EMPRESS: A pan-European project to enhance process efficiency through improved temperature measurement

2nd Stakeholder Community Workshop

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Co-sponsored by
Institute of Measurement and Control
IOP Institute of Physics

NPL, 18 April 2018

Introduction

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- 3 – year project
- Enhancing process efficiency through improved temperature measurement
  - Energy efficiency
  - Reduced emissions
  - Throughput increase
  - Improved quality
  - Less scrap
- High value manufacturing
- Characterised by tight engagement with end-users
- Each activity has an end-user with a specific process control challenge associated with it
- Each activity is aimed at implementing in-situ traceability to ITS-90
- Heat treatment, casting, forming, forging, welding, silicon processing, combustion

1. Solve specific process control problems in advanced manufacturing

2. Establish traceability to ITS-90 in-situ

- Driftless thermocouples and other contact thermometers (WP1,2)
  - Heat treatment of aerospace alloys
  - Casting of aerospace alloys
  - Forming and forging of automotive components
  - Industrial furnace manufacture
  - Silicon processing
  - Ceramic manufacturing
- Surface thermometry (WP3)
  - Forming of Al alloys and composite materials
  - Welding pre- and post- heat treatment of marine structures
  - Coating of marine structures
- Combustion thermometry (WP4)
  - Internal combustion engine, gas turbine, and fuel development

Start May 2015

Finish May 2018

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8 NMIs

NPL National Physical Laboratory

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

Danish Technological Institute

BRML 1864

INRiM Istituto Nazionale di Ricerca Metrologica

CEM Centro Español de Metrología

CMI Czech Metrology Institute

Justervesenet

RMG

6 Companies

MUT Advanced Heating

BAE Systems

Elkem

CCPI Europe Limited

AFRC Advanced Forming Research Centre, University of Strathclyde

gamma forgiati SRL

4 Universities

Universidad Carlos III de Madrid

University of Oxford

University of Cambridge

DTU

5 Collaborators

Bodycote

- United Kingdom
- Romania

ICPE-CA

Imperial College London

KRISS 한국표준과학연구원 Korea Research Institute of Standards and Science

Collaborators

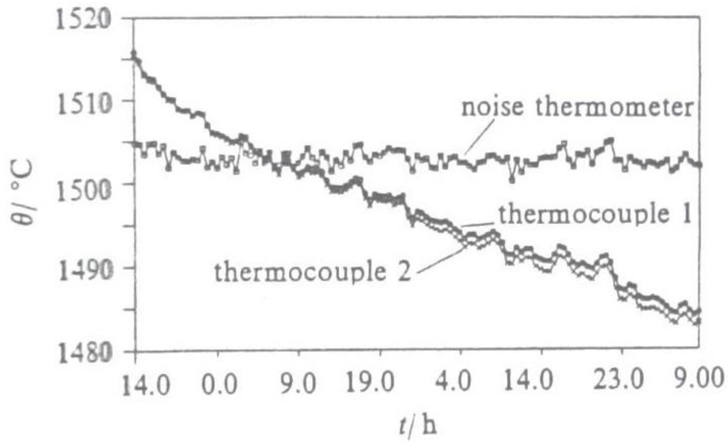
- Bodycote Heat Treatments (UK)
- Bodycote Heat Treatments (Romania)
- Imperial College (UK)
- ICPE-CA (Romania)
- Korea Research Institute for Standards and Science (Korea)
- HTRC (UK)

WP1 Low-drift contact temperature sensors to > 2000 °C (PTB)

- Pt-Rh thermocouples OK to about 1500 °C
- W-Re thermocouples to 2300 °C, not very stable
- Thermocouples sometimes not suitable at all e.g. in silicon environments

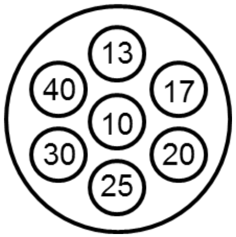
- Determine optimum Pt-Rh composition
- Sapphire tube blackbody device
- Graphite thermocouple

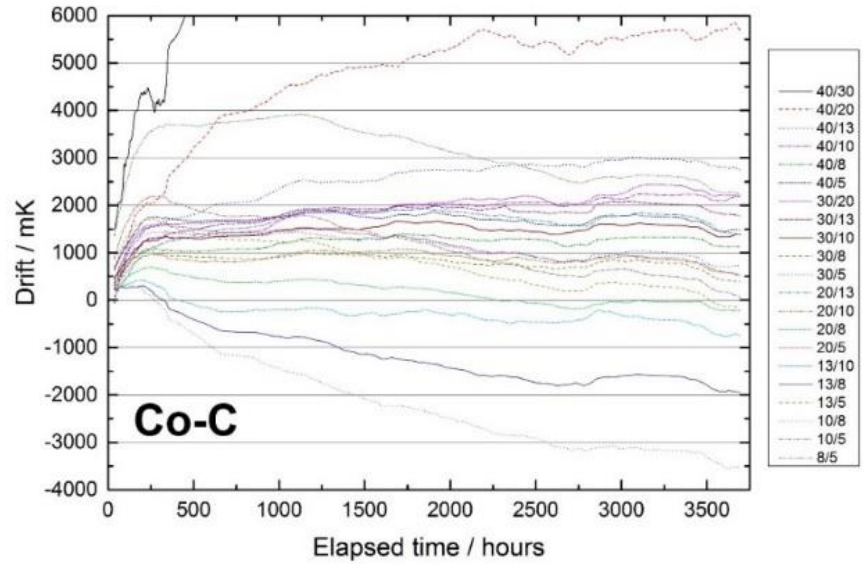
- End-user trials

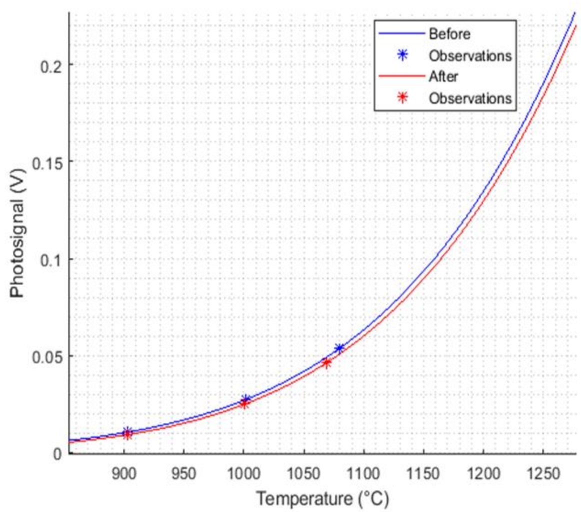


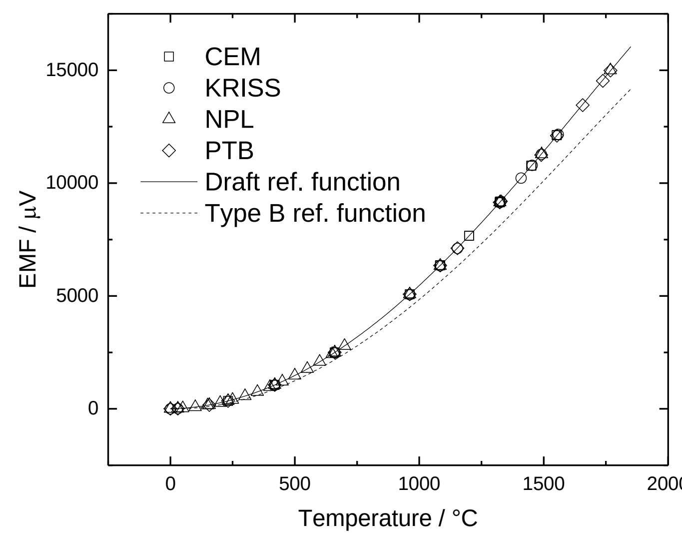
WP1 Low-drift contact temperature sensors to > 2000 °C (PTB)

