Comparison of measured temperature and heat flux in fire resistance test furnaces controlled by six temperature measuring devices

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Comparison of Measured Temperature and Heat Flux in Fire Resistance Test Furnaces Controlled by Six Temperature measuring Devices

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National Research Council Canada

Outline

- Introduction
- Parameters investigated
- Test Facility/Experiments
- Results and Discussion
- Summary

Introduction

Why this research is needed?

- Performance-based fire safety design
  - Lack of engineering data from standard test E119
- NIST Report on WTC (recommendations)
- FPRF Report (recommendations)
  - Furnace instrumentation (plate thermometer)
  - Furnace operation (calibration test to quantify thermal exposure)
- Development of a new E05 standard
  - Heat flux measurement
- Laboratories use different type of temperature sensor in controlling fire resistance furnace temperature

Parameters Investigated

- Compare temperature heat flux responses for fire resistance floor furnace controlled by
  - ASTM E119 shielded thermocouples
  - ISO 834 plate thermometers
  - Directional flame thermometers
  - Bare bead thermocouples
  - Sheathed grounded thermocouples
  - Sheathed non-grounded thermocouples
- Time response for shielded, PT and DFT

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NRC Test Facility Floor/Ceiling Furnace

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Experimental Measurements: Temp. & Incident Heat Flux

- Test 1, Furnace controlled by ASTM E119 shielded thermocouples
  - PT, DFT, BBT, Sheathed T-grounded Sheathed T non-grounded
- Test 2, Furnace controlled by ISO 834 plate thermometers
  - Shielded T, DFT, Sheathed T-grounded Sheathed T non-grounded and BBT
- Test 3, Furnace controlled by directional flame thermometers
  - Shielded T, BBT, PT, Sheathed T-grounded Sheathed T non-grounded

Experimental Measurements: Temp. & Incident Heat Flux

- Test 4, Furnace controlled by bare bead thermocouples (BBT)
    - PT, DFT, Shielded T, Sheathed T-grounded and Sheathed T non-grounded
- Test 5, Furnace controlled by Sheathed Thermocouples-grounded
    - Shielded T, PT, DFT, BBT and Sheathed T grounded
- Test 6, Furnace controlled by Sheathed non-grounded
    - Shielded T and PT, DFT, BBT and Sheathed T-grounded

Temp and Heat Flux Devices

- Heat Flux Meter
- DFT
- PT (ISO 834)
- BBT
- Sheathed Un-G
- Sheathed G
- Shielded (ASTM E119)

Temp and Heat Flux Devices

Shielded Thermocouple

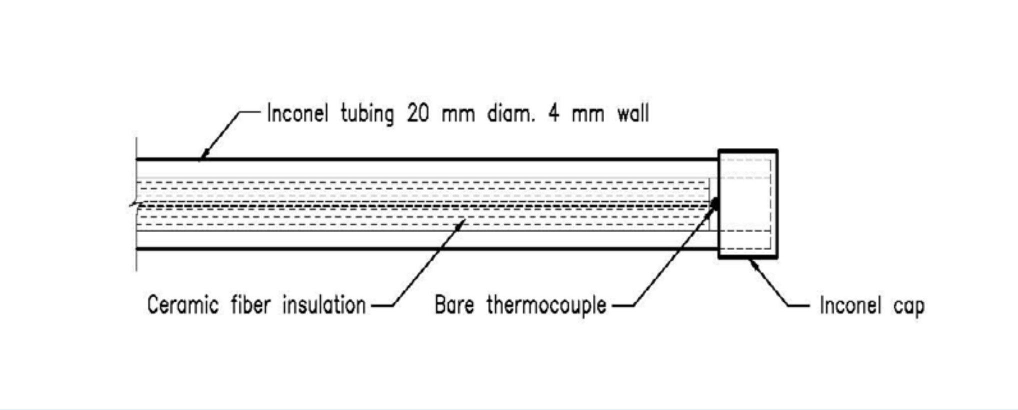
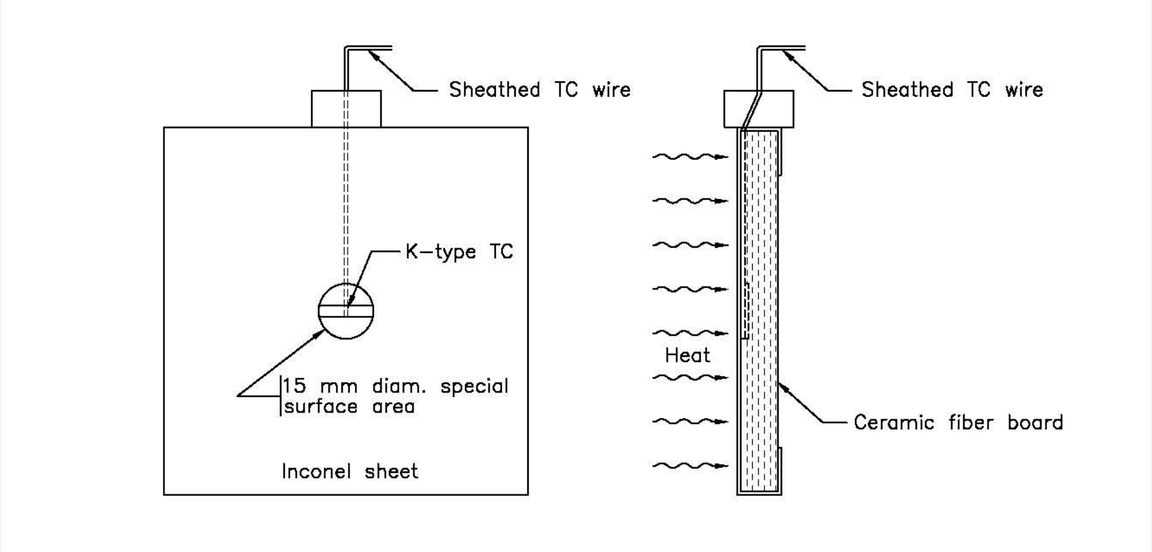
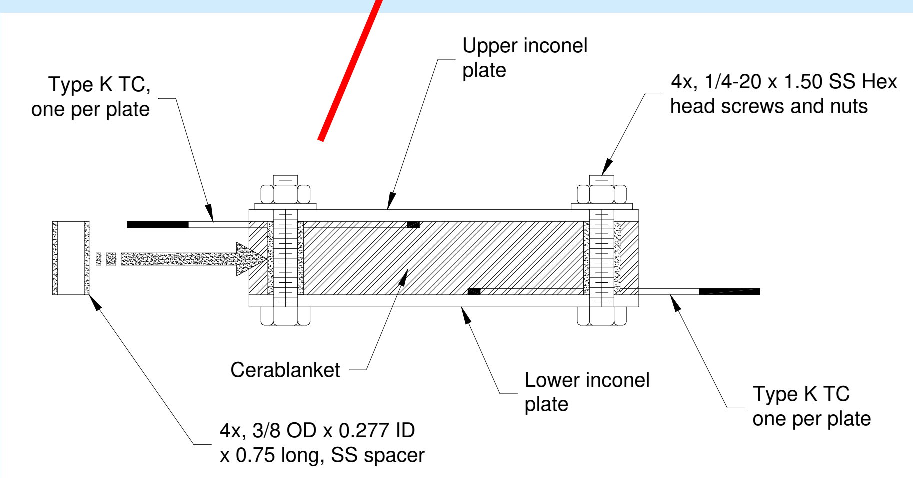
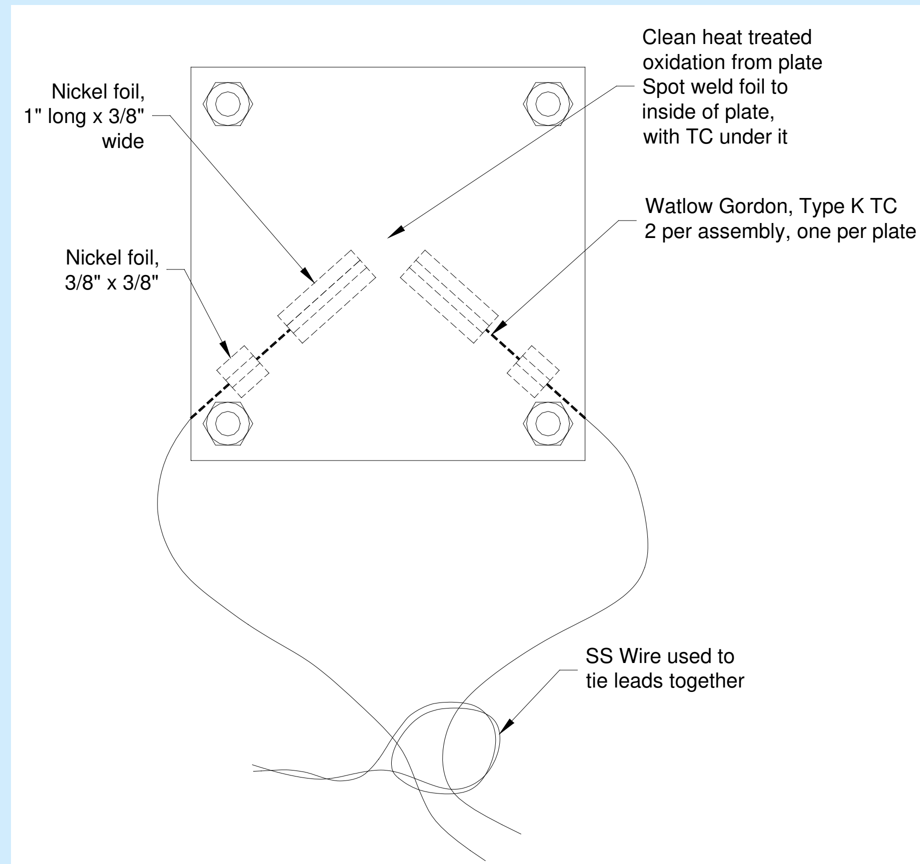


