MECHANICAL TEST FACILITY

Electro-Thermal Mechanical Test Webinar

NPL National Physical Laboratory

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New Mechanical Test Facility

Welcome to the official opening of NPL's state-of-the-art Mechanical Test Facility (MTF).

This facility, combined with NPL's extensive expertise in materials characterisation and assurance, provides a unique capability for research and commercial testing services. As businesses continue to face diverse challenges due to the pandemic, this facility will help boost UK recovery by serving as a UK centre of excellence.

Characterise New Materials & Products

Overcome UK Supply Chain Limitations

Facilitate Quicker Product Development

Support Industrial Innovation

Assist Green Industrial Revolution

Webinar Presenters

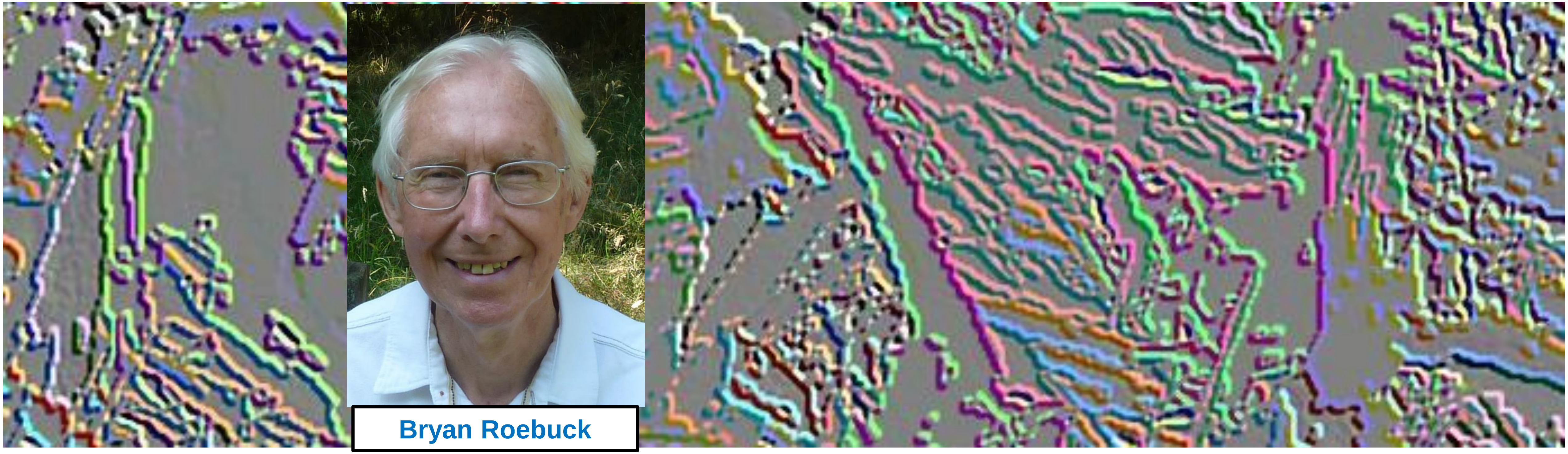
Dr Bryan Roebuck, NPL Emeritus Senior Fellow

Dr Peter Bailey, Senior Applications Specialist – Instron Dynamic Systems

MINIATURISED TESTING SYSTEM

National Physical Laboratory

ETMT - Collaboration between NPL and Instron



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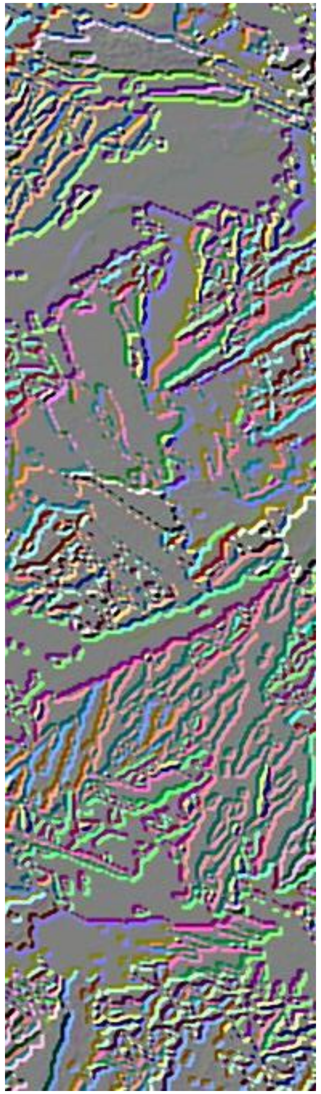
Tuesday 16th March 2021 (3 pm)

Agenda

- Original project drivers
- Unique system capabilities developed
- Building blocks of system
- Continued development
- Considerations for miniature testing
- Why is it a technique even more relevant now.
- Q&A

Mechanical Testing Trends

- More Use Of Smaller Specimens
- Post Service Testing
- Lower Specimen Costs
- Quicker Results Desirable
- Testing In More Demanding Environments
- More Use of DIC
- Dynamic Combinations of Stress and Temperature
- Higher Temperatures
- Complex Stress States
- Rate Effects
- Protective Atmospheres or Vacuum



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Initial drivers

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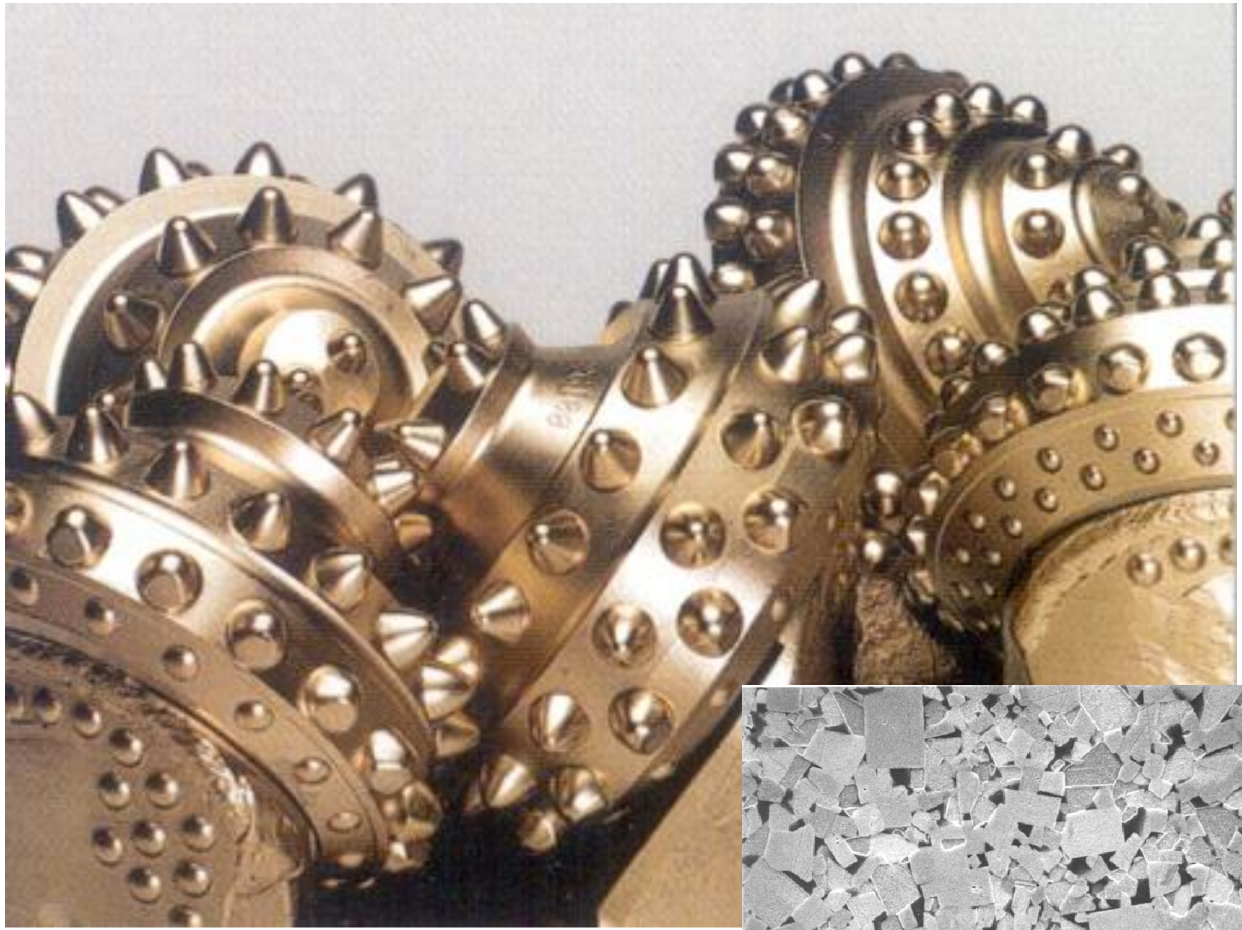

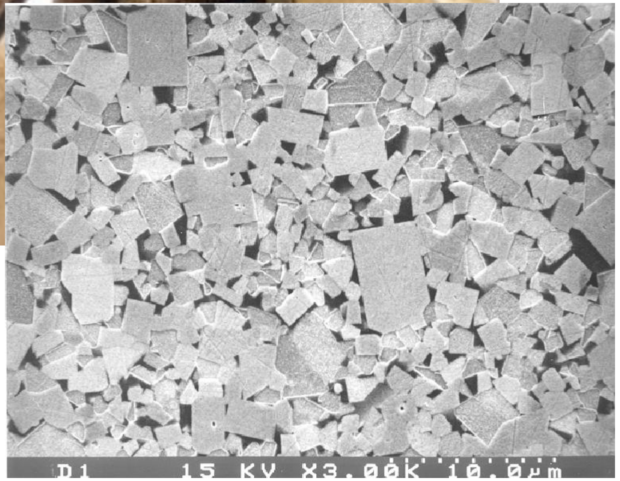

Tooling Materials:
Metal/Carbide Composites

In the early 1990s, NPL investigated various methods for tool material hot deformation.