- Multi-wire Pt-Rh thermocouple stability evaluated to about 1500 °C (NPL, PTB)
- Determination of the Pt-40%Rh/Pt-6%Rh reference function (PTB, CEM, NPL, KRISS)
- JV/Elkem: Sapphire tube blackbody device constructed & operational



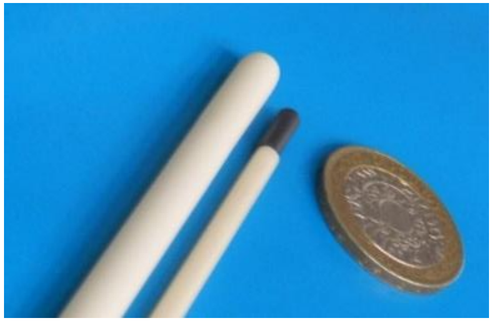


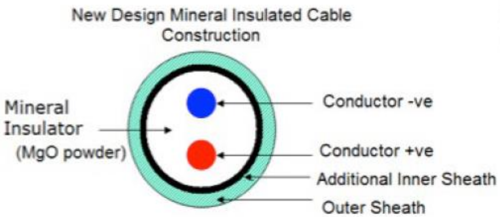


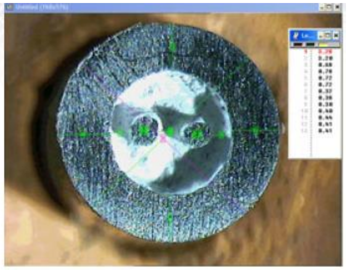


WP2 Zero-drift contact temperature sensors to 1350 °C (NPL)

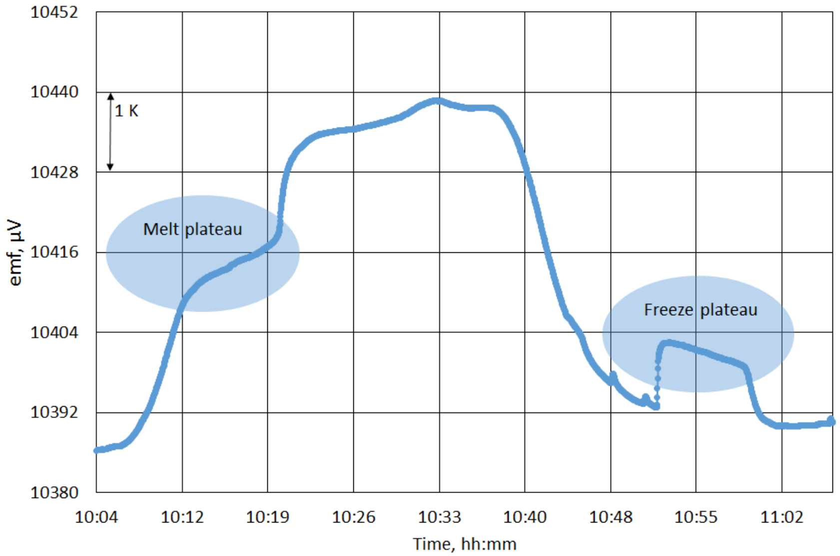
- NPL/CCPI Self-validating thermocouples constructed and working
- MI cable developed by UCAM, metrologically characterised by PTB

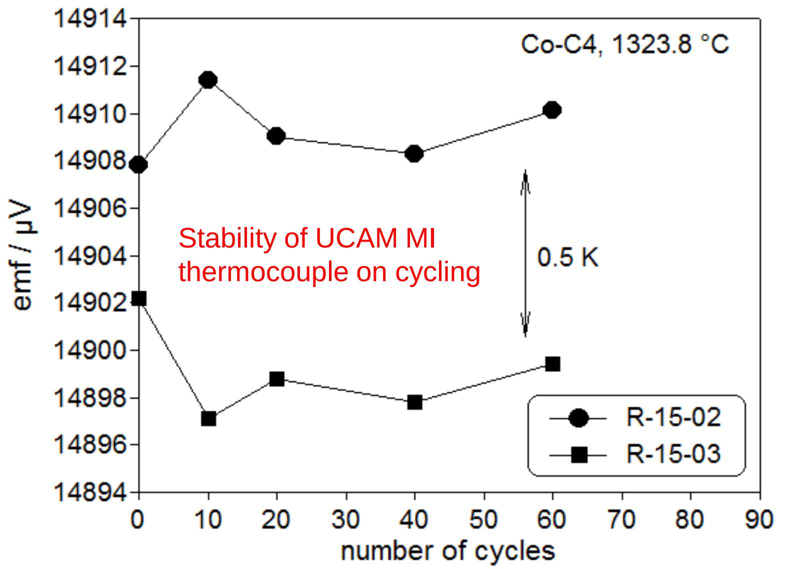




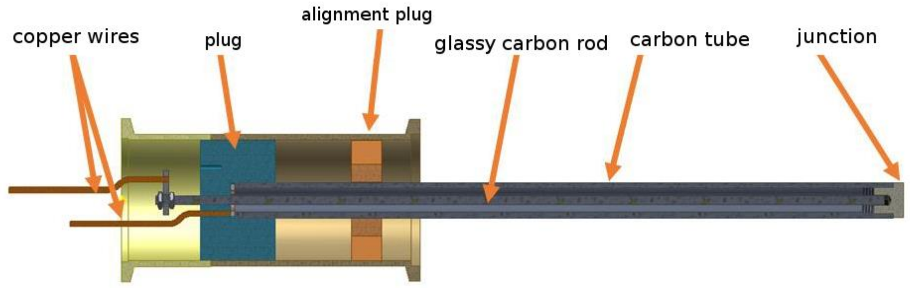


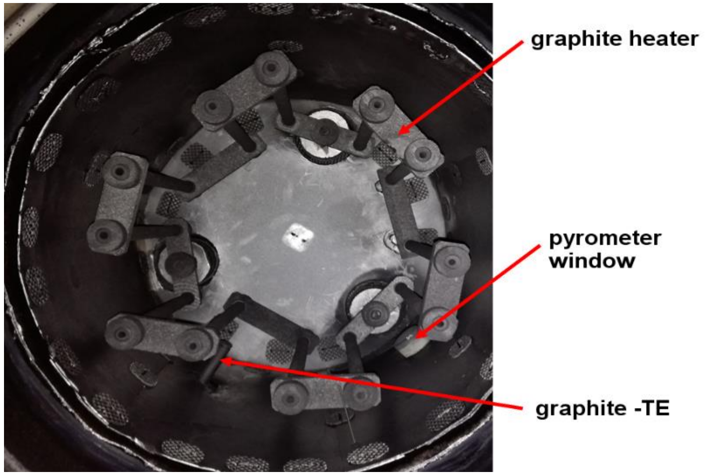
Melting and freezing of miniature FP crucible (Pt-Rh thermocouple, all in 7 mm o.d. sheath)