Plate Thermometer



Directional Flame Thermometer





Sheathed Thermocouple

Grounded and Ungrounded Sheathed Thermocouple

Sheathed Grounded Thermocouple

The thermocouple bear bead is attached to the inside of the probe wall

Sheathed Ungrounded Thermocouple

The Thermocouple bear bead is detached from the inside of the probe wall

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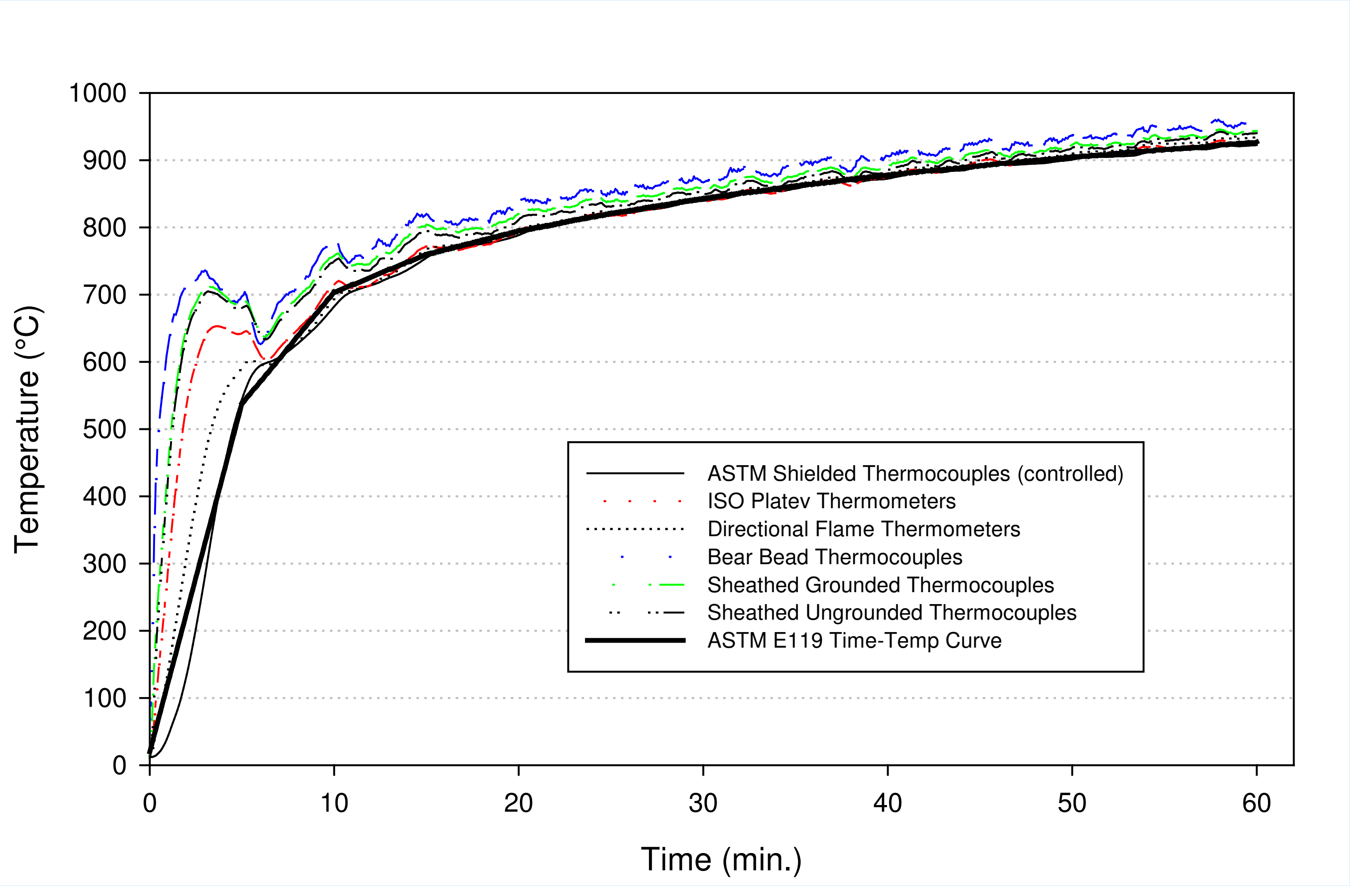
Furnace Controlled by ASTM Shielded Thermocouples