This activity was guided by an Industrial Advisory Group and assessed, in sequence, laser, electron beam and then resistance heating methods.

The latter method proved.

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Unique device developed for that work

- Heating was Electrical Direct Resistance Heating – Electro Thermal
- Mechanical Loading was also applied during the test.
- Hence Electro-Thermal Mechanical Testing Device - **ETMT**

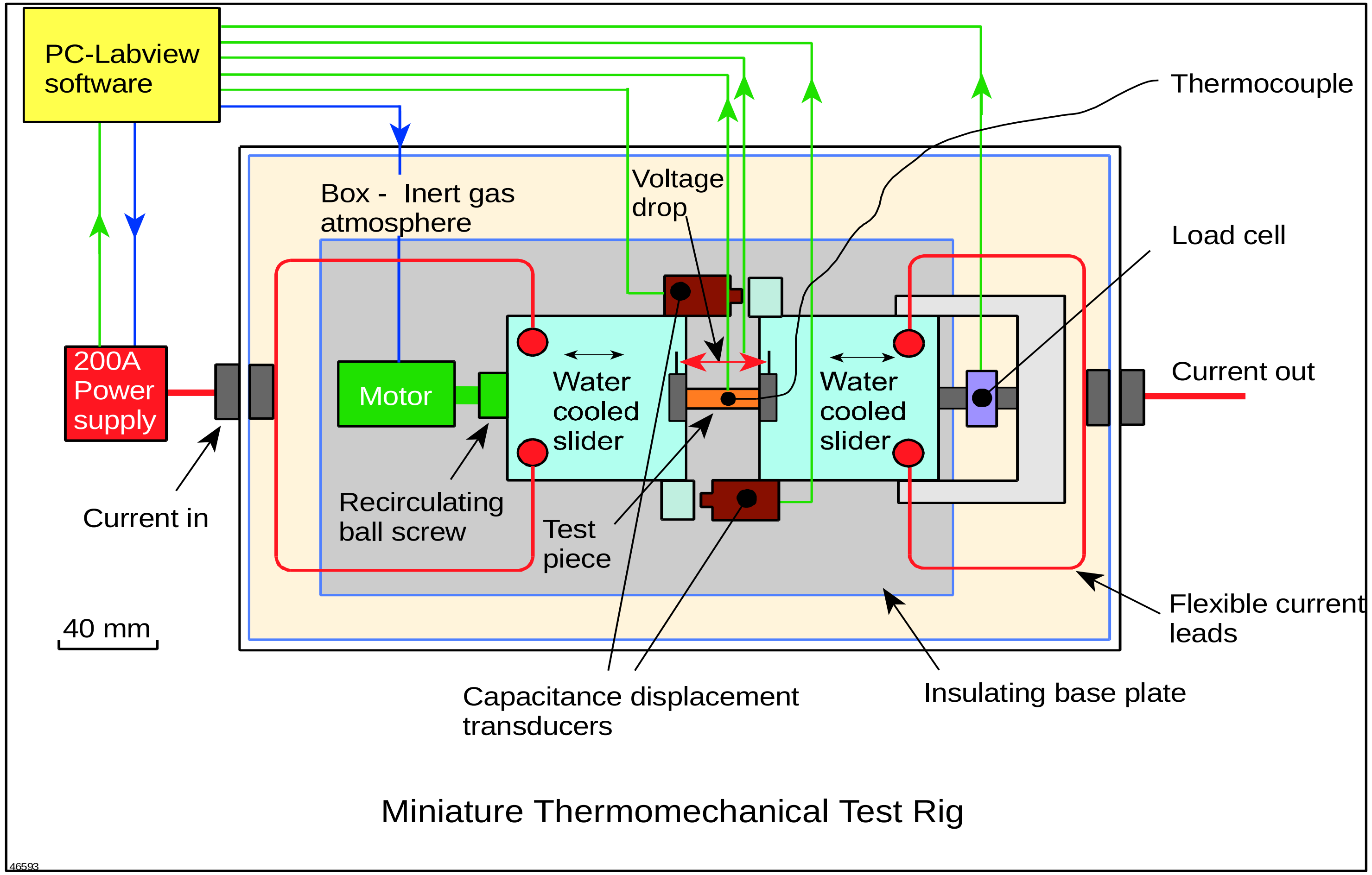
Video of system running test

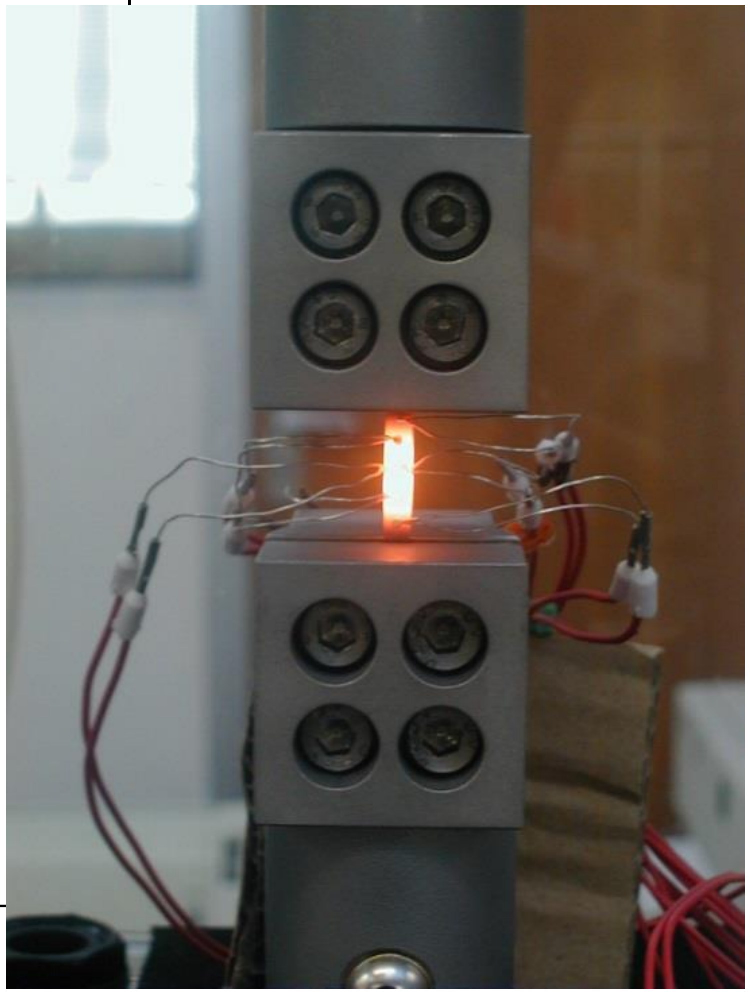
Notes to add on that initial work - Bryan

- Why small samples
- Why was heating rates/temperature important
- Why was mechanical loading important
- Why was controlled environment important
- Some example results of that work, that could only be produced on such a system.

Mk1 NPL ETMT Multiproperty Apparatus - Schematic

NPL National Physical Laboratory





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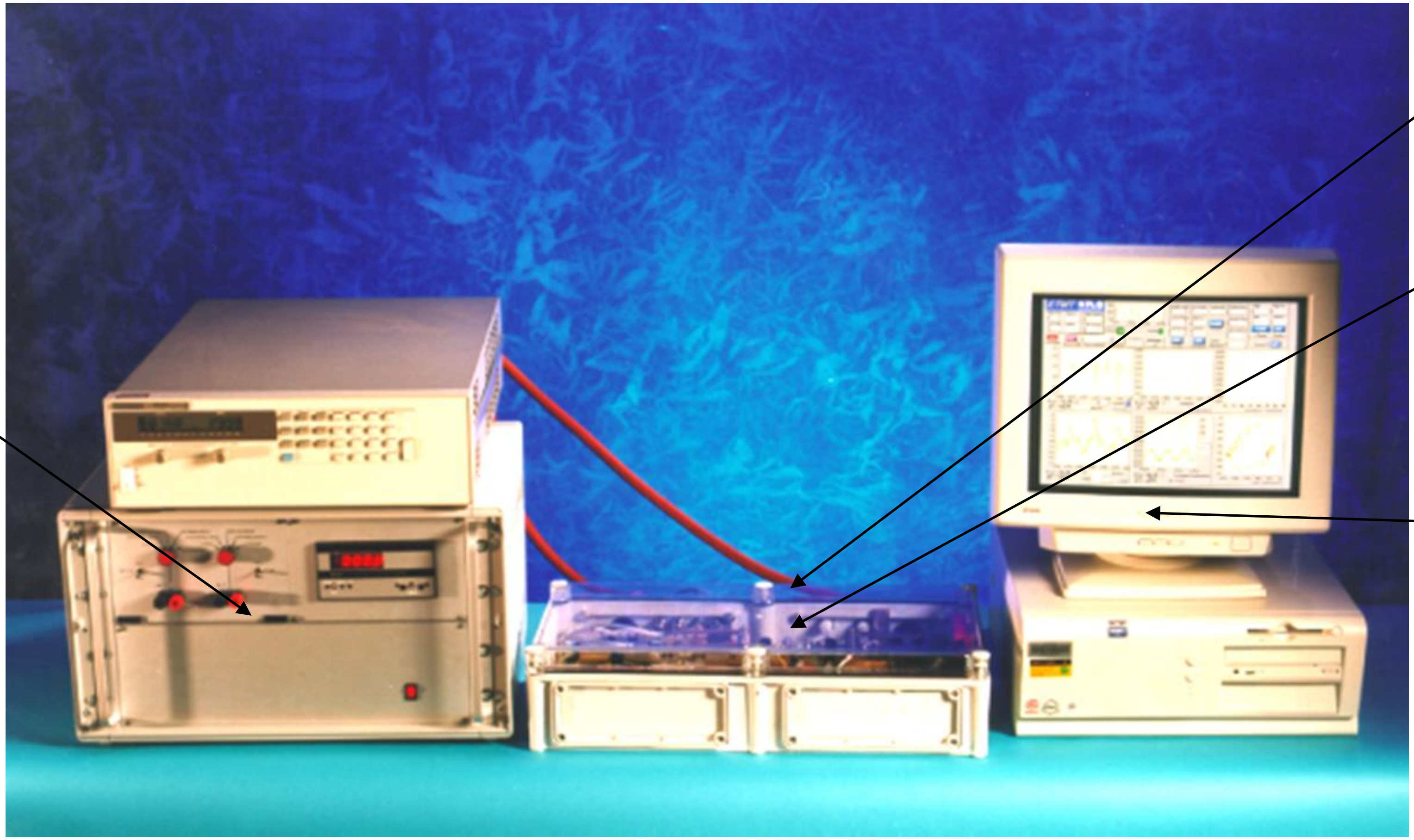
INSTRON ETMT Hot sample

