Development of laboratory facilities for thermo-mechanical fatigue testing

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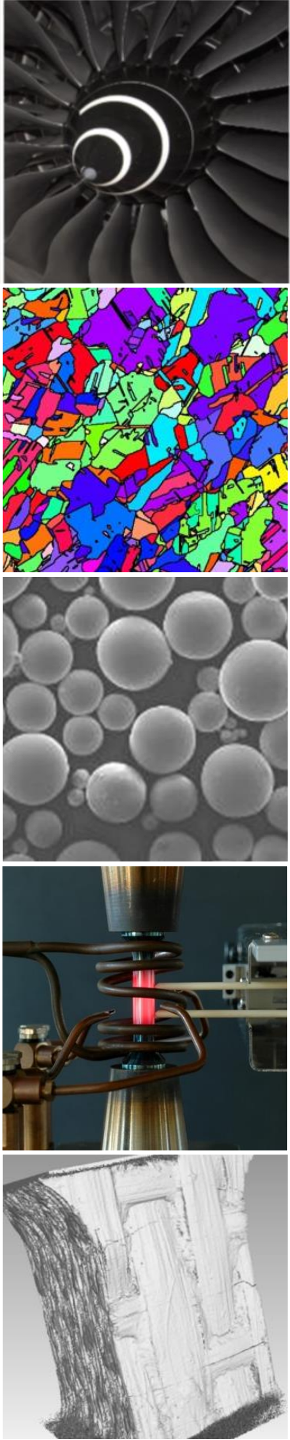
[3] Rolls-Royce plc, PO Box 31, Derby, DE24 8BJ, United Kingdom.



Content

Introduction

TMF tests are designed to bridge the gap between loading regimes simulated in test laboratories and those found in arduous real life loading environments such as those found within a modern day gas turbine.

The development in advanced high temperature test methodologies has led to more robust data generation, through the implementation of innovative control methods, novel experimental design and test standardisation.

CoP EUR 22281 EN. *Thermo-Mechanical Fatigue Testing*. **European Commission - JRC, 2006.**

E2368-10. *Strain Controlled TMF Testing,* **ASTM,2010.**

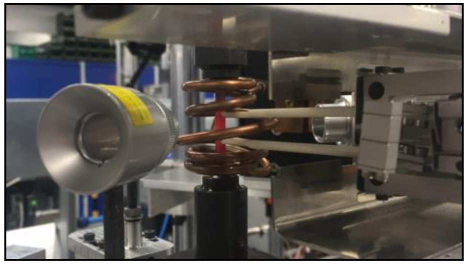
12111:2011. *Strain-controlled TMF Testing,* **ISO, 2011.**

CoP ISO/TC164/SC5. *Force-Controlled TMF Testing,* **BAM, 2015**.

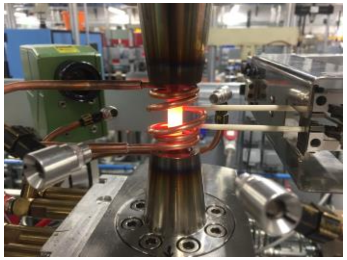
CoP …. *TMF Crack Propagation Testing,* **SU/DevTMF, 2020**.

Background TMF

Strain Control (Solid)

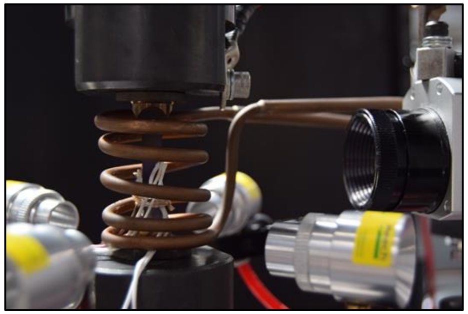


Strain Control (Hollow)

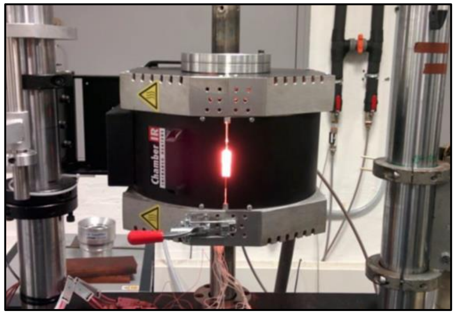


SMaRT Swansea Materials Research & Testing Ltd / ISM laboratory

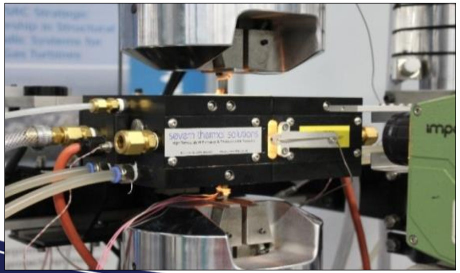
Crack Growth



Stress Control



Non Metallic Testing

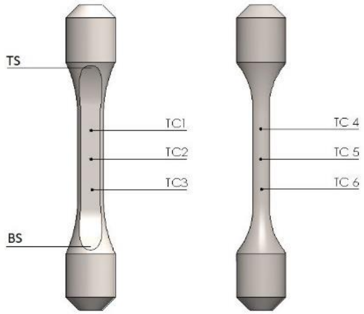


Thermo-mechanical fatigue and fracture of INCO718 Walter J. Evans, J. E. Screech, S. Williams. DOI:10.1016/j.ijfatigue.2007.01.041. **2007**

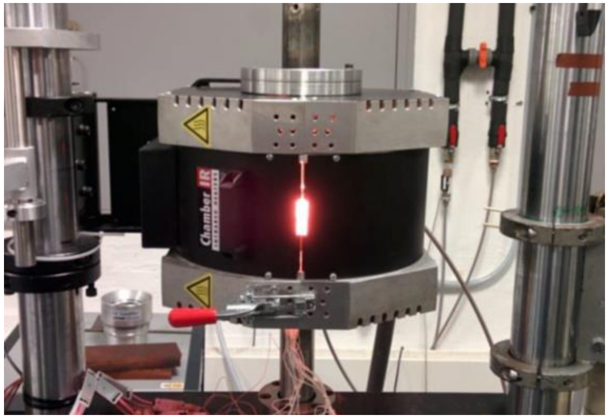
Development of test facilities for thermo-mechanical fatigue testing. J.Palmer, J.Jones, A.Dyer, R.Smith, R.Lancaster, M.Whittaker. https://doi.org/10.1016/j.ijfatigue.2018.12.015. **2018**