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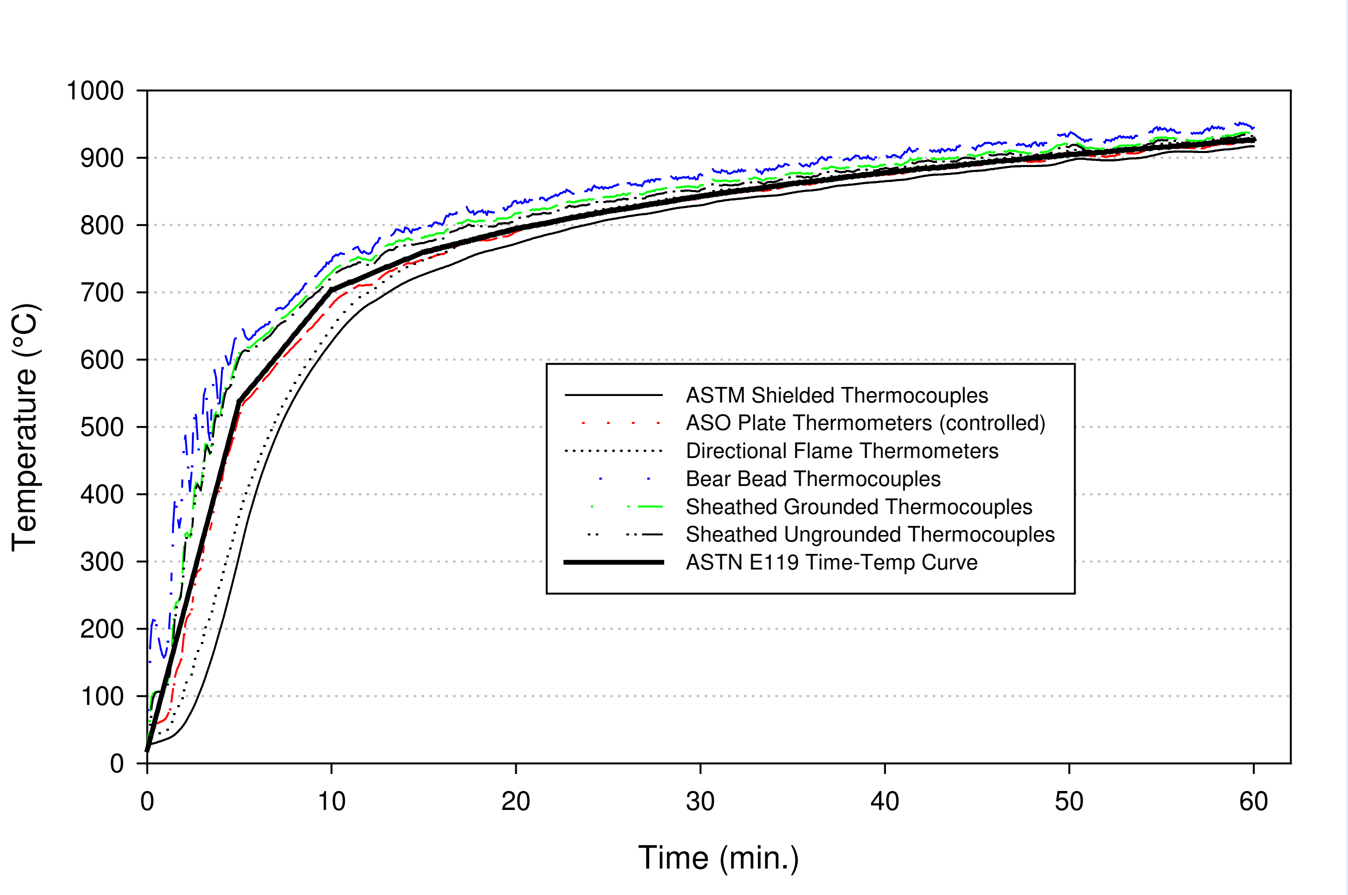
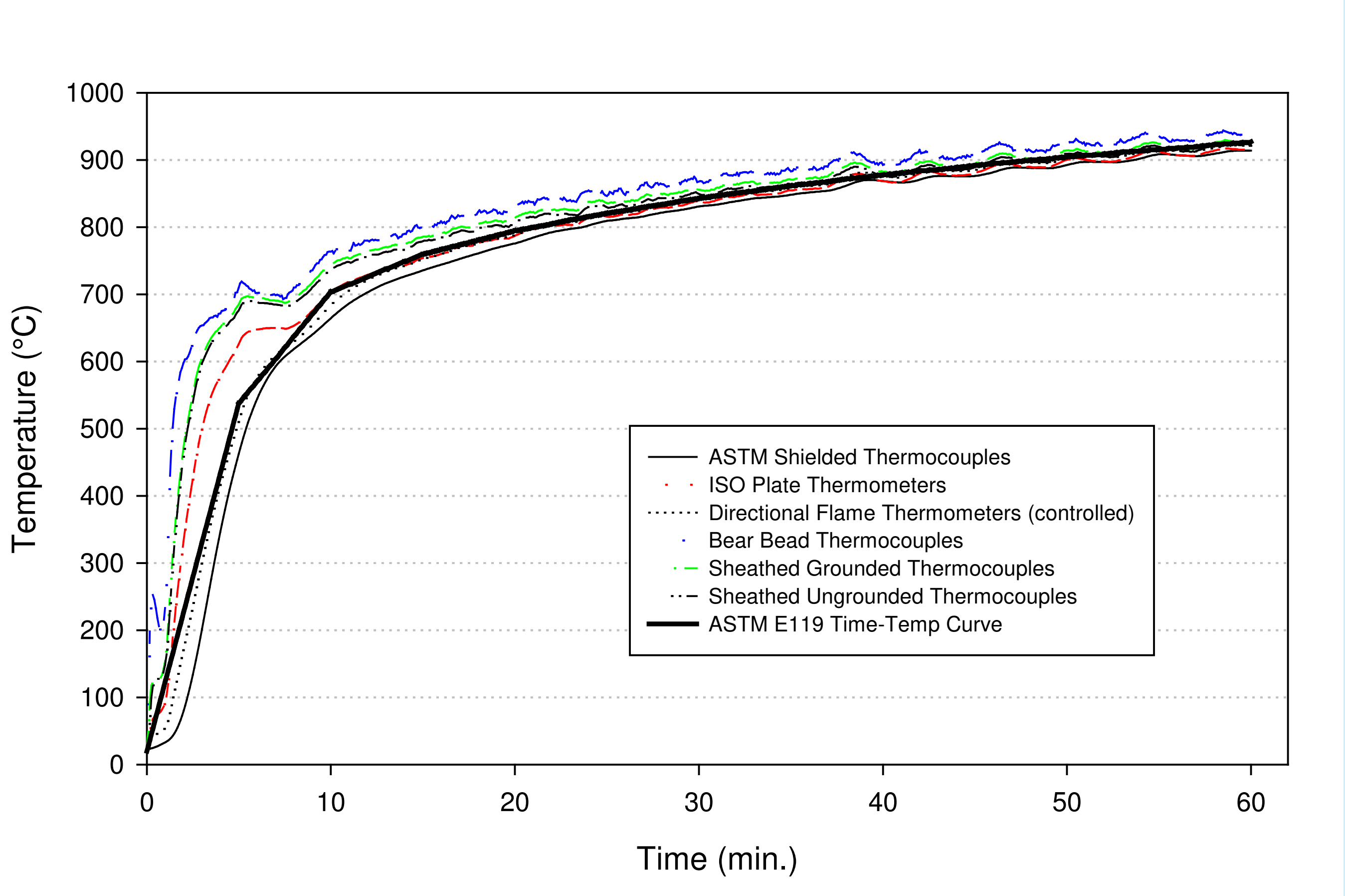
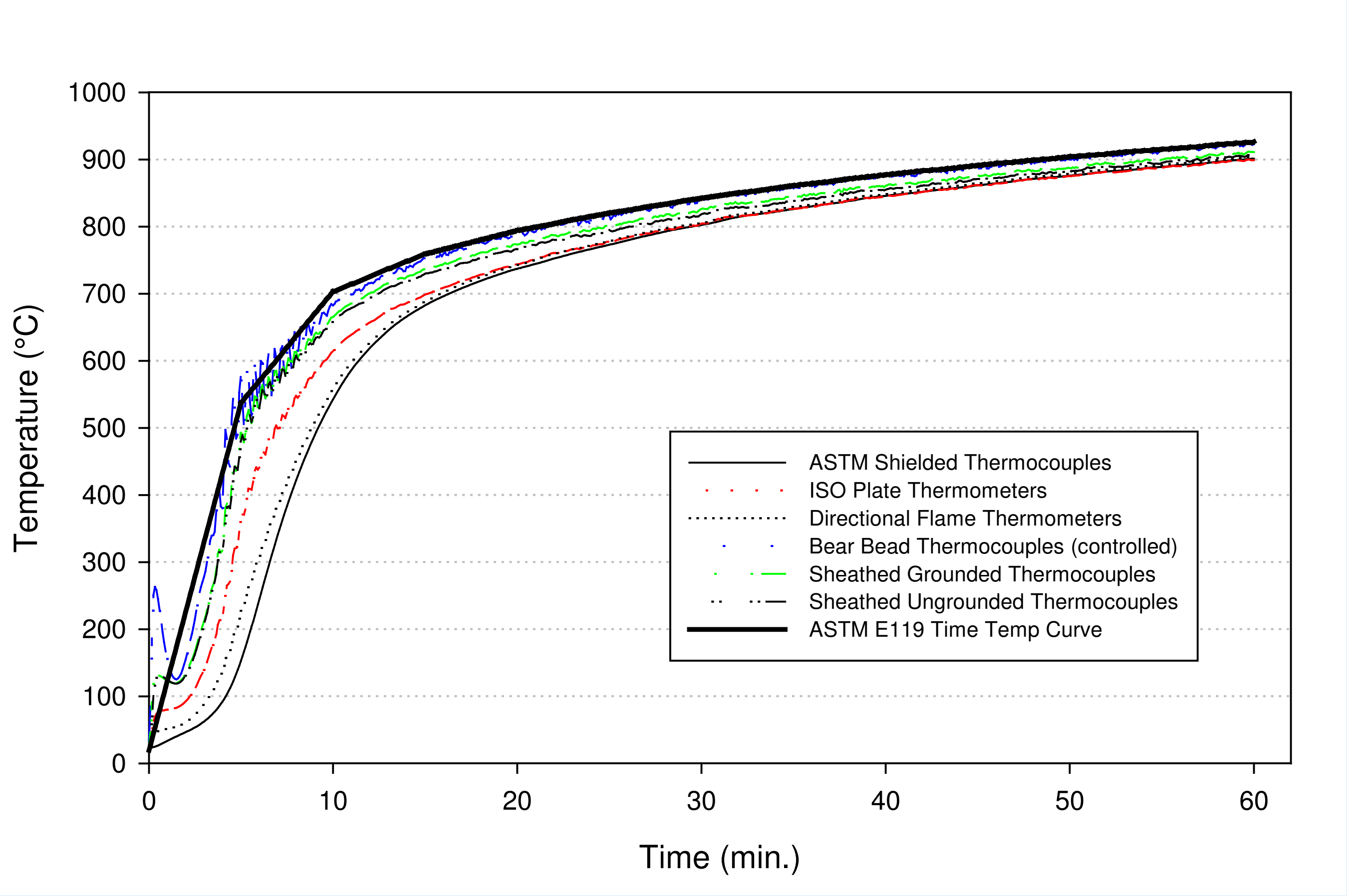
Furnace Controlled by ISO Plate Thermometers