Initial system

Heating



Control environment

Closed loop mechanical loading stage

Control and data acquisition

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Unique capabilities

- As already mentioned, samples were ~ 50 times smaller in cross-section than traditional fatigue sample.
- Direct resistant Heating rates were controlled and rapid in comparison to traditional methods.
- Heating and loading could be synchronized.
- Conventional instruments involving testing “in air”, This device used a controlled environment.

Industrial interest

- Key properties for process and performance modelling
  - Modelling is now business-critical – understanding every conceivable outcome, but minimizing number of physical tests
  - Large range of characteristics can be tested within one testpiece design
  - Accurate control of heating rates – both fast and slow
- Small samples
  - Efficient use of materials when quantities limited
  - Investigation of ex-service material and failures
  - Accelerated characterisation of materials in early/intermediate development
  - Very relevant in aerospace / turbines / power generation

- This unique combination of features resulted in increased interest globally, with systems produced by NPL for laboratories in the UK, US and Canada.

Commercial development

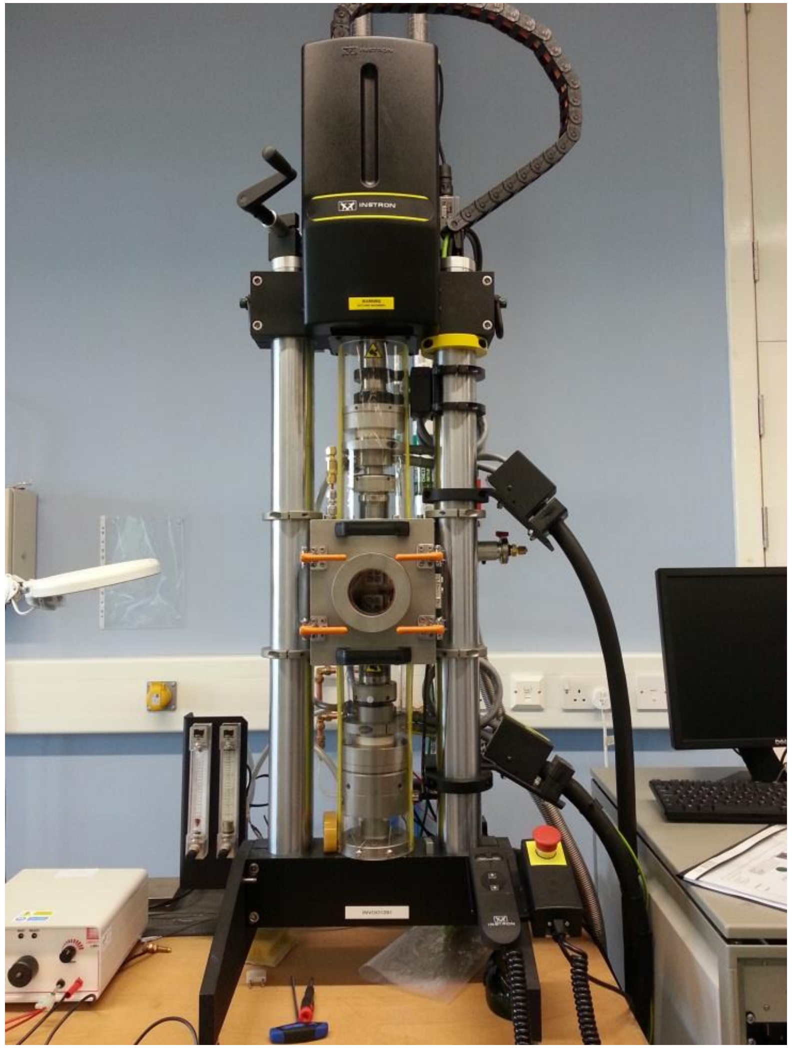
Instron involvement – Mark 2

- However, NPL is not a volume manufacturer or able to support multiple systems globally.
- This began the Instron NPL collaboration.

Continued development – Mark 3

- Instron developed the system to use standard frame drives and control systems that could be supported, serviced and maintained anywhere in the globe.

- The core functionality remained the same.



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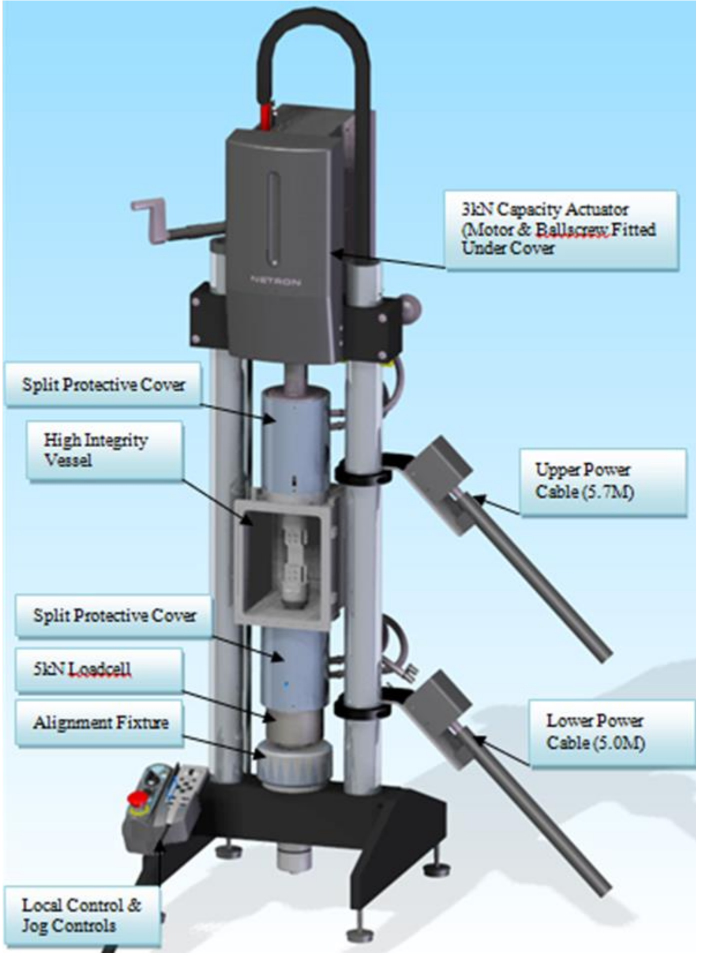
Mk3 – Instron microtester chassis

- Move to custom system based on standard platform technology
  - High frame stiffness
  - Backlash free drive
  - Standard 8800 machine control system
- Customer requests for inert gas environment
  - Addition of high integrity chamber
- Customer request for direct strain control
  - Addition of miniature high temperature extensometer
  - Capability for miniature TMF tests



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Mark 4 – Instron Electropuls

- Move to dynamic test frame
  - Better support and integration
  - Extending capability into fatigue
  - Potential for superimposed loading

- Platform will provide for 10kN or 20kN capacities for larger specimens
  - Large specimens will require very high current and/or high resistivity

Mk 4 overview technical specification

- Load
- Temp
- Heating rates
- Environment

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Specific Features

Advanced control and real-time calculations

- Integrating the ETMT with standard Instron equipment brings advantages from established platform technology

