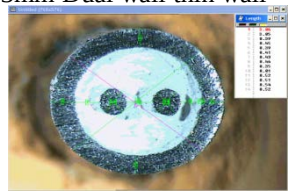
3mm Dual wall thick wall



3mm Single wall (conventional)



3mm Dual wall thin wall



# Test results for dual wall thin wall coming soon !

# The Next Step

Finally all the results from testing conducted on the dual wall MI cable has currently only been done under standard atmosphere conditions. During the first half of 2017 addition testing will be conducted under inert and vacuum conditions replicating many customers actual operational environments.

# Questions