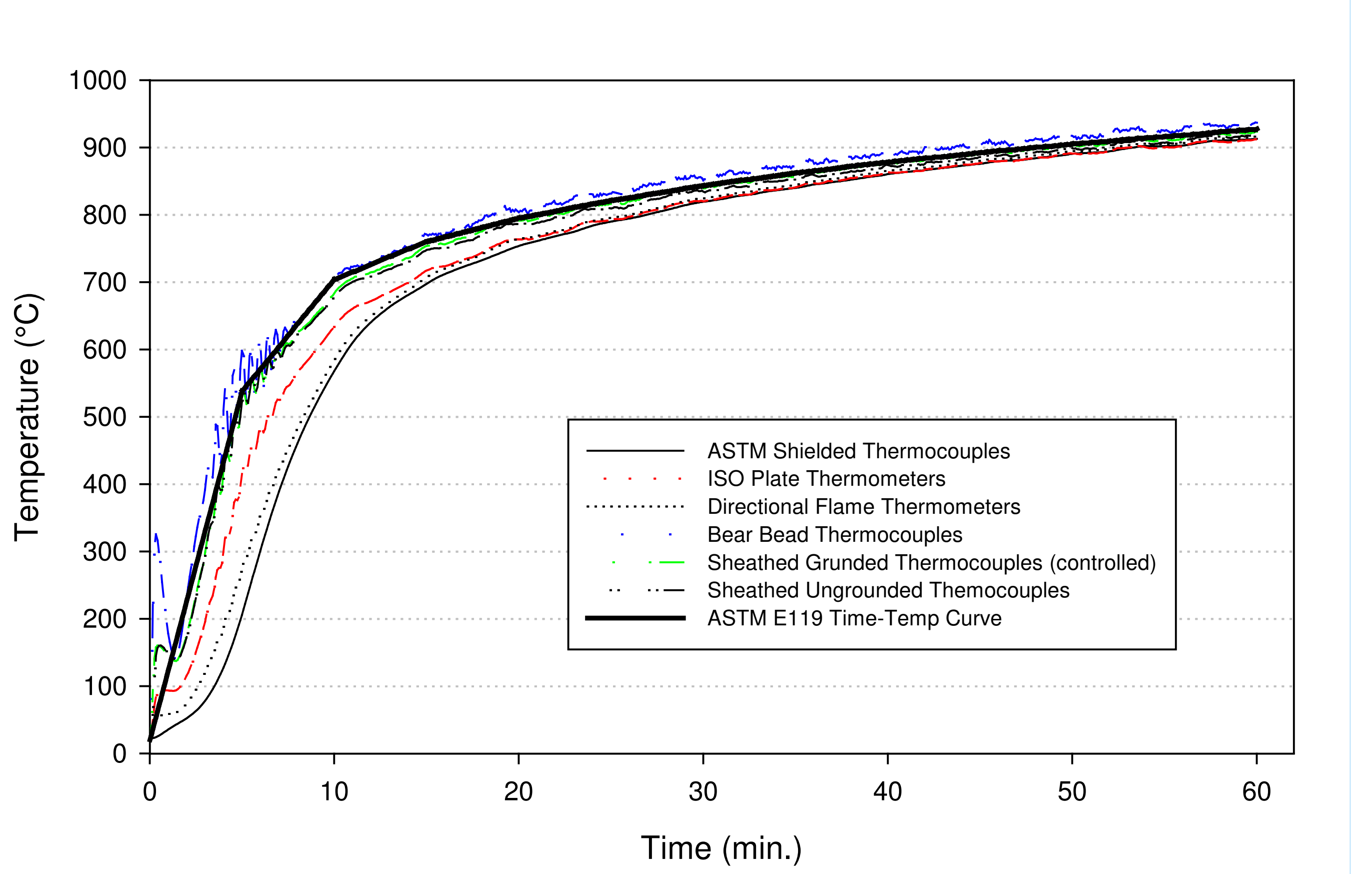
Furnace Controlled by Directional Flame Thermometers