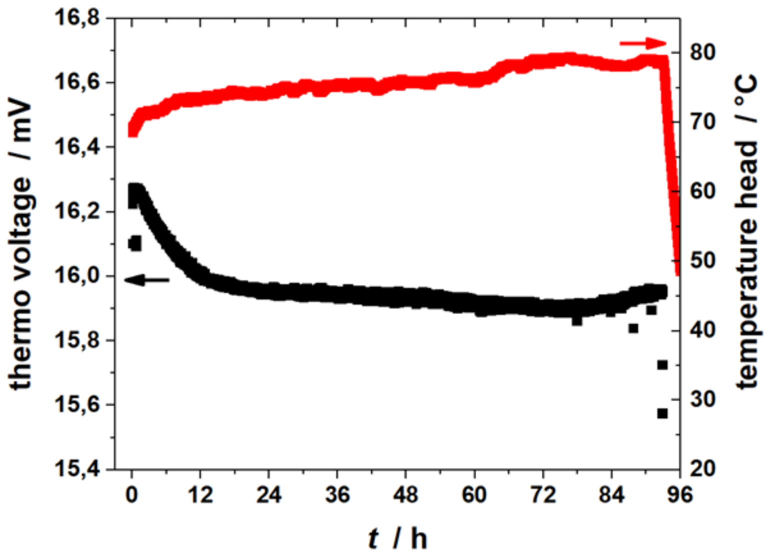




Graphite thermocouple





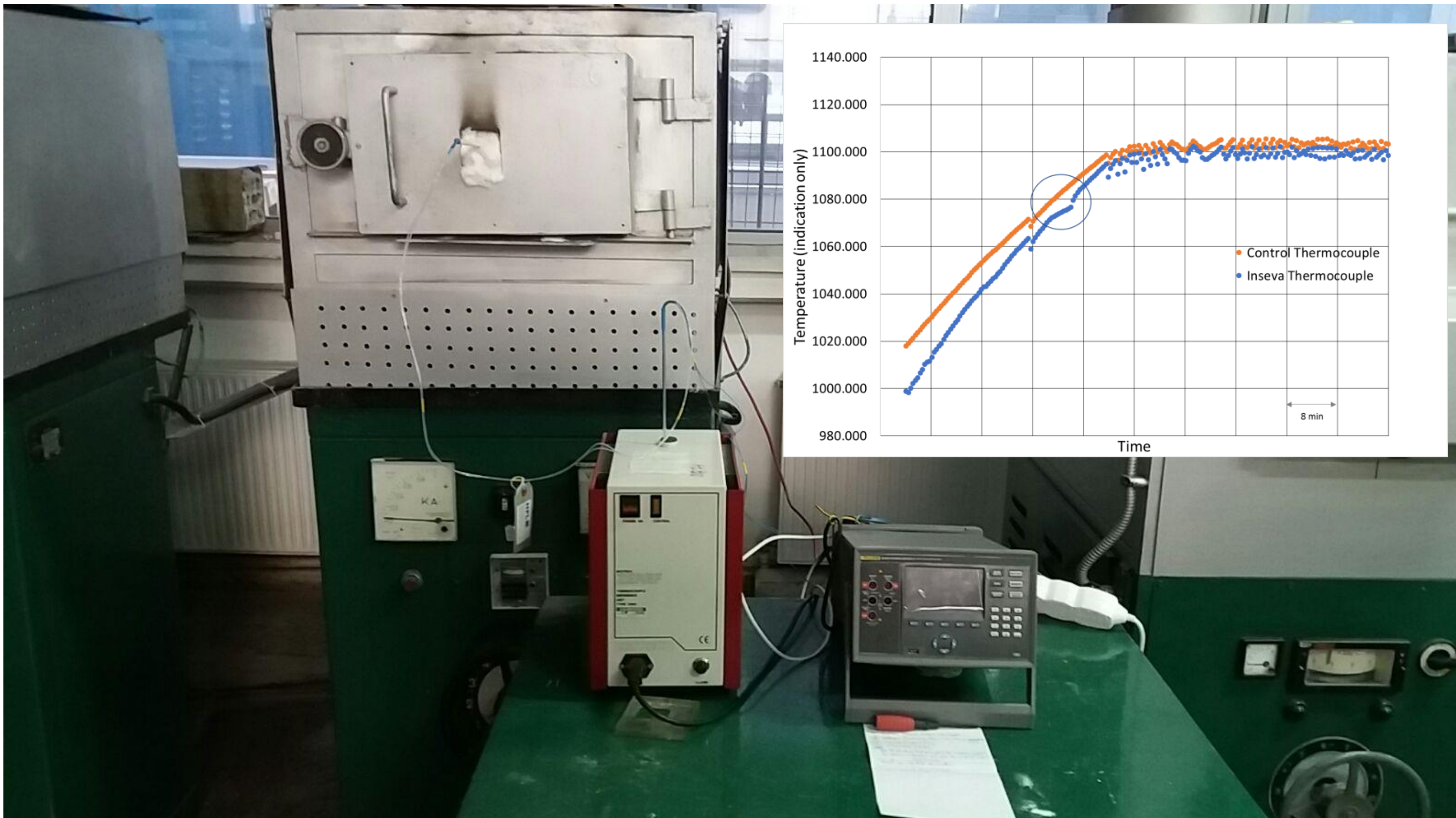


WP1 & WP2 in-situ trials

- Heat treatment
- Forming and forging
- Ceramic manufacture

In-process tests

- ICPE-CA (Romania) and AFRC (Glasgow)
- Up to 6 months



In-process tests

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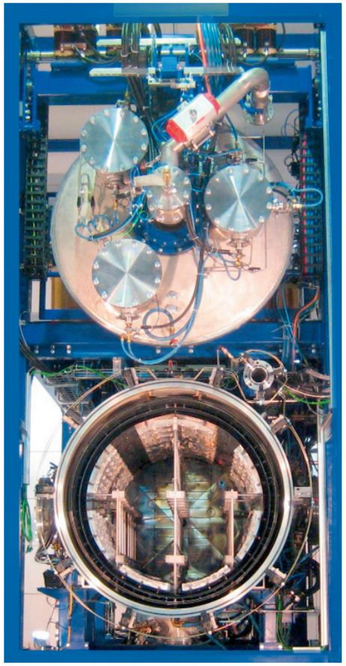