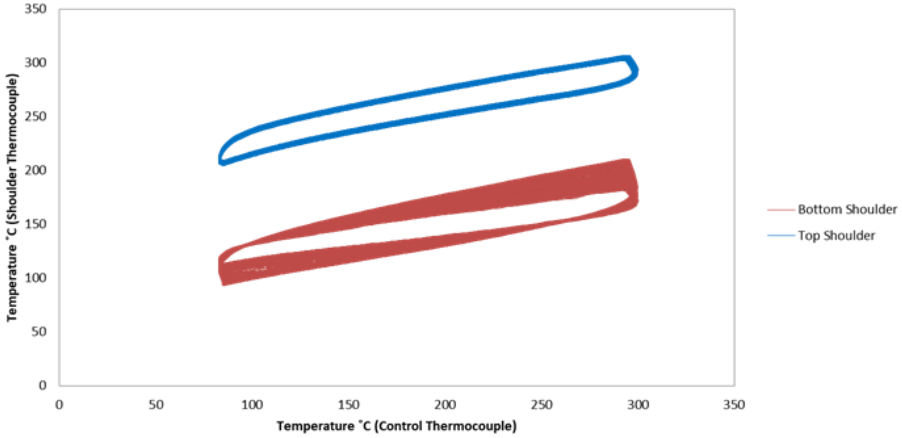
Alternative thermocouple control options

Shoulder Thermocouple Control



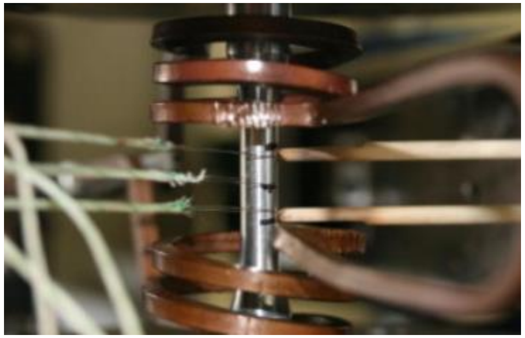
Specimen schematic showing the locations of the 6 thermocouples during the profiling stage (Front and back views).





Thermal response at the specimen shoulders. Shoulder temperature plotted against TC2 centre gauge control thermocouple.

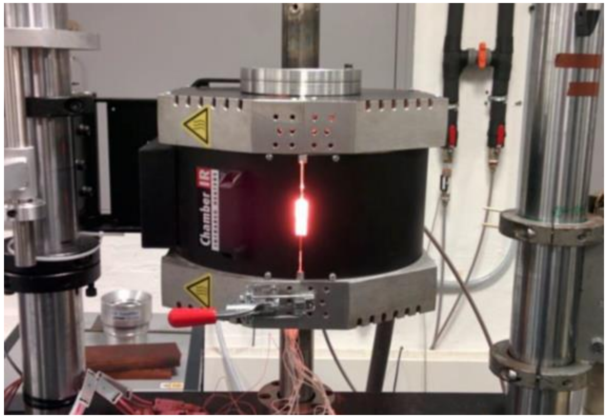
Ribbon Thermocouple Control



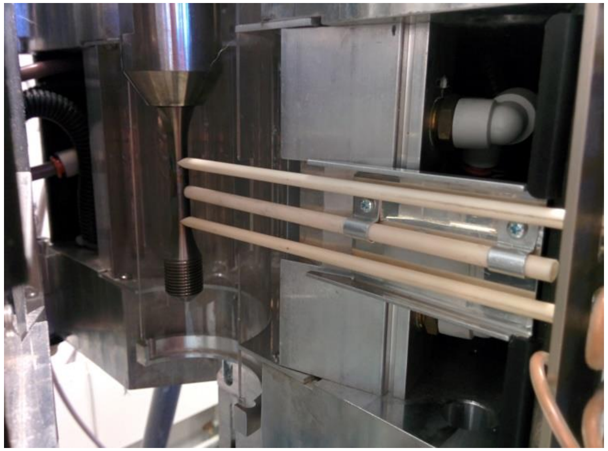
M. Azadi, M. M. Shirazabad, Heat treatment effect on thermo-mechanical fatigue and low cycle fatigue behaviors of A356.0 aluminum alloy, Materials & Design, Volume 45, 2013, Pages 279-285, ISSN 0261-3069.

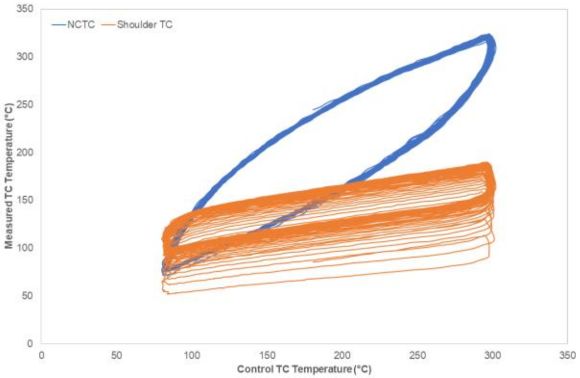
Alternative thermocouple control options