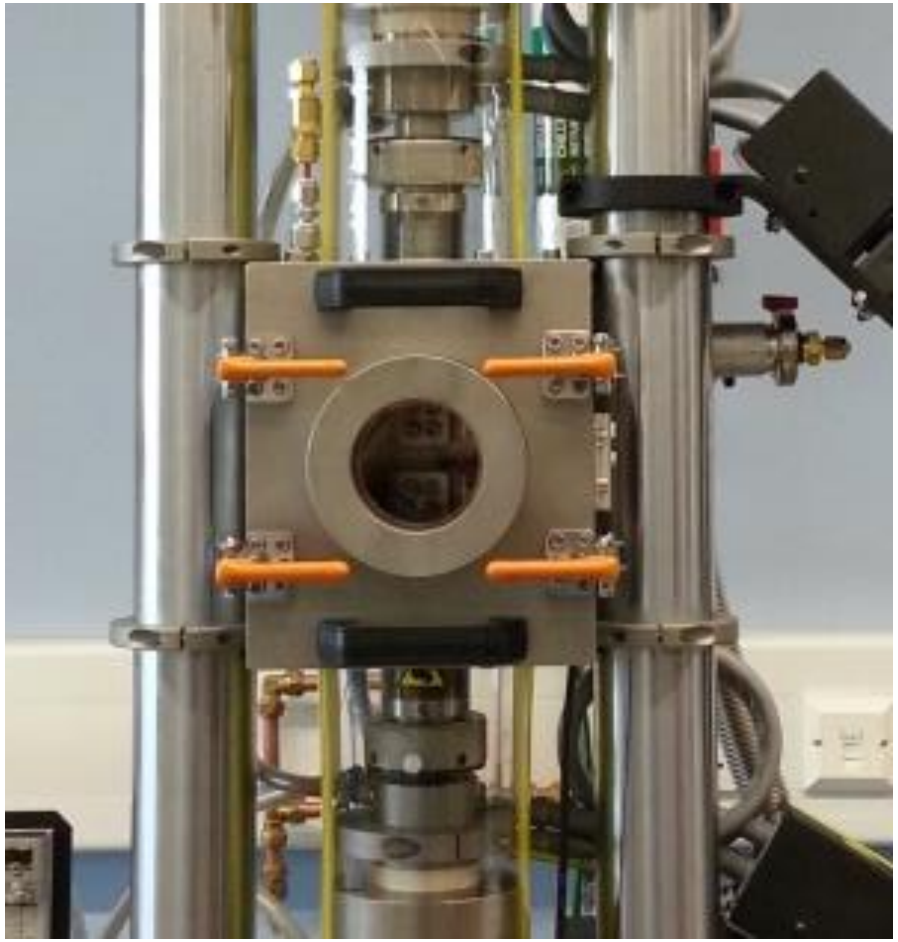
- 8800MT controller
  - Fast, high-fidelity control from feedback signals
  - Create “modal” parameters with user-defined relationships
  - Control using functions from multiple transducers

- WaveMatrix test software:
  - Smart data capture
  - Live calculation of cyclic behaviour
  - Block sequence control of temperature and loading operations
  - Identify changes or critical points and automatically respond

High integrity chamber

- Provides vacuum or inert gas environment
  - Proportional impact of skin effects is high on miniature specimens
  - Enables testing without surface oxidation effects
  - In slow tests at very high temperature loss of mass could affect data

- Future possibility for reactive atmospheres
  - Deliberate control of surface diffusion effects
  - Small core volume will make the impact more measureable

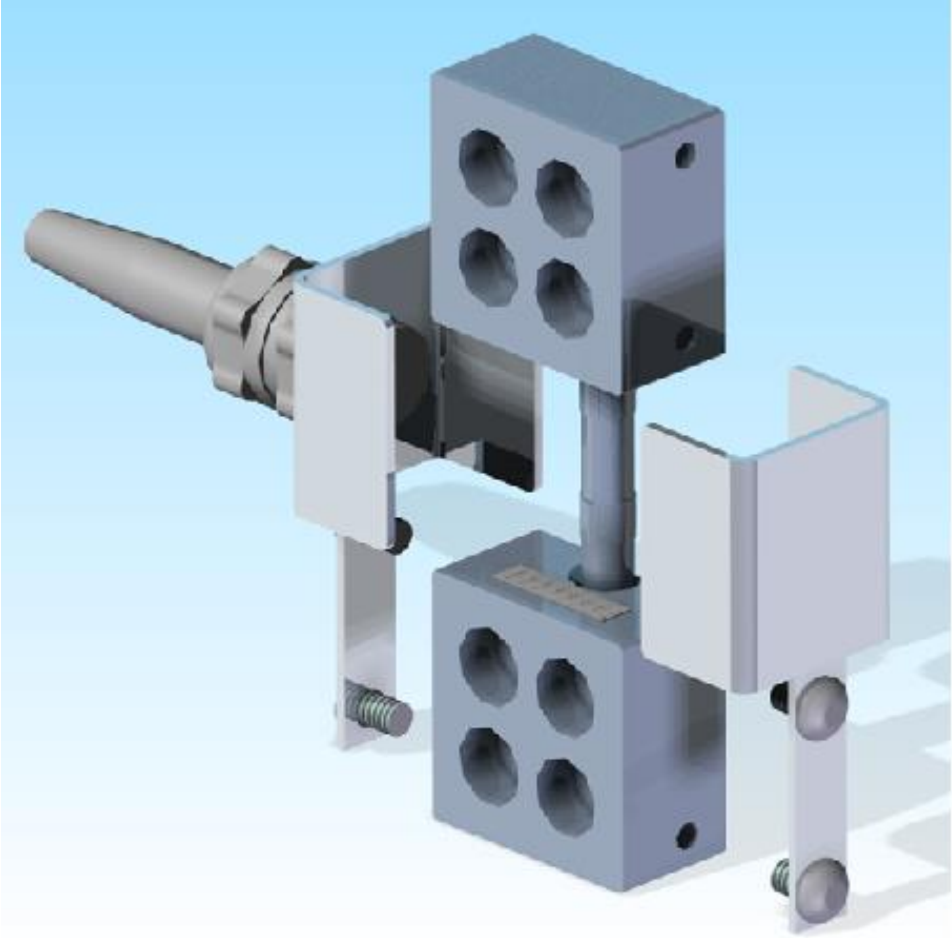


Alignment

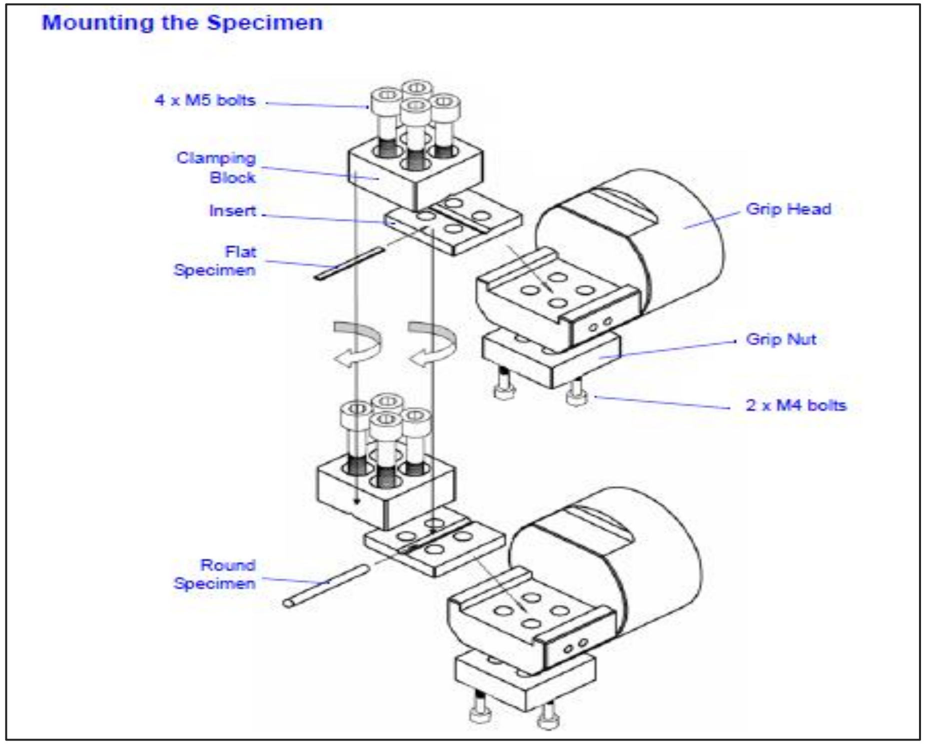
- Alignment is always important, but especially:
  - High stiffness, work hardening metals
  - Reverse stress
  - Non-linear / yielding conditions

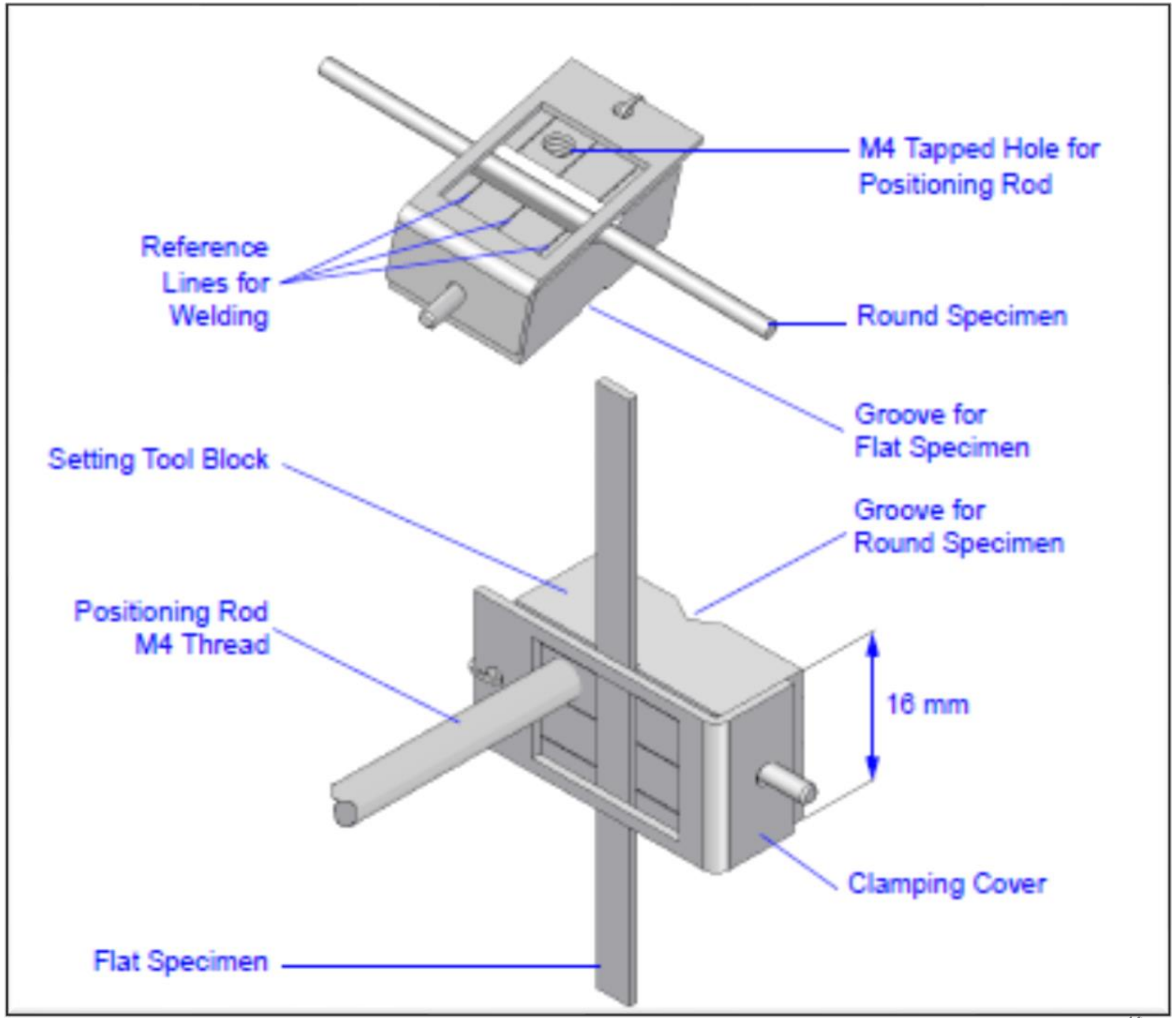
- Recent machines integrate mechanical adjustment mechanism
  - Progress with miniature strain-gauged specimens