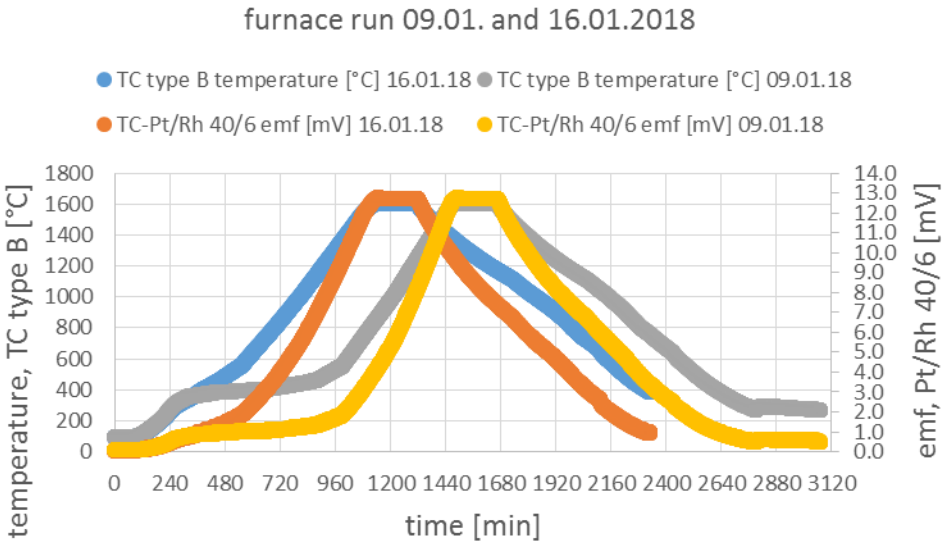
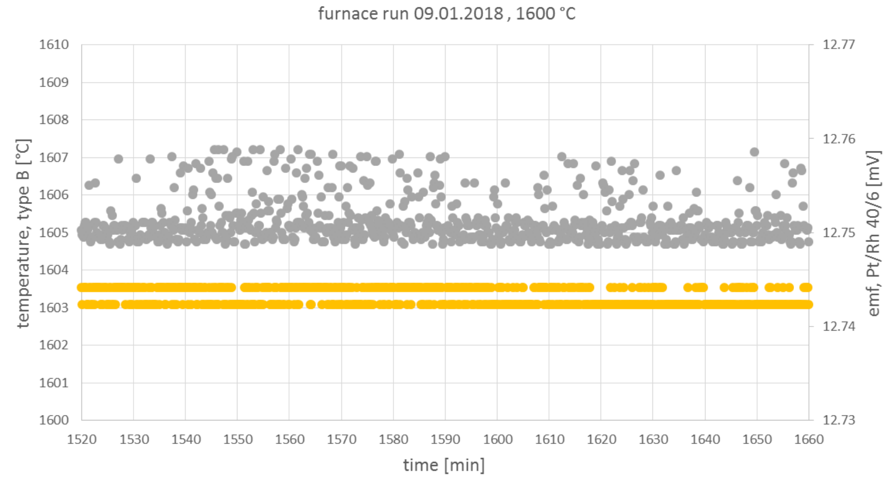
National Physical Laboratory

AFRC
ADVANCED FORMING RESEARCH CENTRE
UNIVERSITY OF STRATHCLYDE

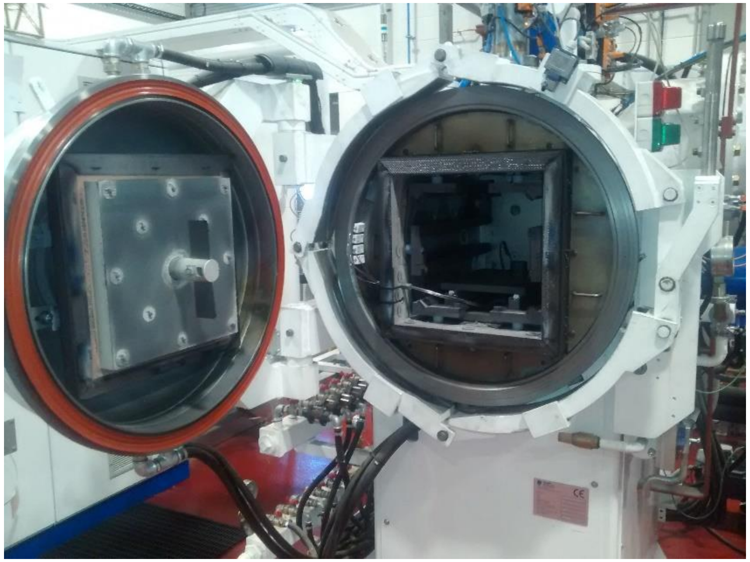
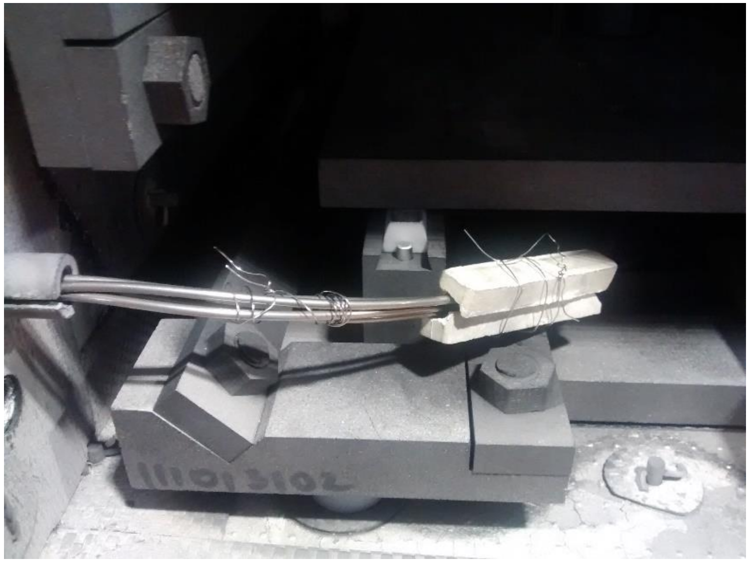
In-process tests (industrial furnaces)

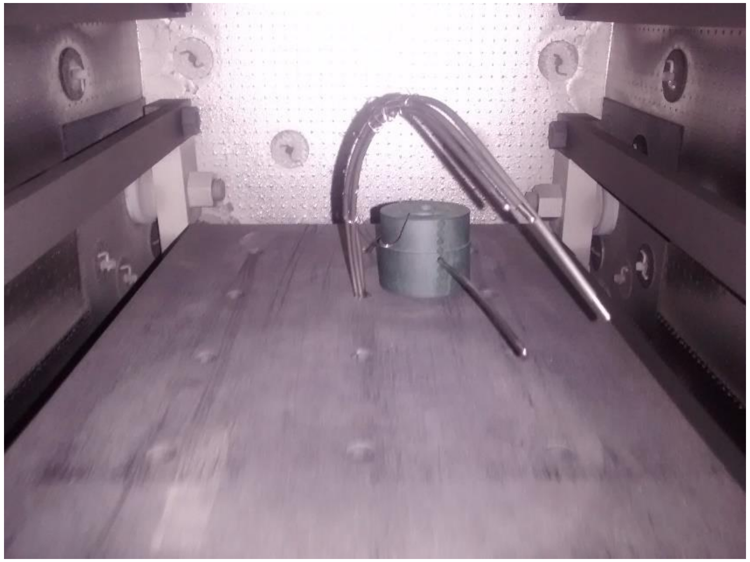
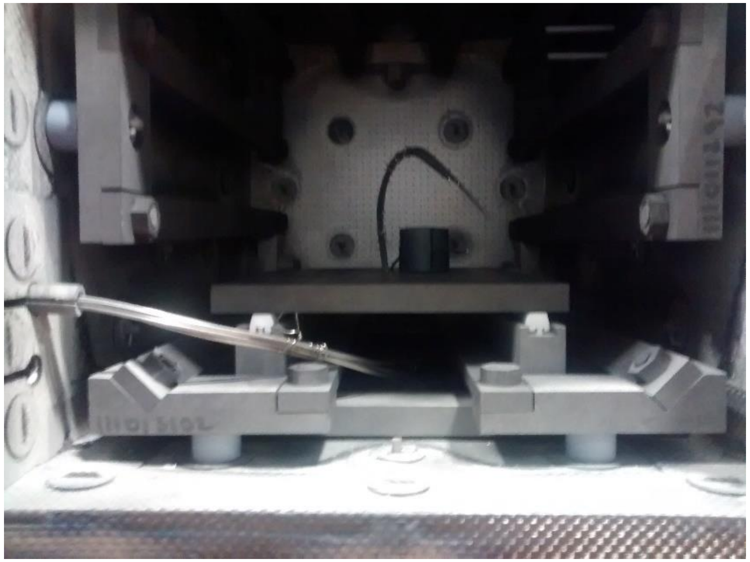