Lamp Furnace

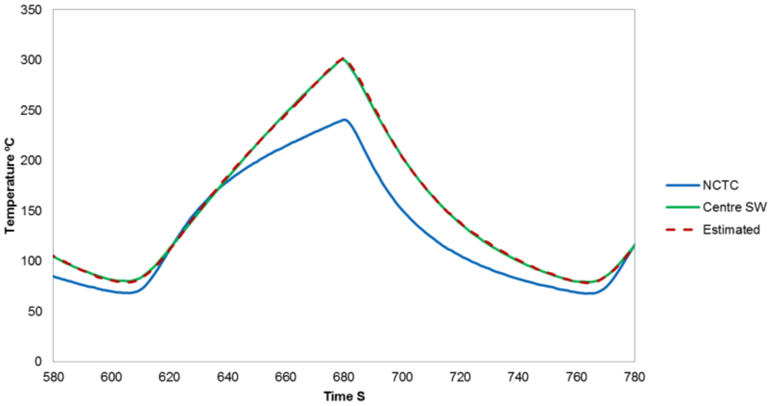


Close proximity (Non-Contact) thermocouple mount



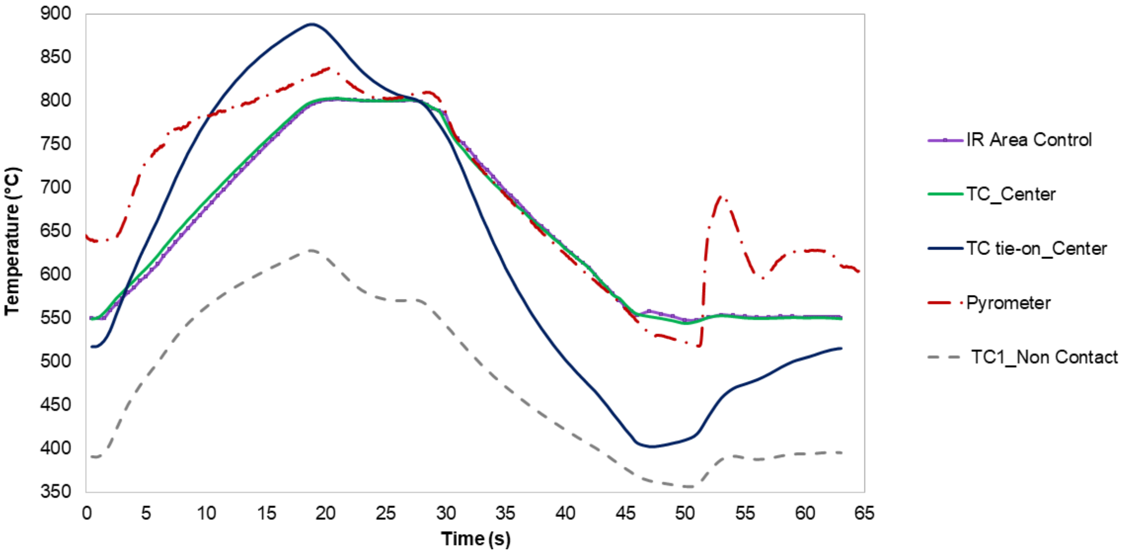


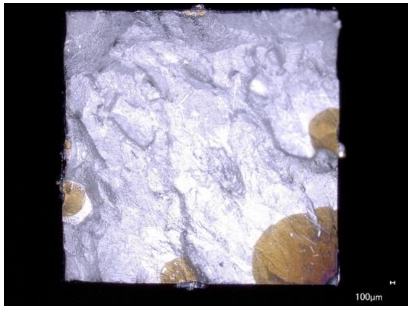
Relationship between the control (centre gauge) thermocouple and the close proximity mounted thermocouple.

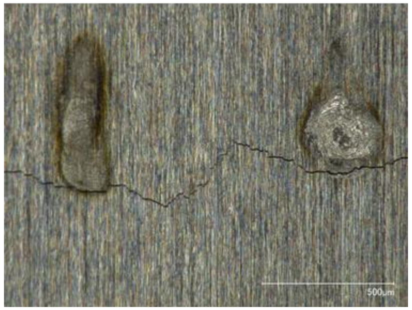


TMF Profile indicating the temperature read from the non-contact (close proximity) thermocouple (NCTC).