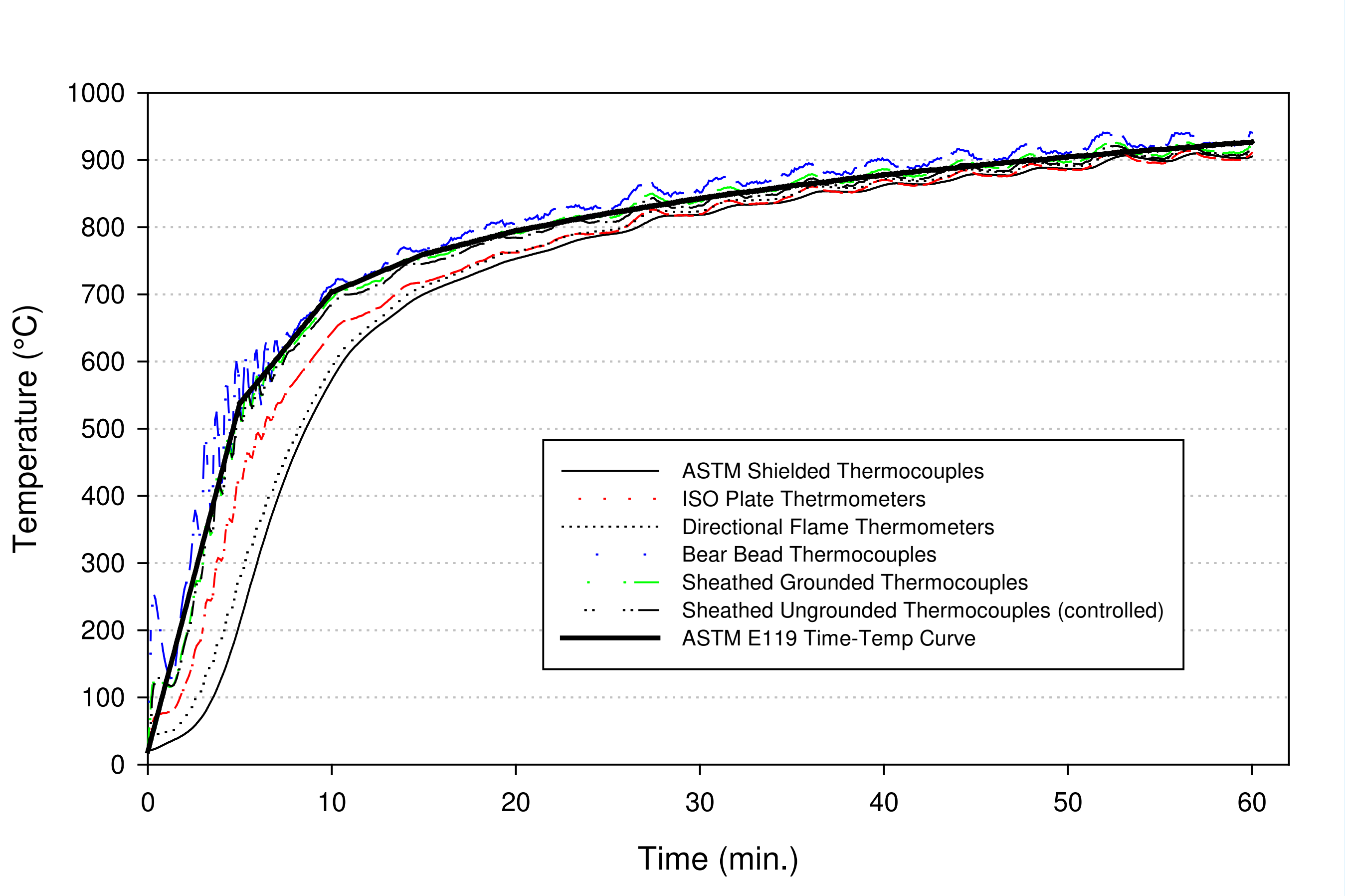
Furnace Controlled by Bare Bead Thermocouples