- Ongoing grip development to address needs
  - Intimate electrical & thermal contact
    versus
    Repeatable clamping & alignment



Repeatable effective gripping





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Contacting extensometry

- High temperature extensometer customized for 5mm gauge length
  - Ceramic knife-edge contacts take direct strain measurement of a suitable working length

- Direct & accurate strain measurement enables more accurate rate control
  - Near material phase transitions strain rate is critical
  - Enables TMF tests potentially comparable with conventional specimens

Integrating strain from image correlation

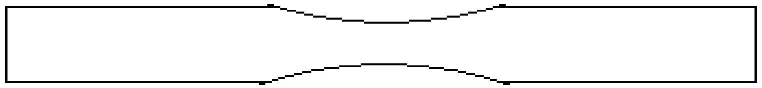
- Digital Image Correlation software allows full-field evaluation of strain along the specimen
- Non-contacting
  - Avoids influence of contact points from extensometer
  - Requires surface coating and patterning on specimen
- Possible to integrate “live” DIC strain signal for strain control of very slow tests

Video of system running test

Miniature testing challenges

ETMT - Testpiece Geometries

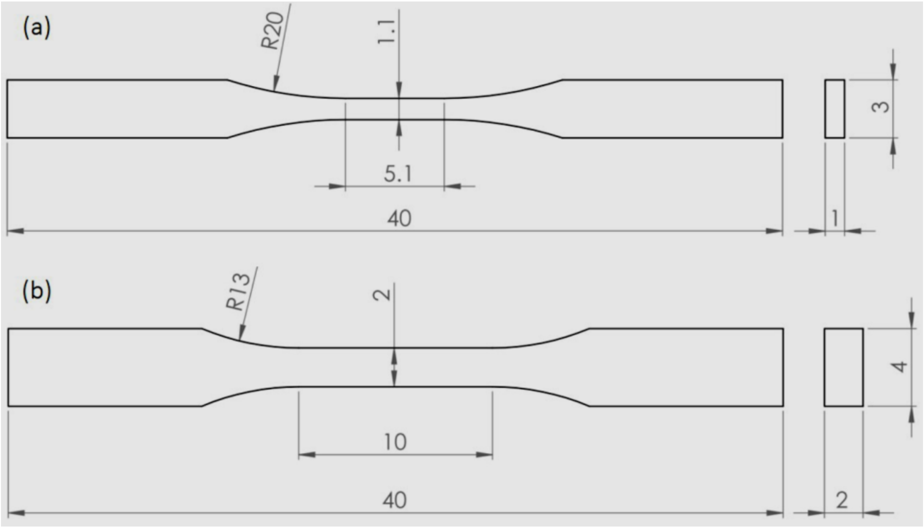
Initial NPL design *40 x 2 x 1mm*



NPL design for very strong materials

Radius wheel (diamond grinding) = 75 mm

Width at centre = 1.2 mm



Oxford University ETMT Geometries for Superalloys

AD gives more options for Specimen dimensions

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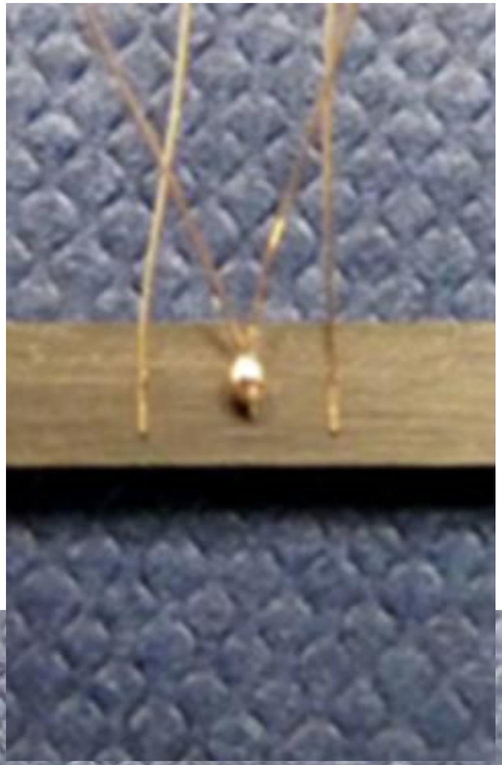
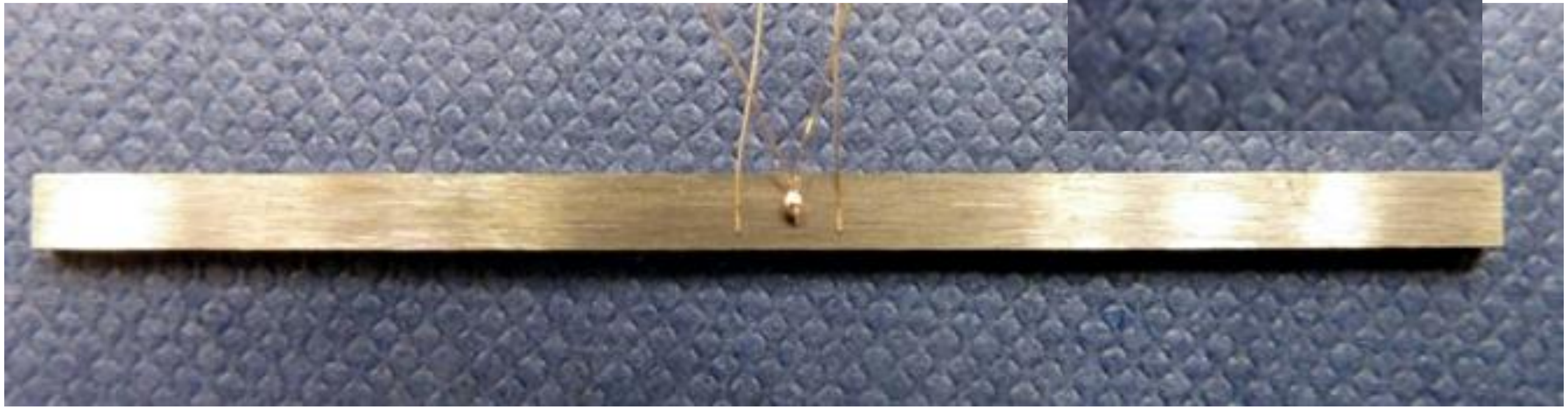
- Limitation on sample size, due to heating method

ETMT – Temperature measure

- Issue with non contacting temp measurement
- Mostly use thermocouples but pyrometry is a possibility
- Type R manufactured from 0.1 mm diameter wires fusion welded then spot welded to sample



- Type R (Pt/Pt-Rh) is good from RT to 1600 °C



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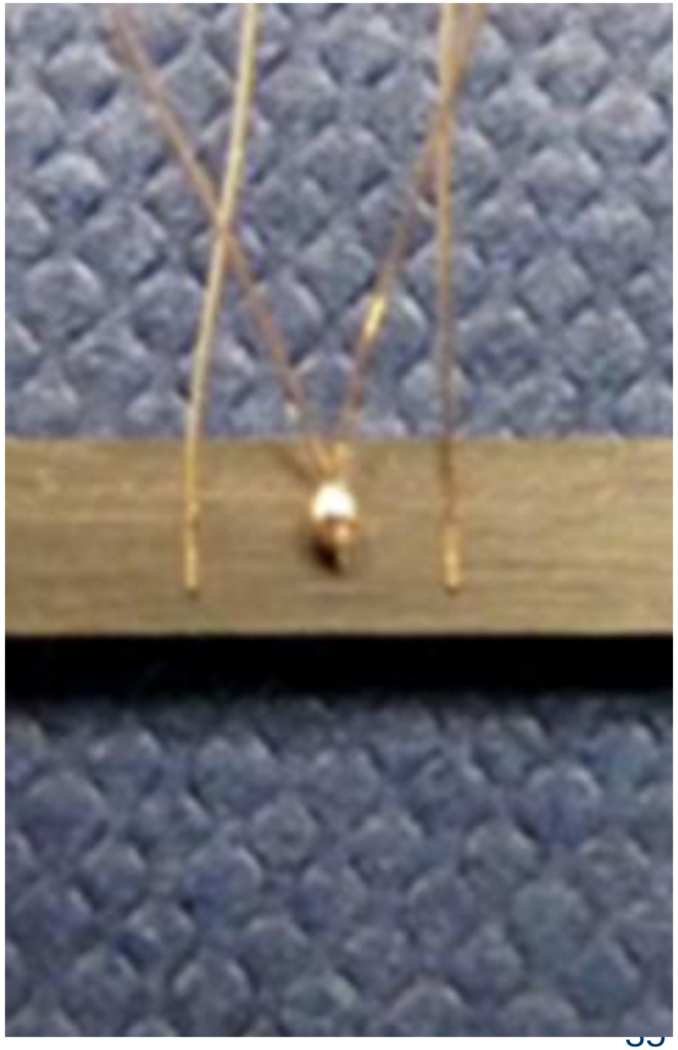
Thermocouple Manufacture and Positioning

Spot welded Thermocouple fusion bead the preferred route.