Non-Invasive Temperature Control

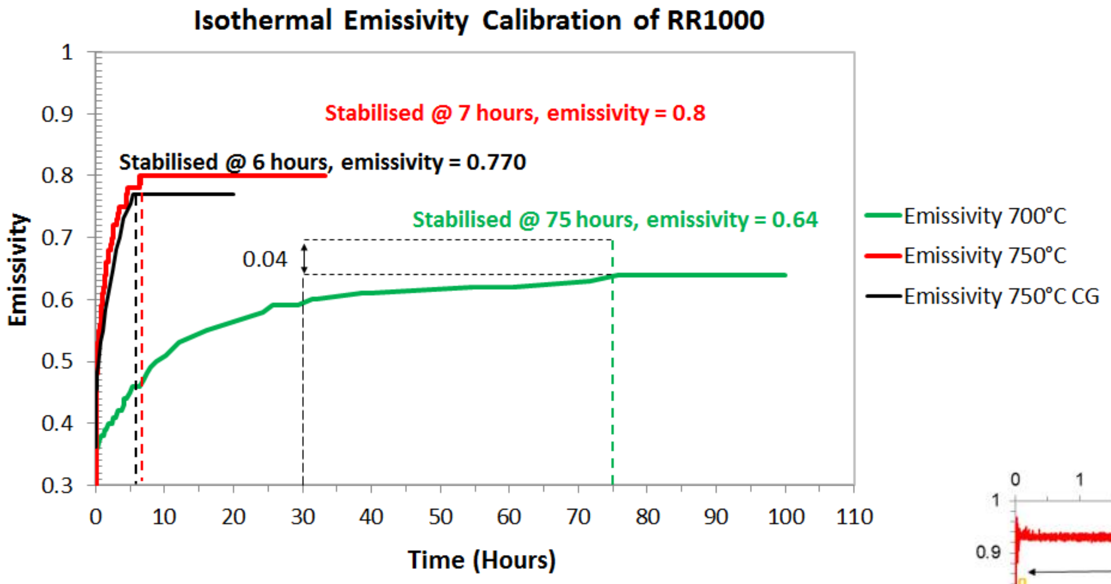


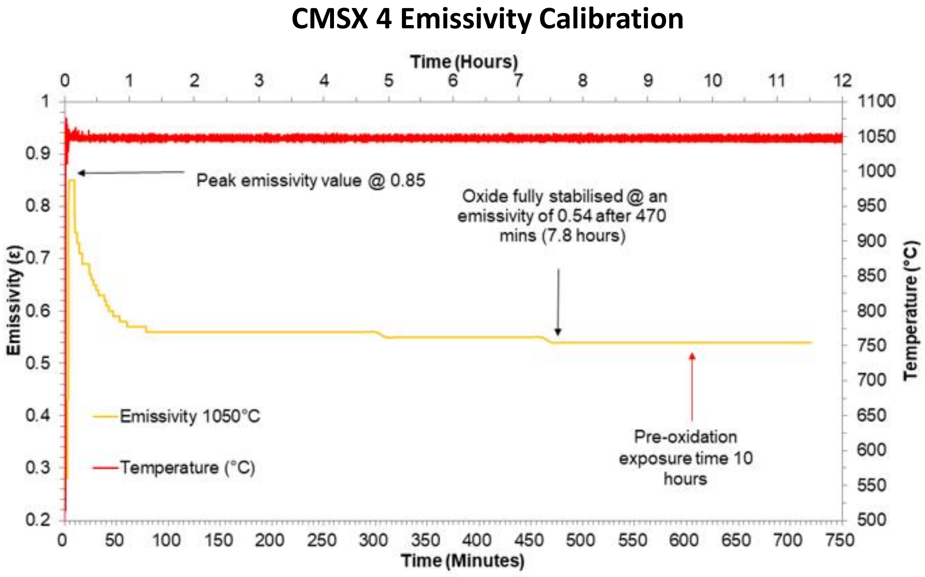




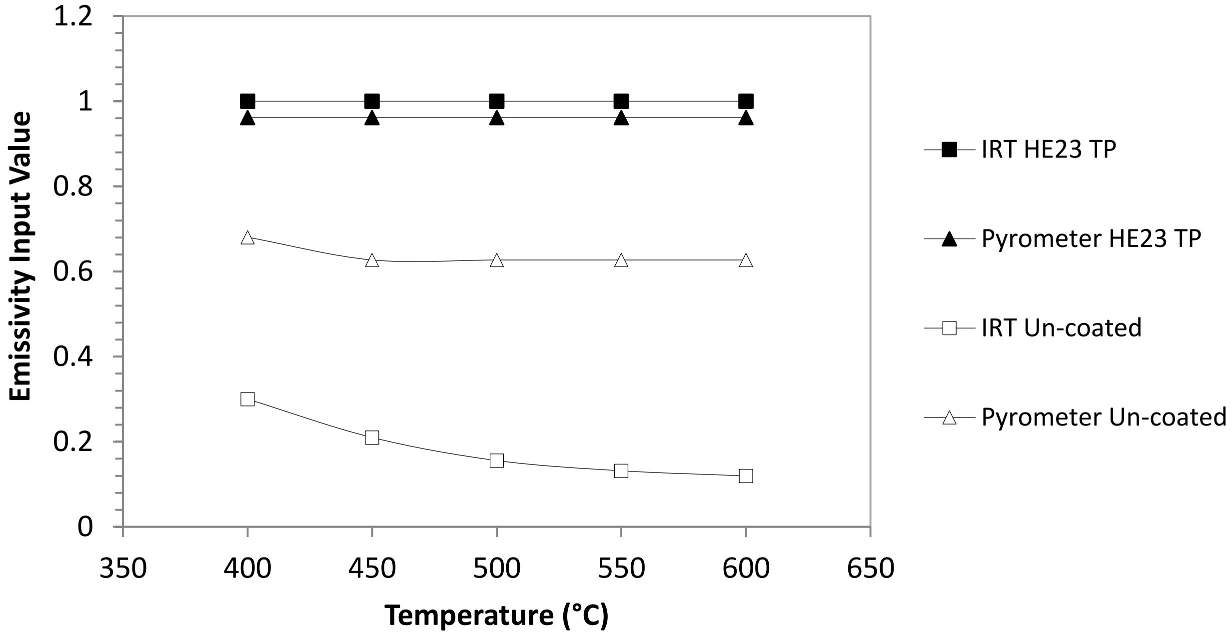
Enhancing the Accuracy of Advanced High Temperature Mechanical Testing through Thermography
March 2018Applied Sciences 8(3):380
DOI: 10.3390/app8030380