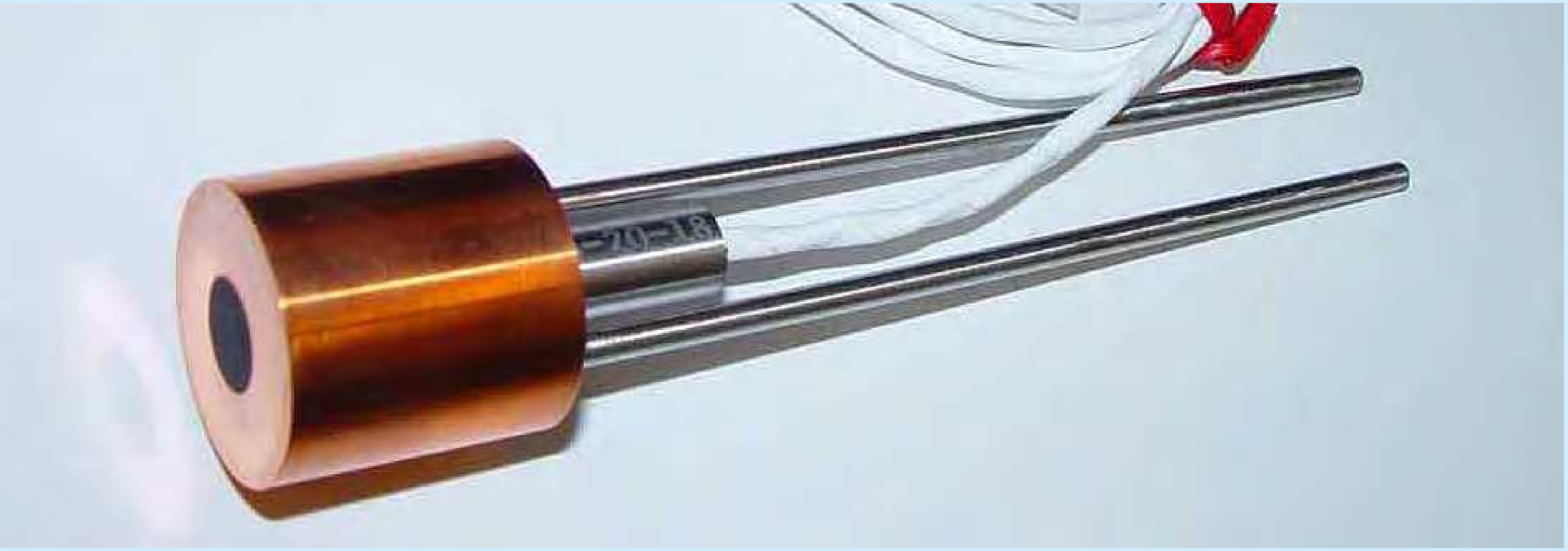
Furnace Controlled by Sheathed Grounded Thermocouple