In-process tests (double-walled MI cable)

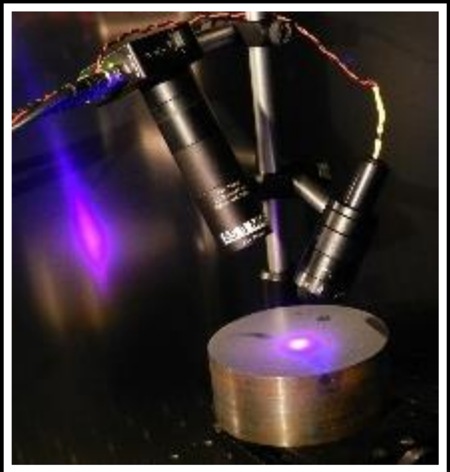



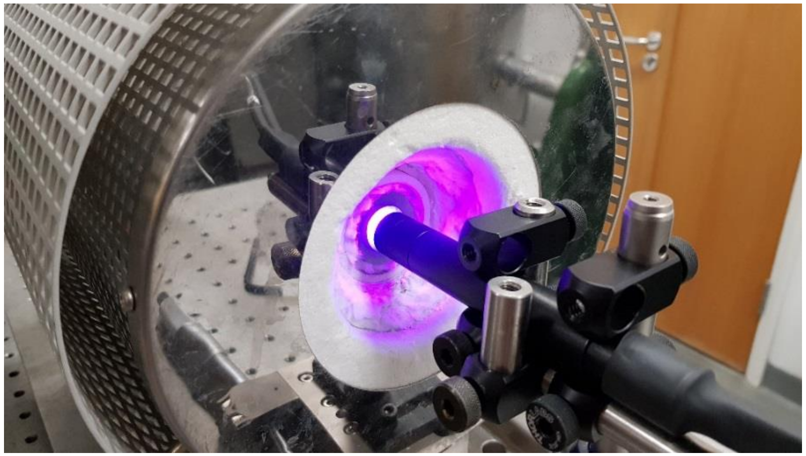
In-process tests

WP3 Surface temperature (INRIM)

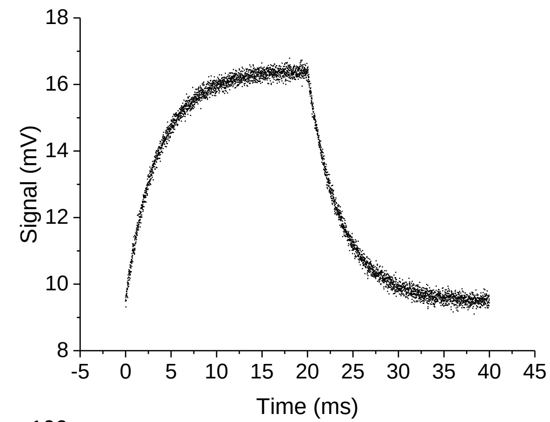
- Forming, forging, welding heat treatment, coating
- Contact thermometers for surface temperature measurement are subject to large errors
- Fluorescence thermometer
  - Surface temperature calibrator
  - Directly applied to surface
- Heat flow compensating sensor