Non-Invasive Temperature Control





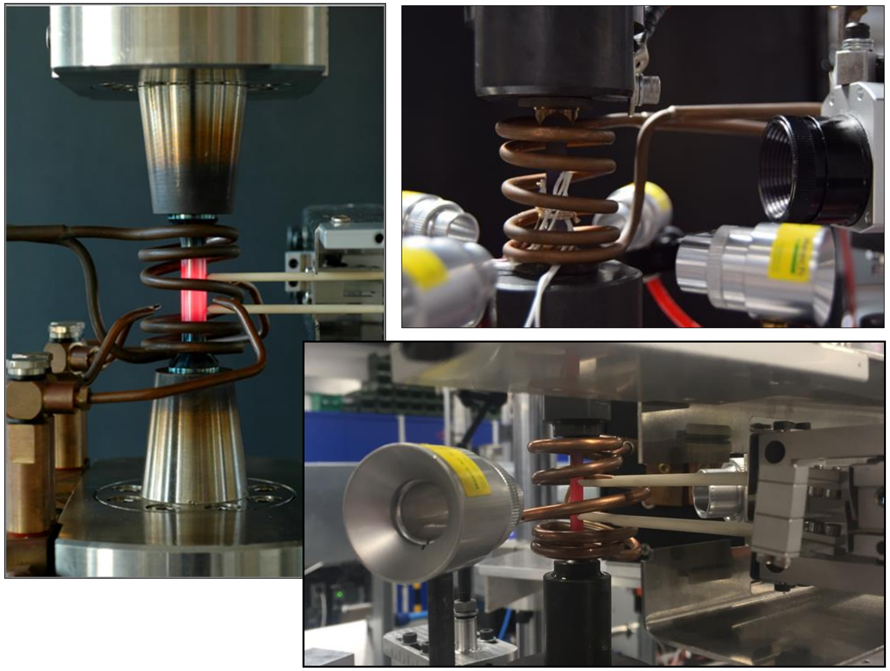
Non-Invasive Temperature Control



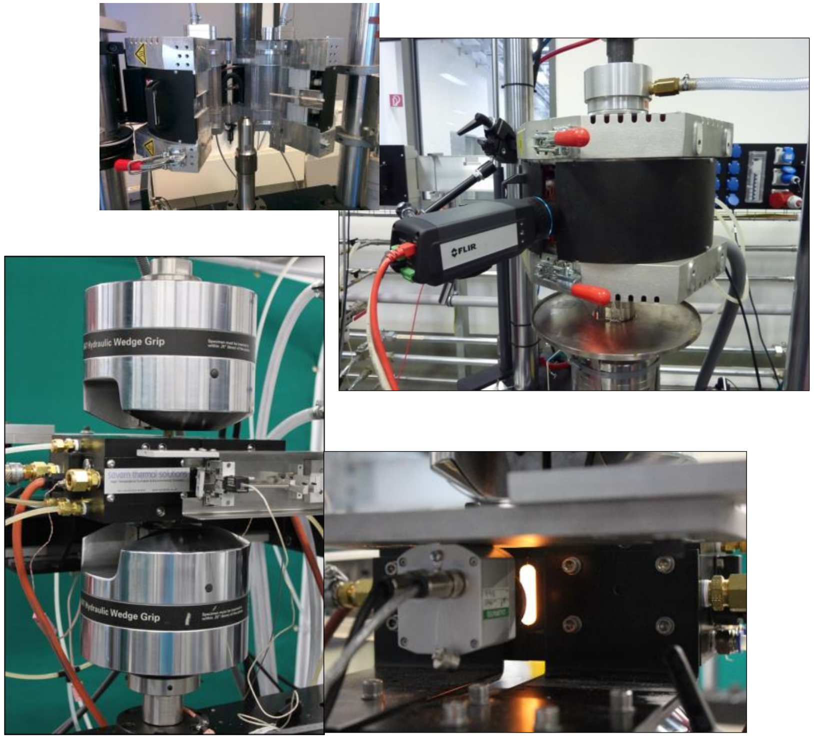
Now: Emissivity correcting technologies such as pyrometers

Heating and Cooling Methods

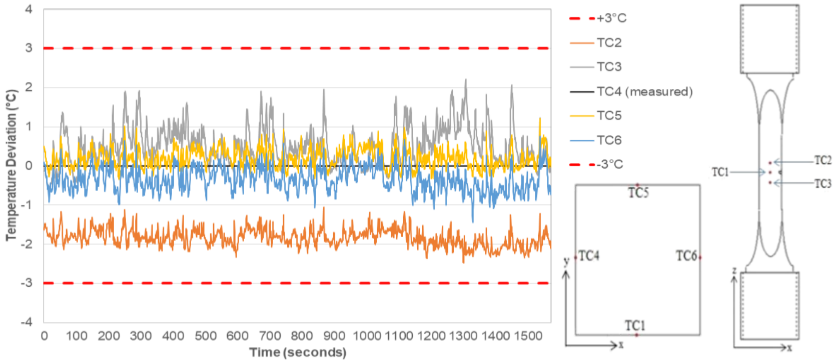
Induction



Lamp Furnace



Heating and Cooling Methods



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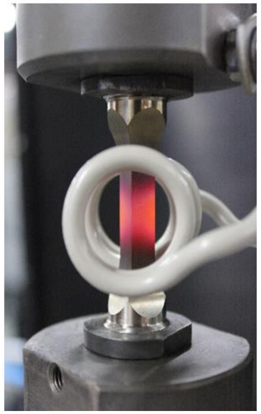