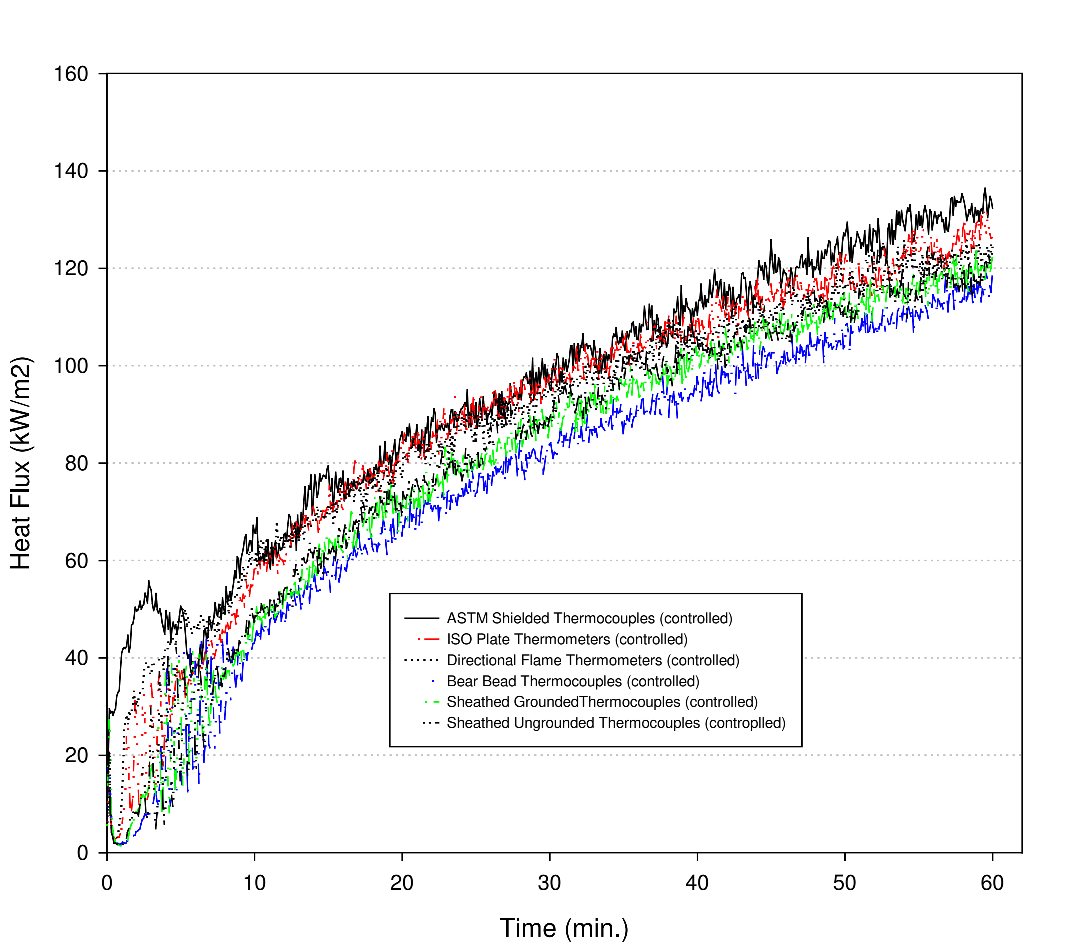
Furnace Controlled by Sheathed Ungrounded Thermocouple



Gardon Gauge
Heat Flux Sensor



Incident Heat Flux



Eurocode 1, 1991

Total heat transfer to fire exposed surface

$$Q_{total} = \text{Radiation} + \text{Convection}$$

$$= \varepsilon\sigma (T_{AST}^{4} - T_{s}^{4}) + h_c (T_{AST} - T_s)$$

Where:

T_{AST} Plate Thermometer temperature measurement (Adiabatic Surface Temperature)

T_s Surface temperature (target surface)

h_c Convective heat transfer coefficient

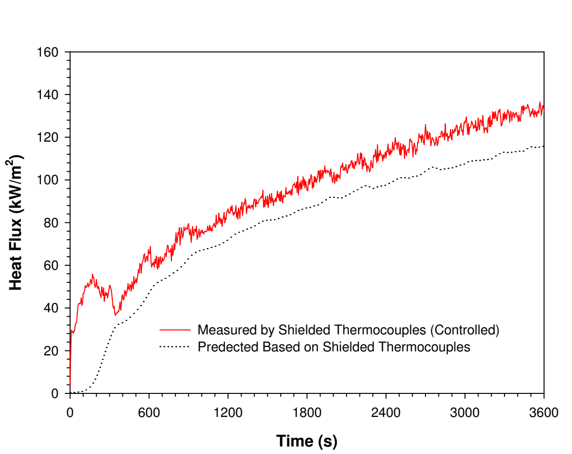
Incident Heat Radiation

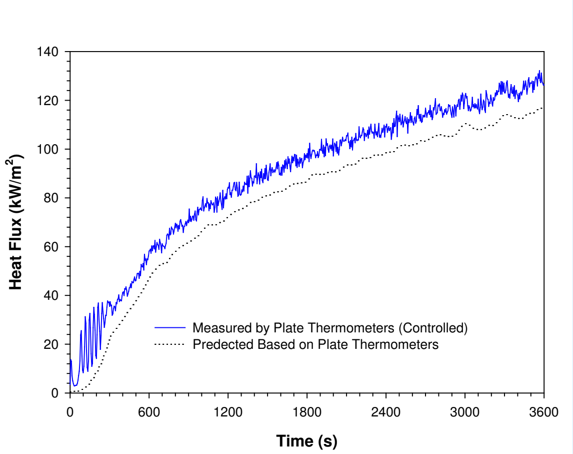
$Q_{inc} = \sigma T_f^{\ 4}$ (assuming convective heat is small) Predicted

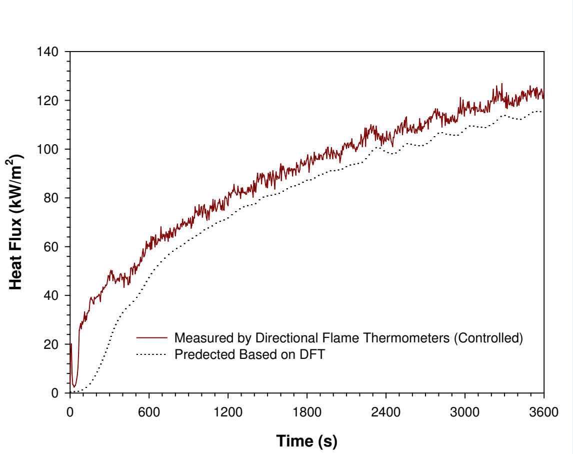
Q_{inc} measured by Gardon gauge heat flux meter