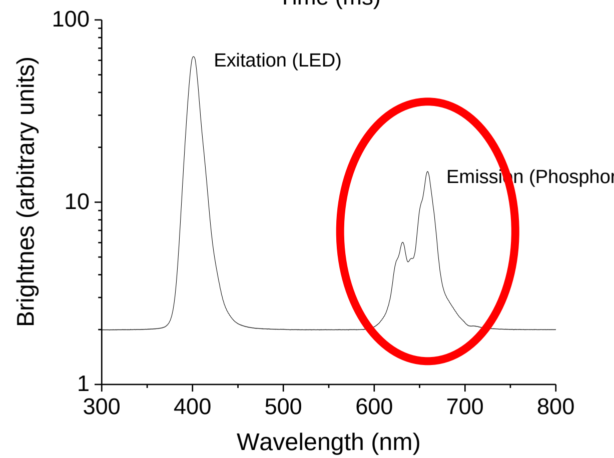


WP3 Surface temperature – NPL probe

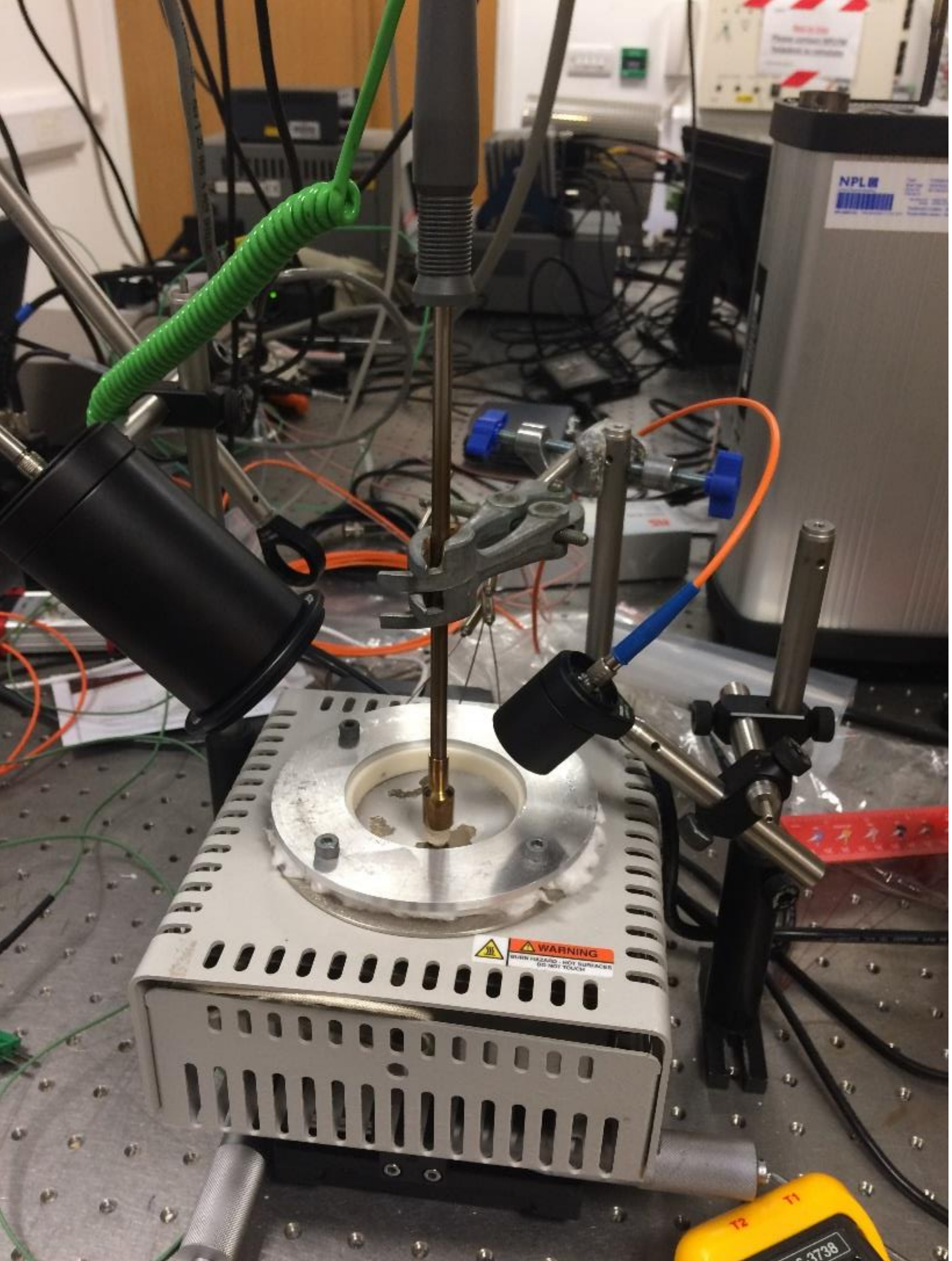
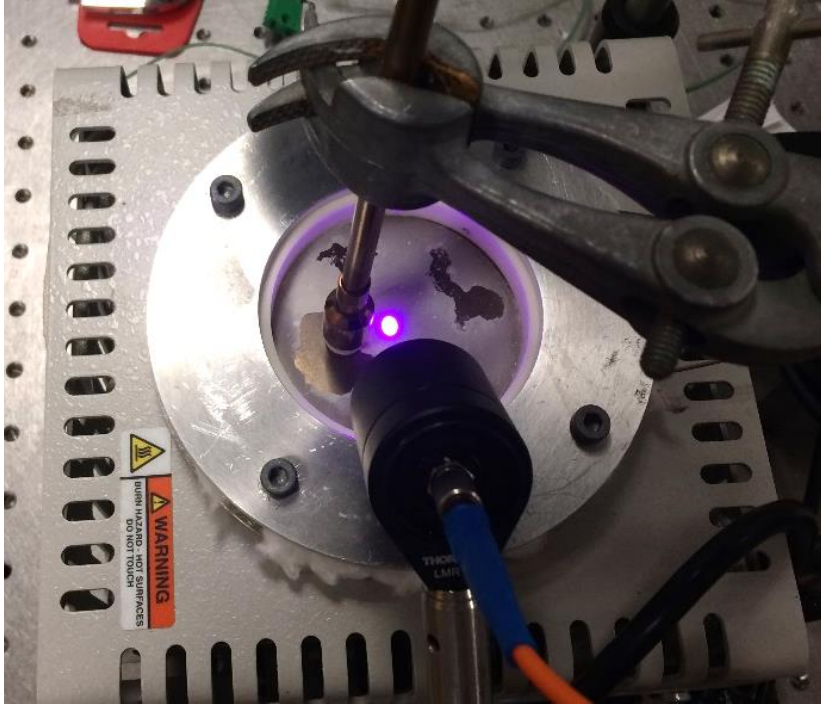


- Apply specific phosphor to surface and activate
- Either
  - Decay time of emitted light
  - 2-line ratio method
- Prototype instrument 20 C to 500 C
- Uncertainty < 1 C for 1 s measurement





Ratio of intensity at different wavelengths is also T dependent


NPL
WARNING
BURN HAZARD - HOT SURFACES DO NOT TOUCH

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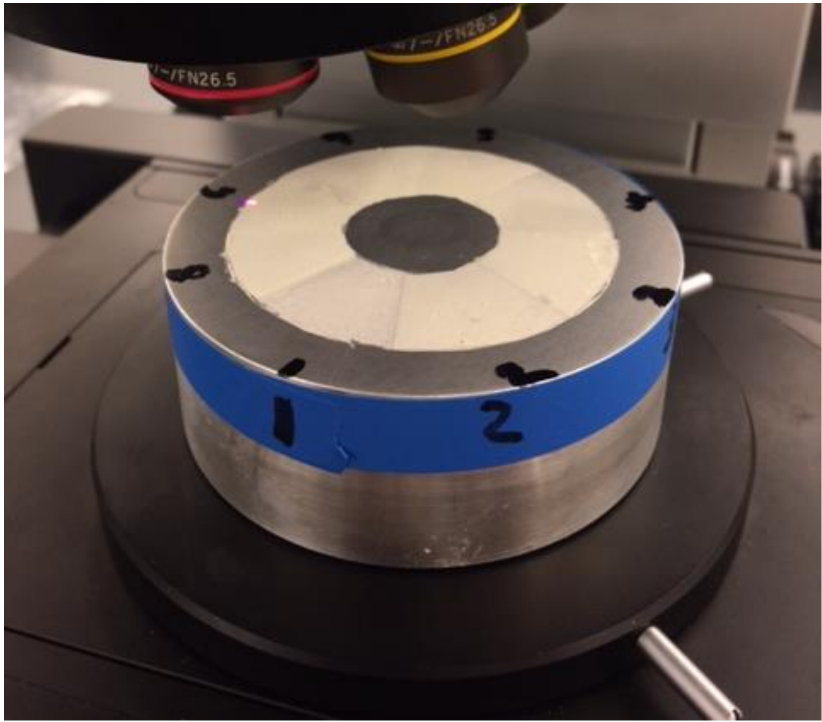
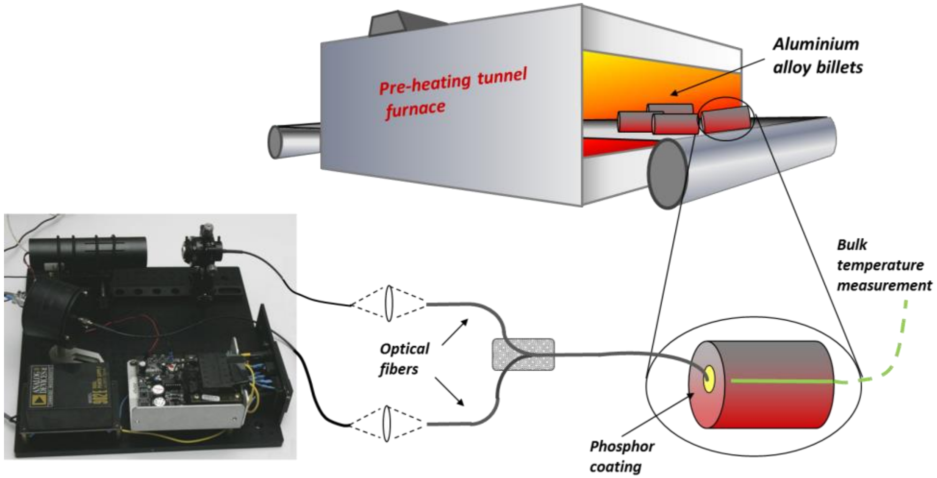