Possibility of measuring Potential Drop as ‘parasitic voltage’ if not a bead.

Manufacture from calibrated matched pairs of Thermocouple wire

Care needs to be taken to use minimum welding energy to attach thermocouple so as to minimise any local microstructural changes



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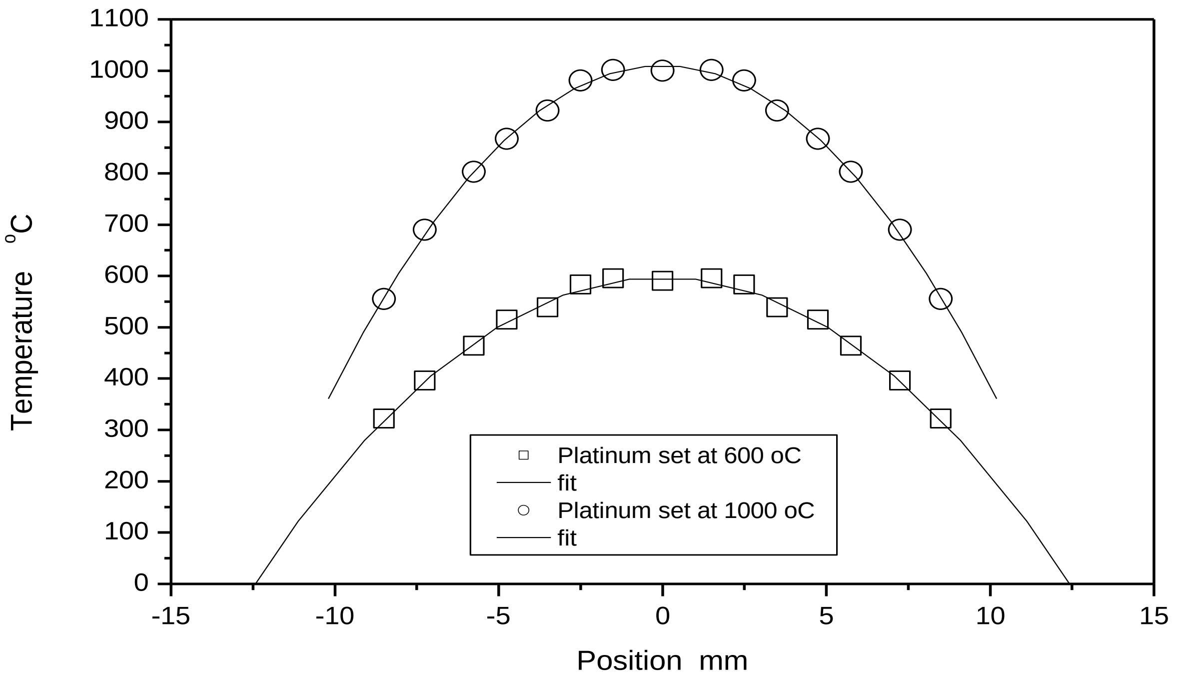
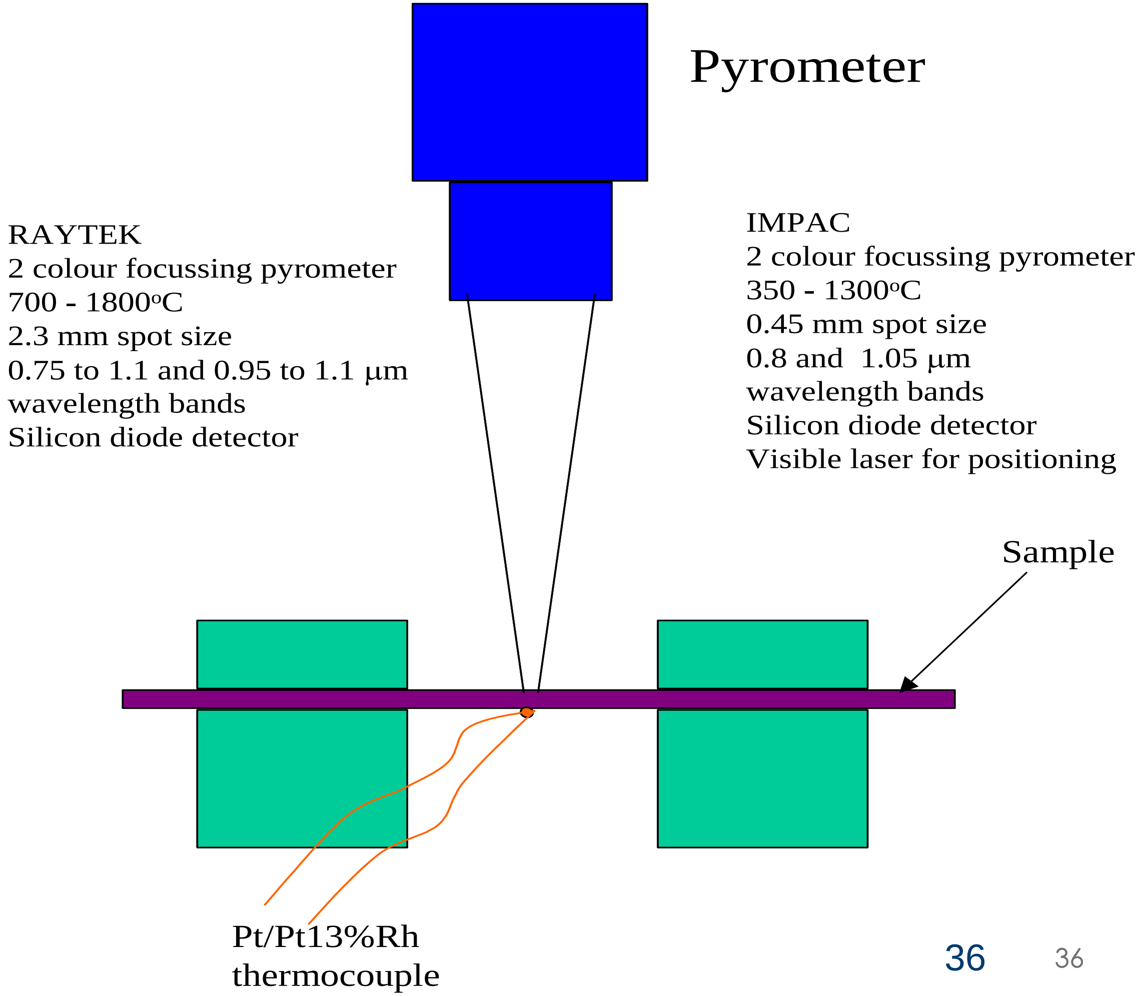
ETMT Temperature Gradients