Furnace Controlled by

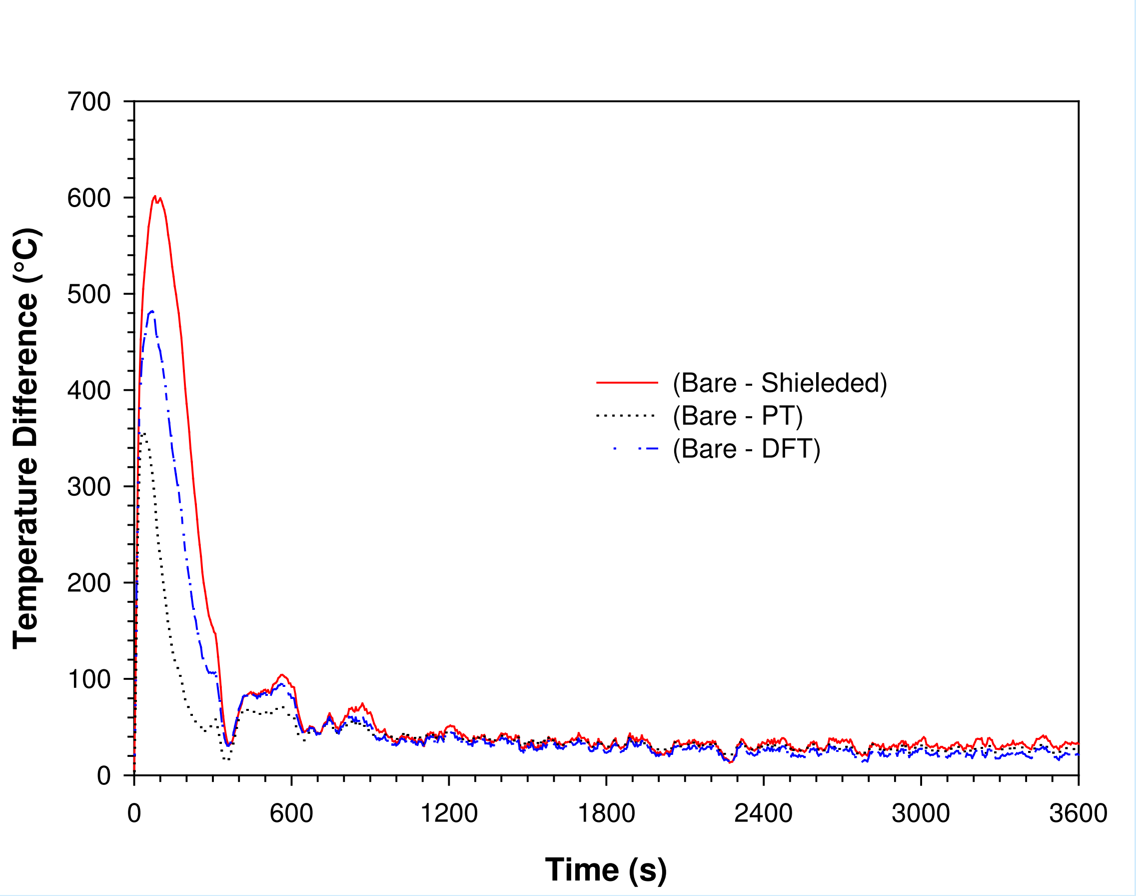
Shielded Thermocouples | Plate Thermometers | Directional Flame Thermometers





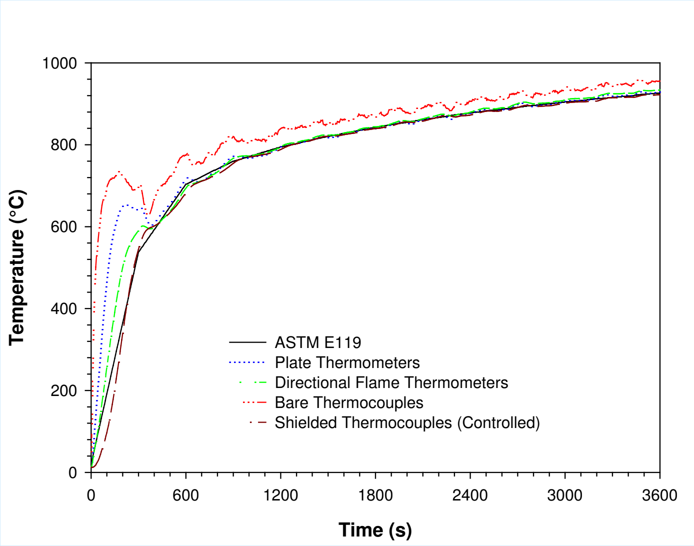


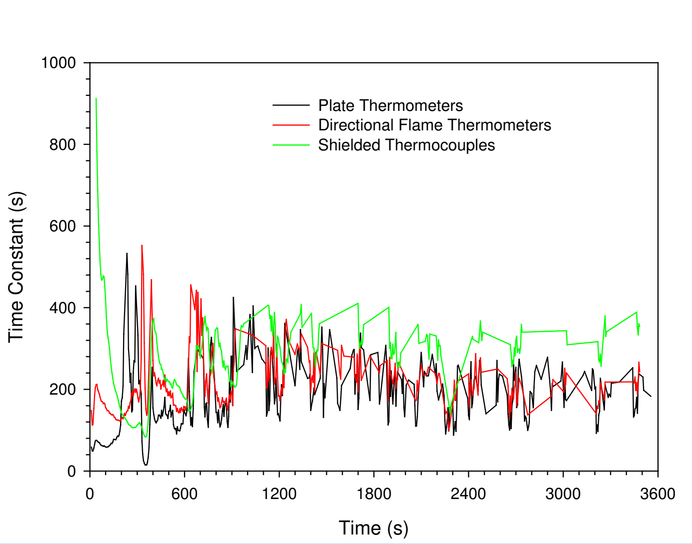
Temperature Lag with Respect to a Bare Bead Thermocouple



Time Constant

Time Constant $\tau(t) = (T_f - T_t)/(\Delta T_t / \Delta t)$
T_f bare bead thermocouple





Summary

- In first 8-10 min, the effect of furnace control method on furnace temperature is significant, however, after 8-10 min, difference is insignificant.
- In first 8-10 min, the effect of furnace control temperature on heat flux is significant, however, after 8-10 min, difference is insignificant for the plate and directional flame thermometers and significant for bear bead and sheathed thermocouples.

Summary

- Furnace temperature and incident heat flux are comparable for furnaces controlled by bear bead and sheathed thermocouples.
- In first 8-10, time constant for DFT, PT and Shielded are different, however, after 8-10 min, difference is insignificant.

Summary

- The predicted incident heat flux is approximately10-15% less than of the measured value.
- For a short duration fire resistance test (i.e. 15 min test), the type of the thermocouple used to control the furnace is important.

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Questions