1
2

WP3 Surface temperature (INRiM)

- End-user trials
- BAE Systems
- Gamma Forgiati



Pre-heating Al alloy billets at Gamma Forgiati

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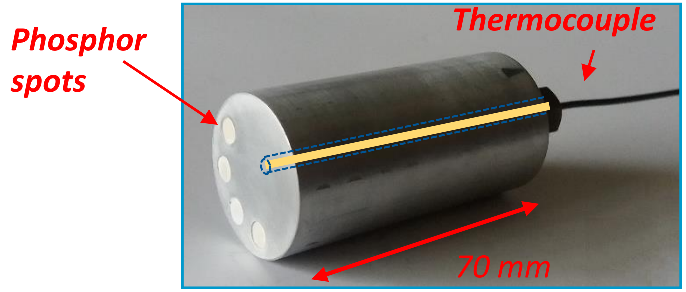
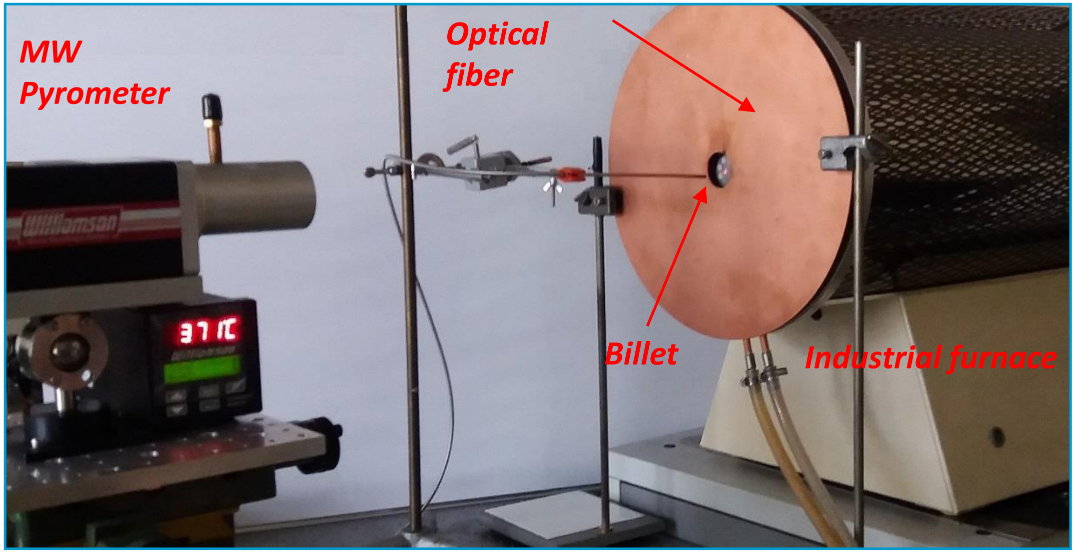
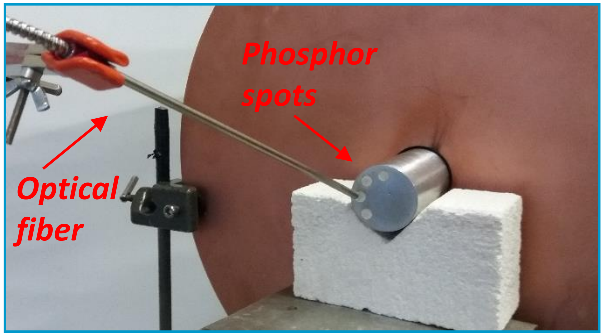
Three different techniques, i.e. Phosphor-based technique, Radiation thermometry and Contact thermometry, were employed for the measurement of surface temperature of aluminium alloy billets in pre-heating treatment at the manifacturing facilities of Gamma Forgiati have been performed





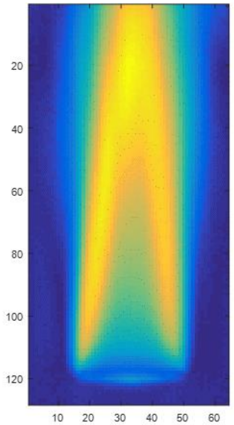


WP4 Combustion temperature (NPL)

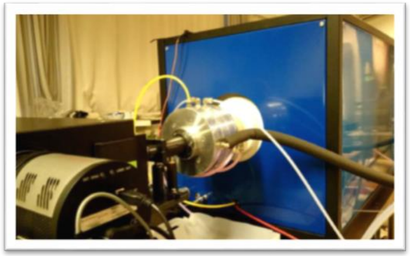
- ICE, gas turbines, fuel development
- There is currently no traceability of flame and combustion temperature measurements
- Develop portable standard flame
- Validate it & assign traceable temperature across Europe
- Make it available to end-users

WP4 Combustion temperature (NPL)

- NPL: portable standard flame commissioned
- CEM/UC3M: hyperspectral imaging
- DTU: UV spectrometer measurements on hot gas, compilation of UV CO2 and H2O absorption spectral database
- UOXF: DFWM and LIGS models
- End-user linkage via universities (mainly automotive)



Hyperspectral image


UV spectrometer observing the hot gas cell.