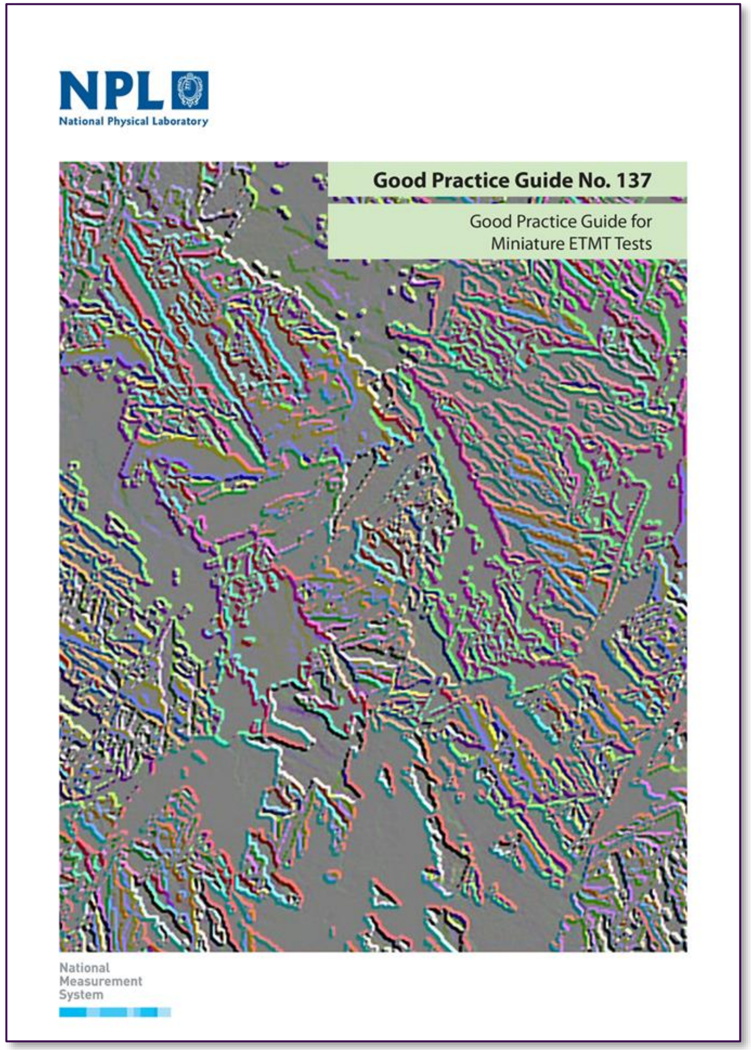
Parabolic



ETMT Pyrometry



Consolidated in Best Practice guide



ETMT – Good Practice Guide

***Explore the guide to learn about**:*

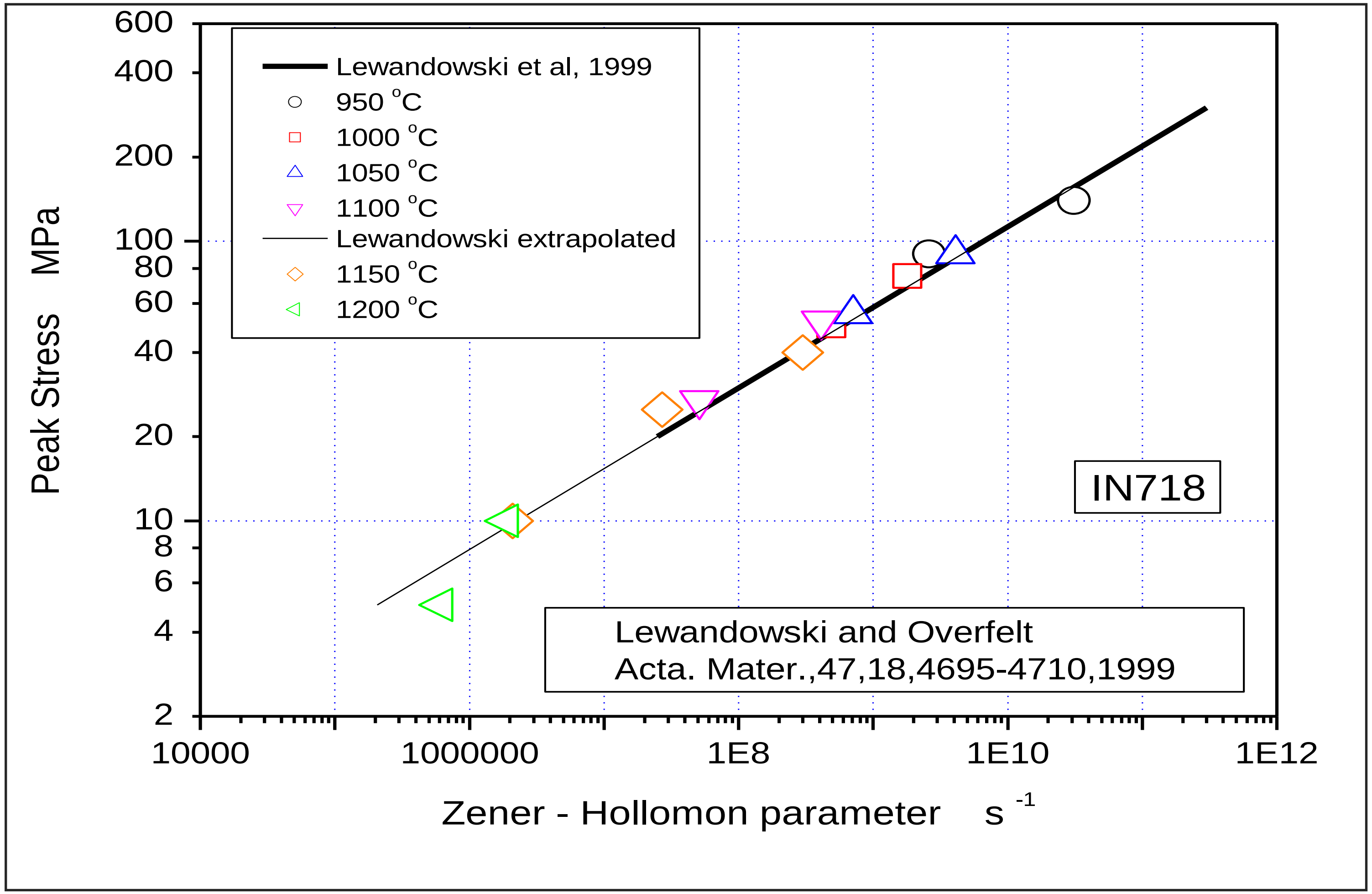
- **The principles underpinning Electro-Thermal Mechanical Test (ETMT) system**
- **The application of the ETMT system to test miniaturised testpieces of engineering alloys**
- **How to use ETMT to measure mechanical properties of conductive materials**
- **The different strain measurement techniques**
- **Issues regarding load calibration and uncertainties in strain, load and temperature measurements**
- **How results from miniature ETMT tests compare with macroscopic deformation behaviour**
- **Case studies from NPL, Instron and ETMT users**
- **Record keeping**

The guide is aimed primarily at scientists and engineers who are interested in the use of ETMT for studying mechanical properties of engineering materials

ETMT application examples

Small specimens – very high temperatures

Comparison of ETMT and literature high temp strength data on IN718



Zener-Hollomon parameter, $Z = e_R \exp [Q/RT]$

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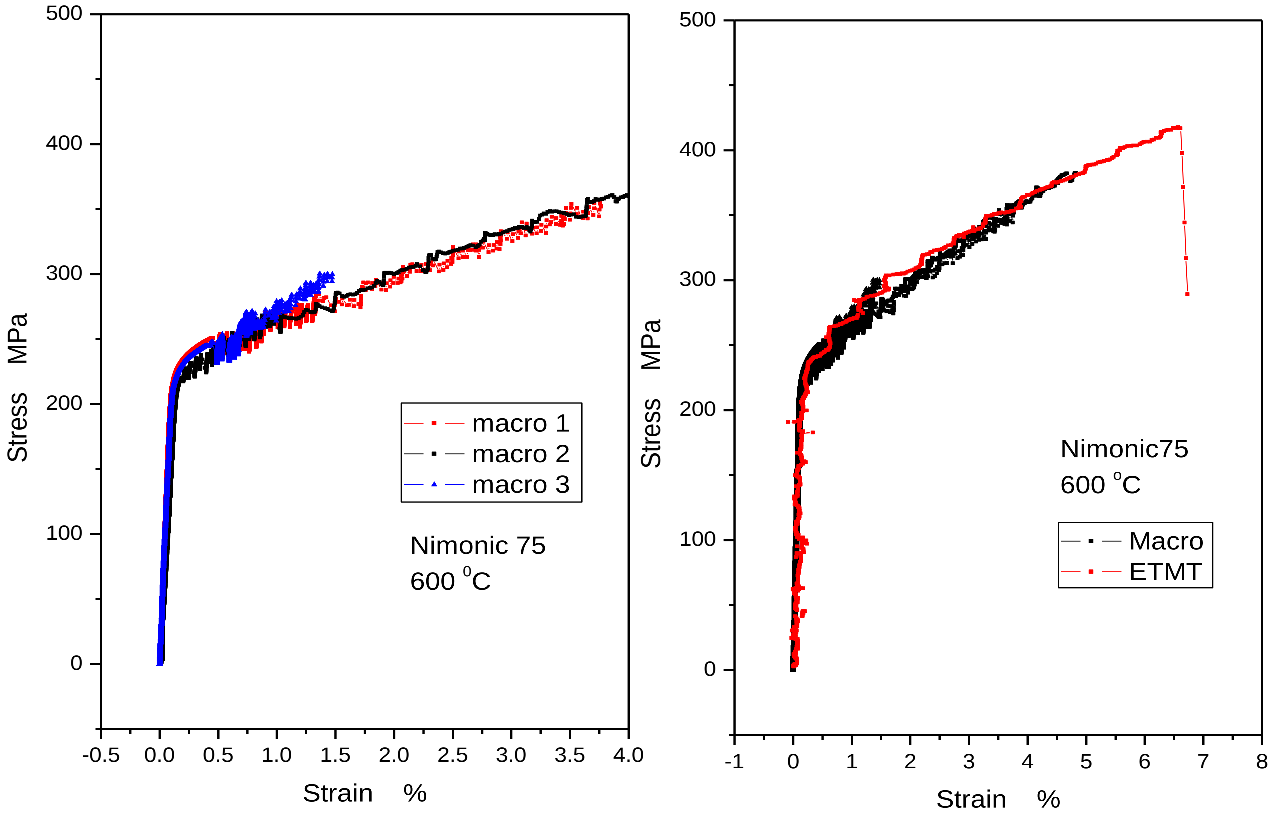
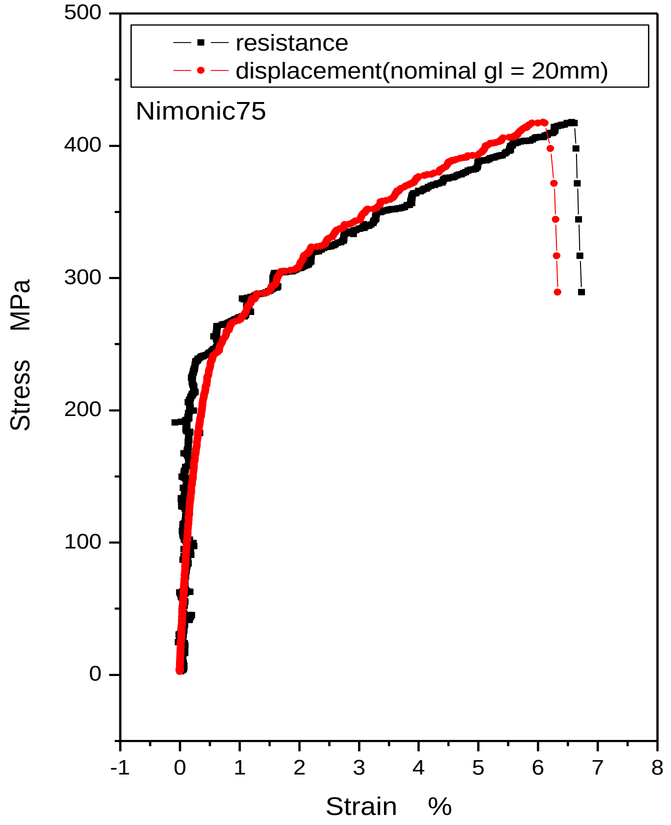
Miniaturised testing in the ETMT - Nimonic75 Creep Reference Material