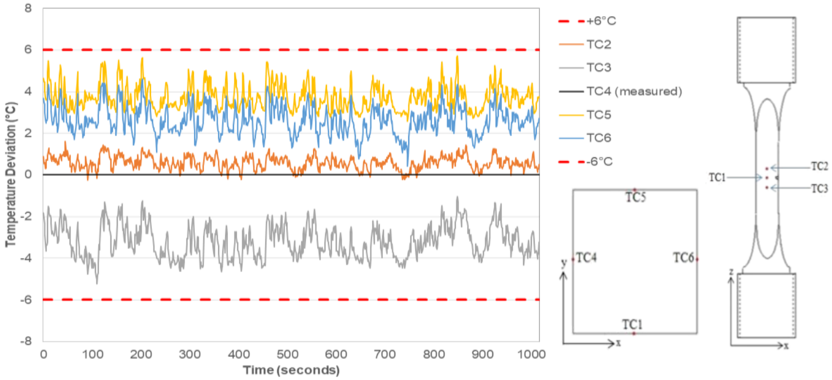

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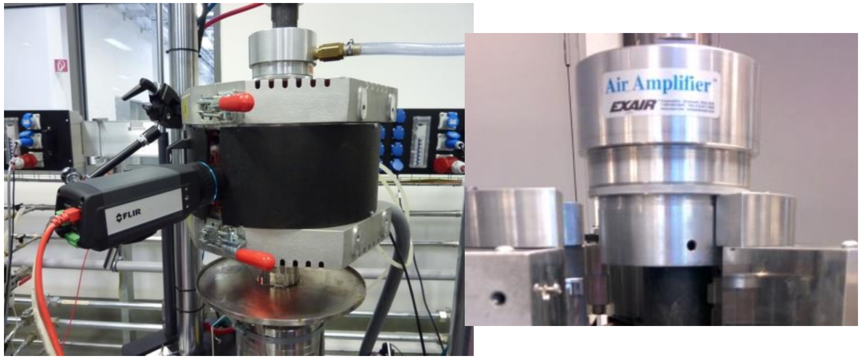
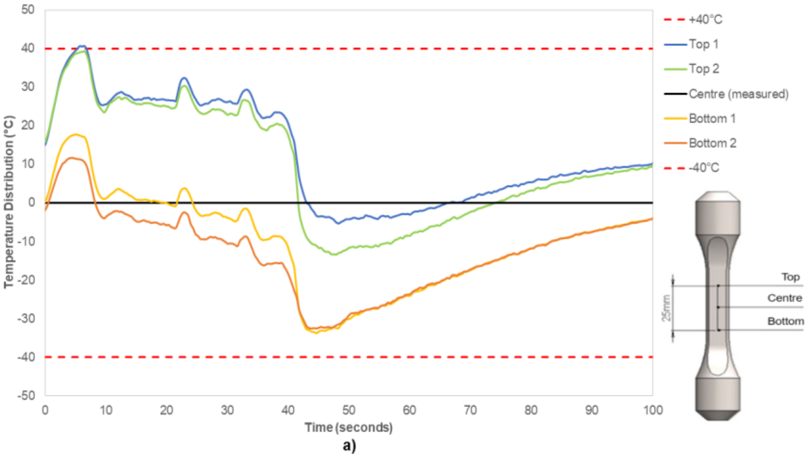
Heating and Cooling Methods





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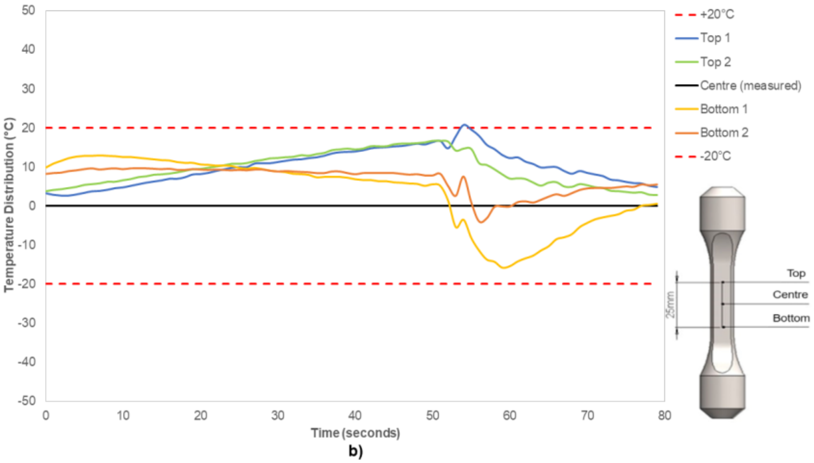
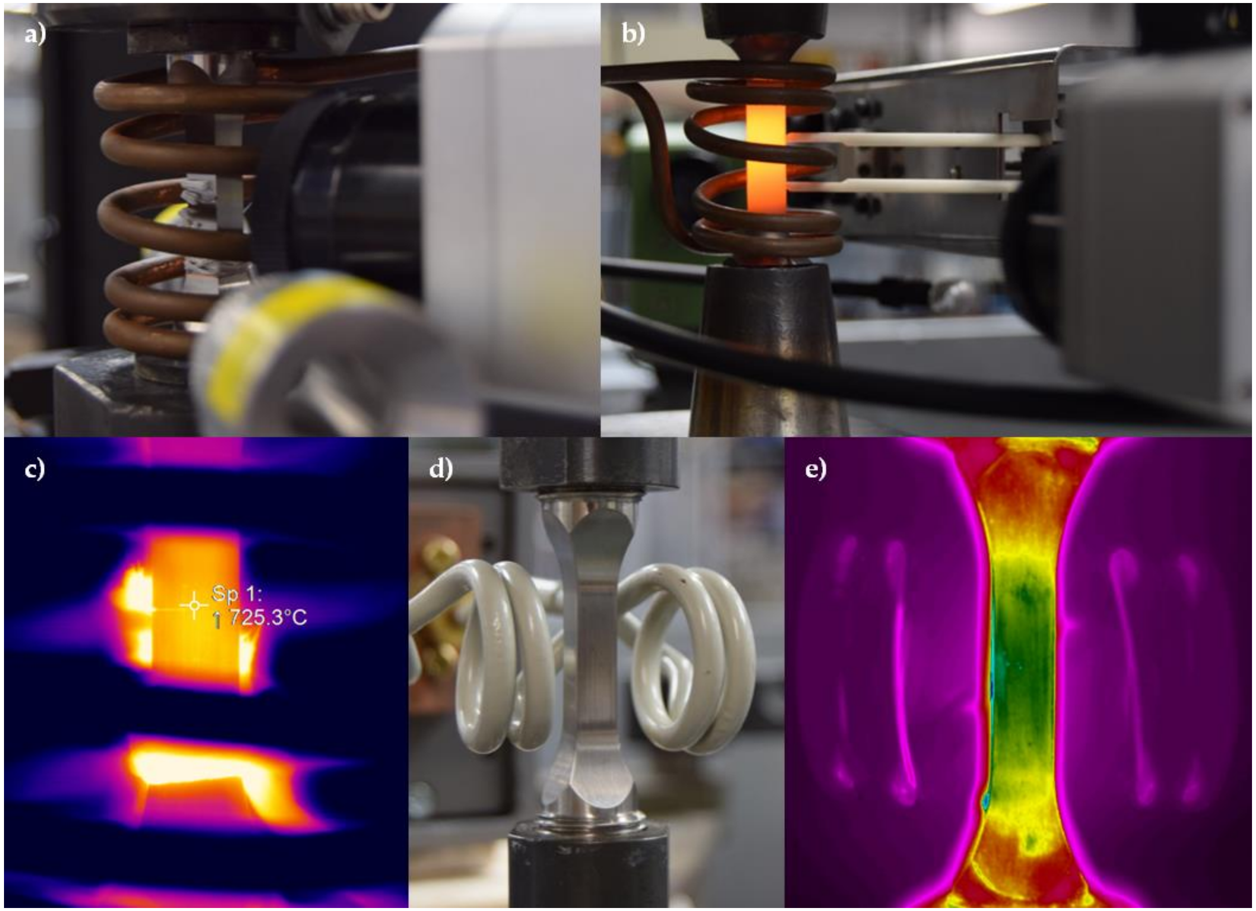
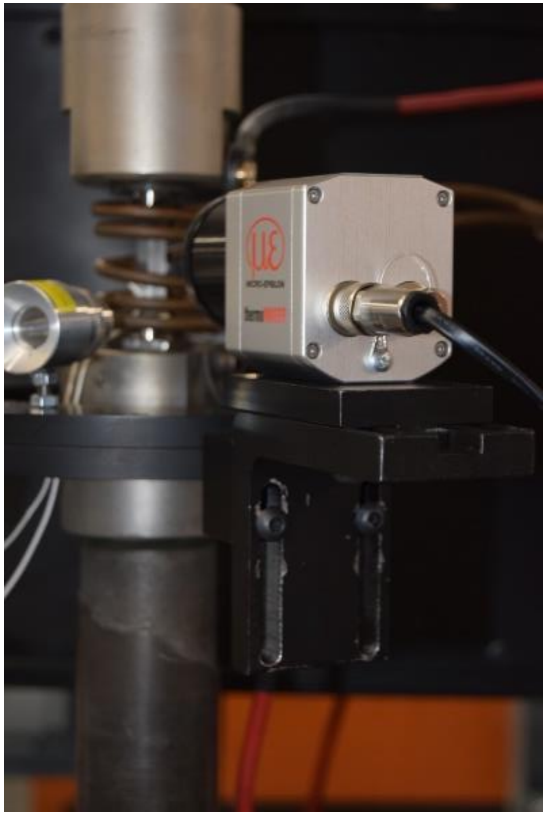