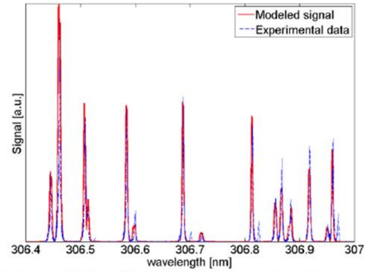
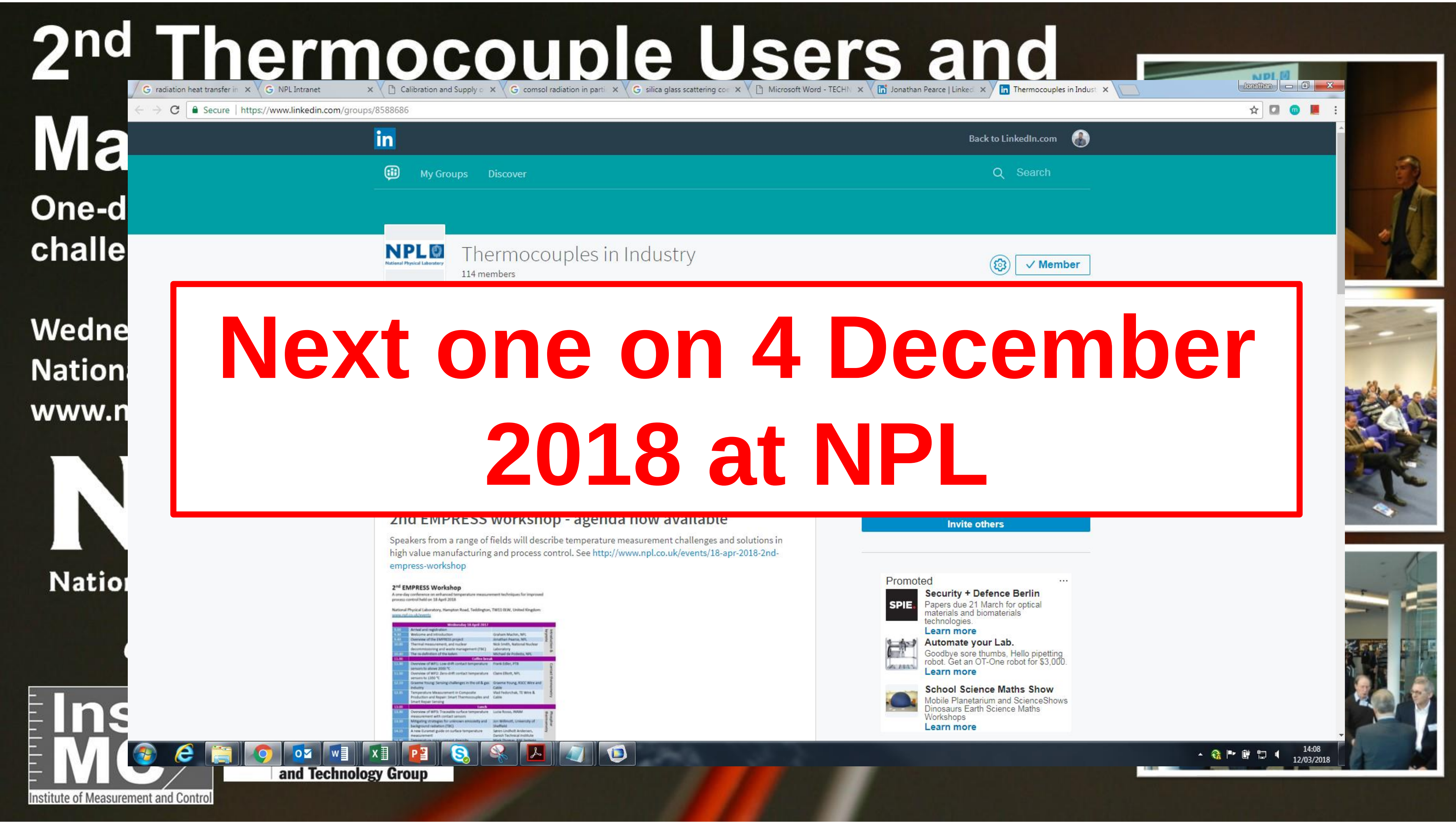


Figure 2. DFWM spectrum of OH and analytical simulation

Unexpectedly good agreement


ADVANCED FORMING RESEARCH
AFRC
• Impact / outreach
• In-process trials

Thermocouple users group



Next one on 4 December 2018 at NPL

Enhancing process efficiency through improved temperature measurement – EMPRESS2

EMPRESS 2
TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY

T (°C) — 2500, 2000, 1500, 1000, 500, 0

Thermometry developments

Combustion thermometry (WP3)

- Circulation of calibrated portable standard flame
- Practical IR thermal imaging system
- Practical sweeping FTIR-based system

Portable standard flame

Standardising high stability thermocouples (WP2)

- Pt40%Rh/Pt6%Rh thermocouple reference function standardised
- Optimised, validated double-walled mineral insulated, metal sheathed thermocouples

Platinum/rhodium thermocouple

Surface temperature: phosphor thermometry (WP1)

- Practical 2D intensity-ratio phosphor thermometer to 1000 °C
- Combine with thermography to overcome emissivity problem
- Decay-time phosphor thermometer to 1000 °C

Phosphor thermometer

Harsh environments: fibre-optics (WP4)

- Phosphor-tipped fibre-optic thermometers to 650 °C, cross-validated
- Hollow-core phosphor-tipped fibre-optic thermometer suited to harsh environments
- Distributed fibre-optic temperature sensor based on Brillouin scattering, to 650 °C
- Hybrid blackbody/FBG thermometer to 1500 °C
- New traceable calibration techniques for fibre-optic temperature sensors

Hollow-core fibre-optic

In-process trials

- Waste incineration
- NO_x processing
- Fire resistance testing

- Forging & forming
- Heat treatment
- Furnace manufacture
- Glass manufacture
- Steel manufacture

- Automotive brake disks
- Welding
- Forging

- Ionising radiation
- Magnetic fields
- Plasma storms
- Forging & forming
- Silicon processing
- Steel manufacture
- Furnace manufacture

IMPACT

- In-process trials of new sensors and techniques
- Exploitation of IP
- Traceability to ITS-90 in-situ
- Strong linkage to standardisation
- Presentations at trade fairs and conferences
- 13 peer-reviewed + 10 trade journal articles
- Updated Euramet guide on surface temperature measurement
- Two industrial-focused workshops
- 67 letters of support from industry
- 118 members of the EMPRESS stakeholder community

Consortium and Supporters

NPL National Physical Laboratory · CEM · CMI Czech Metrology Institute · CSIC · Danish Technological Institute · DTU · INRiM · Justervesenet · PTB · UME · Elkem · Leibniz ipht · ITT · MUT Advanced Heating · University of Southampton · University of Strathclyde · University of Cambridge · AFRC · Acerinox · BAE Systems · B&W vølund · CCPI Europe Limited · Johnson Matthey · Sensia

Conclusion

- Solve specific, documented process control problems in high value manufacturing
- Currently undergoing *in-process* trials

- More stable thermocouples
- Fibre-optic BB sensors
- Surface temperature measurement
  - Phosphor thermometry
  - Surface probe calibrators
- Combustion thermometry: portable standard flame

- Substantial stakeholder engagement

Wednesday 18 April 2017			
9.00	Arrival and registration		Introduction & keynote
9.30	Welcome and introduction	Graham Machin, NPL	
9.40	Overview of the EMPRESS project	Jonathan Pearce, NPL	
10.00	The re-definition of the kelvin	Michael de Podesta, NPL	
10.30	Update on the development of a practical Johnson noise thermometer	Paul Bramley, Metrosol	
11.00	**Coffee break**		
11.30	Overview of WP1: Low-drift contact temperature sensors to above 2000 °C	Frank Edler, PTB	Contact thermometry
11.50	Overview of WP2: Zero-drift contact temperature sensors to 1350 °C	Claire Elliott, NPL	
12.10	Graeme Young: Sensing challenges in the oil & gas industry	Graeme Young, Marmon Engineered Wire & Cable	
12.35	Temperature Measurement in Composite Production and Repair: Smart Thermocouples and Smart Repair Sensing	Vlad Fedorchak, TE Wire & Cable	
13.00	**Lunch**		
13.30	Overview of WP3: Traceable surface temperature measurement with contact sensors	Claire Elliott, NPL (on behalf of Lucia Rosso, INRiM)	Phosphor thermometry
13.50	Mitigating strategies for unknown emissivity and background radiation (TBC)	Jon Willmott, University of Sheffield	
14.15	Imaging phosphor thermometry at NPL: Recent developments and future prospects	Gavin Sutton, NPL	
14.40	Temperature measurement diversity	Mark Thomas, BAE Systems Maritime	
15.05	**Tea break and networking**		
15.35	Overview of WP4: Traceable combustion temperature measurement	Gavin Sutton, NPL	Combustion thermometry
15.55	In-situ temperature measurements by optical spectroscopy from lab to industrial scale	Alexander Fateev, Technical University of Denmark	
16.20	Thermocouple use for aircraft powerplant fire testing	Mary Kelly, Resonate Testing	
16.45	**Tour of NPL temperature labs**		

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