Comparison of macroscopic and ETMT tests, and different strain measurement methods





Comparison of Macroscopic and ETMT test

Nimonic75 – 600 °C (Resistance method)

Comparison of strain methods

Resistance and Displacement

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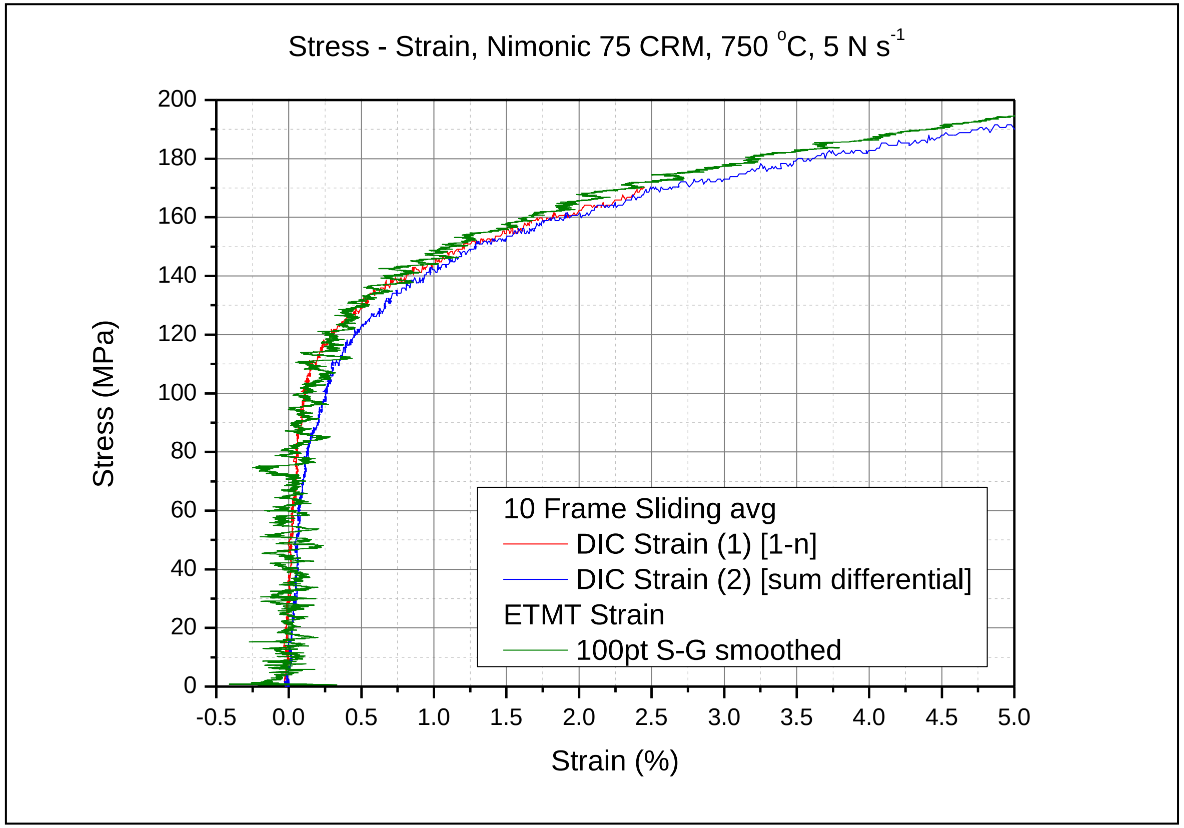
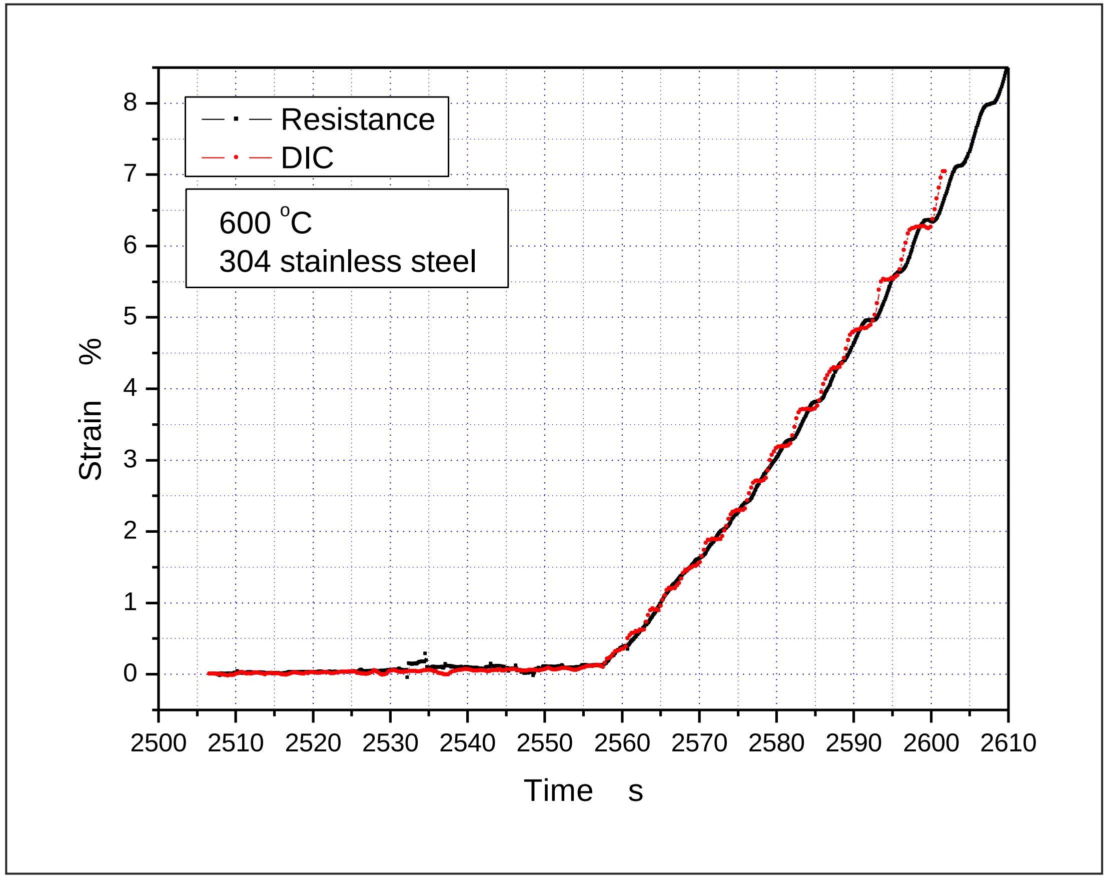
Phase behaviour and electrical properties

DIC strain and resistance

- **4kN ETMT – High Temperature DIC Performance – ETMT Strain**





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Beamline systems

Beamline systems

Conclusion

Are there any questions?

Q & A

Q&A Session

George Pask - Group Leader, Advanced Engineering Materials (AEM) - NPL

Dr Bryan Roebuck - Emeritus Senior Fellow - NPL

Peter Bailey - Senior Applications Specialist – Instron

Andrew Pearce – Advanced Application Technical lead - Instron

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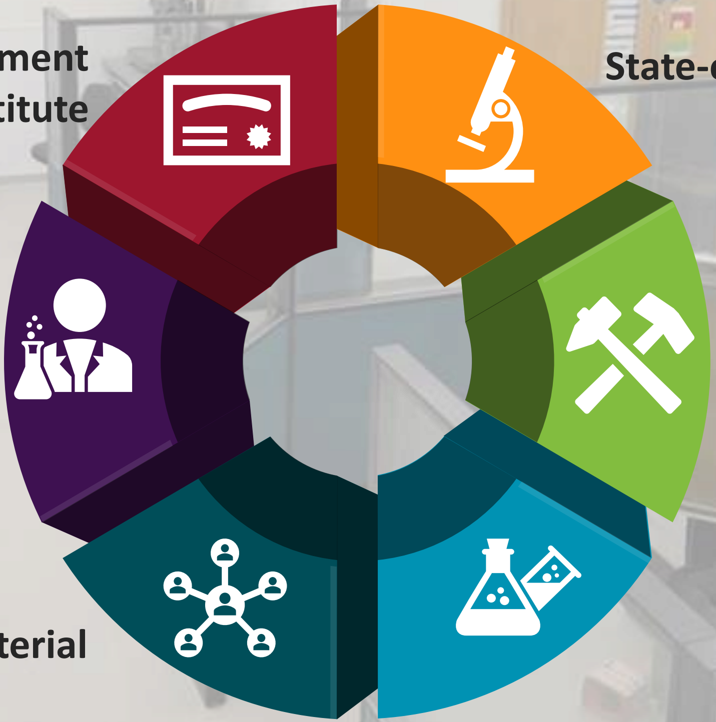
Why NPL?

National Measurement Institute

State-of-the-art Facility



Trusted Experts

Sector Agnostic

Leaders In International Material Standardisation

Bespoke Test Methods

Challenge-specific meetings

Next Webinar:

27^{h} April @ 3:00pm

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