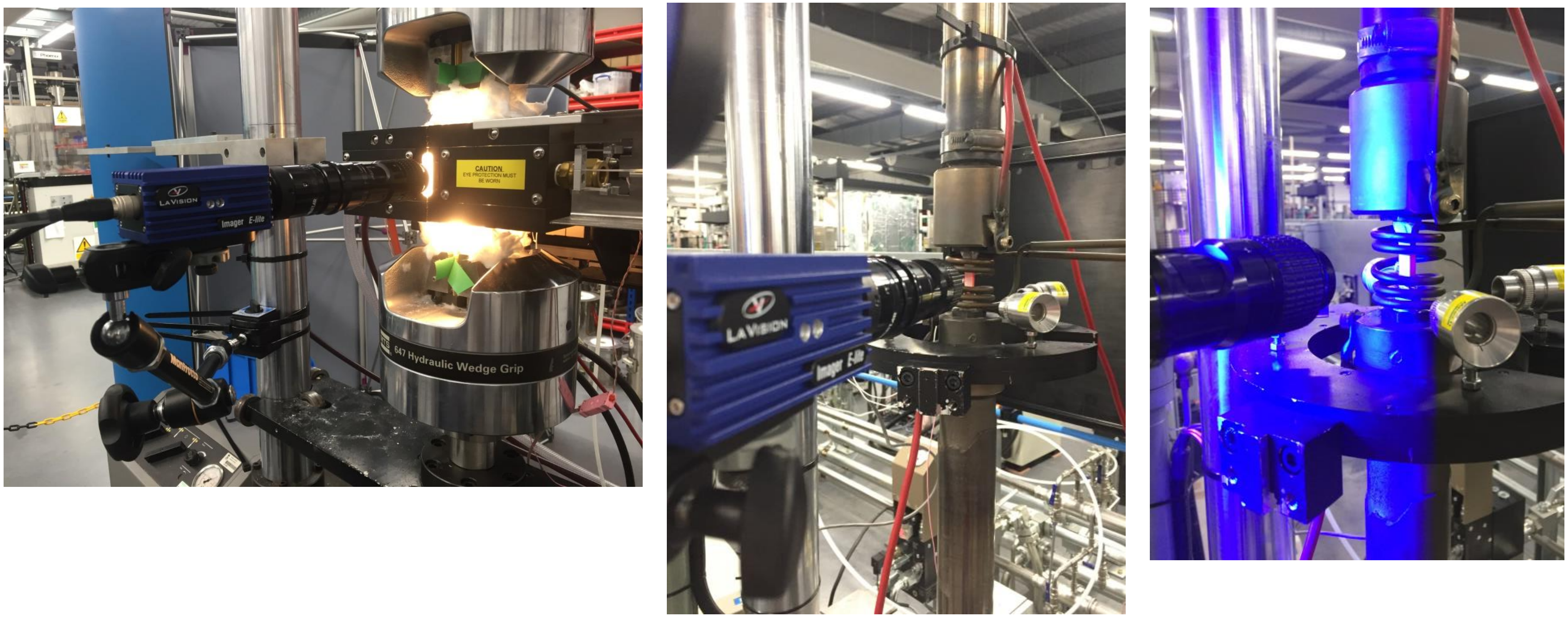
b)

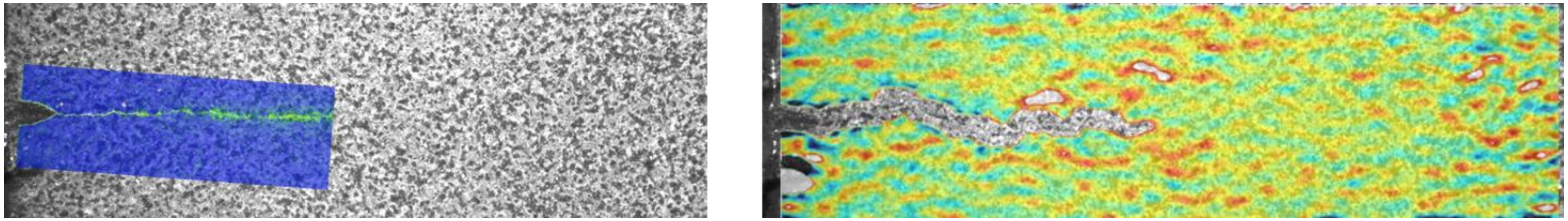
TMFCG with Thermography



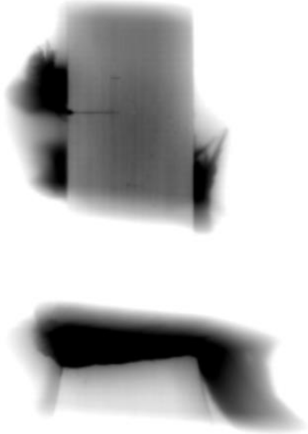


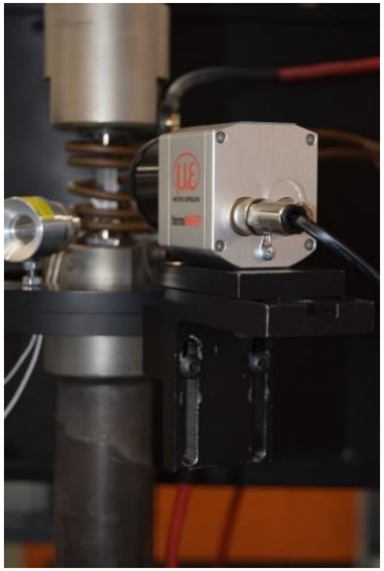
TMFCG with DIC

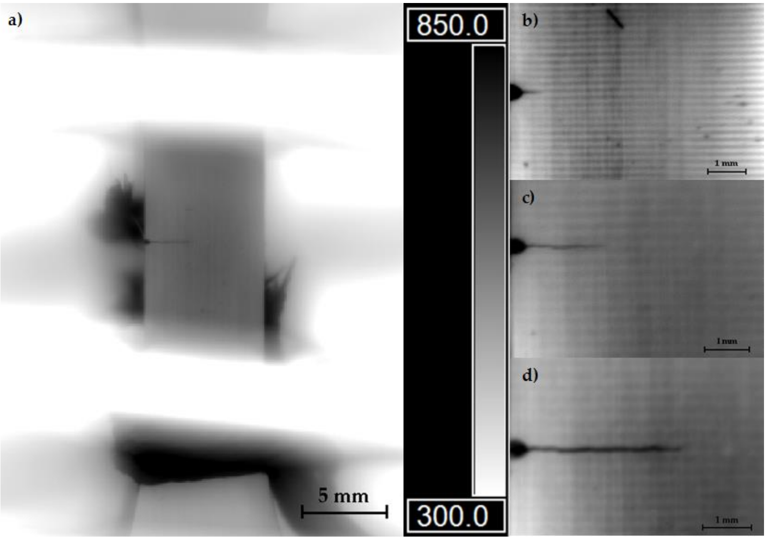


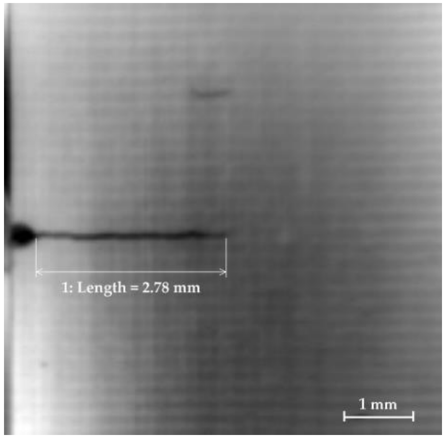


IR Crack Growth Measurements

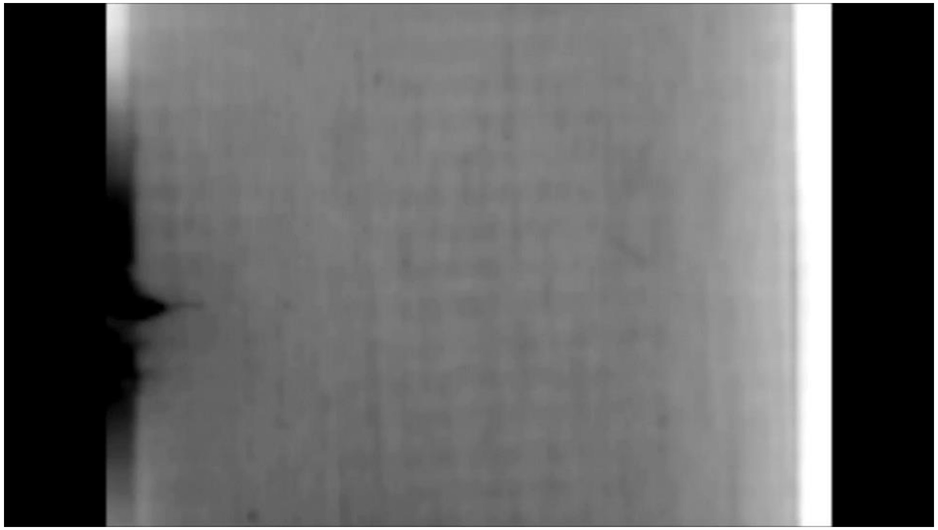


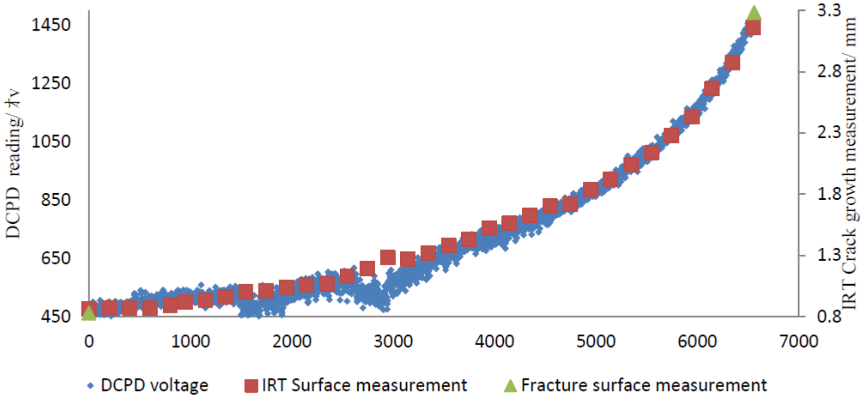


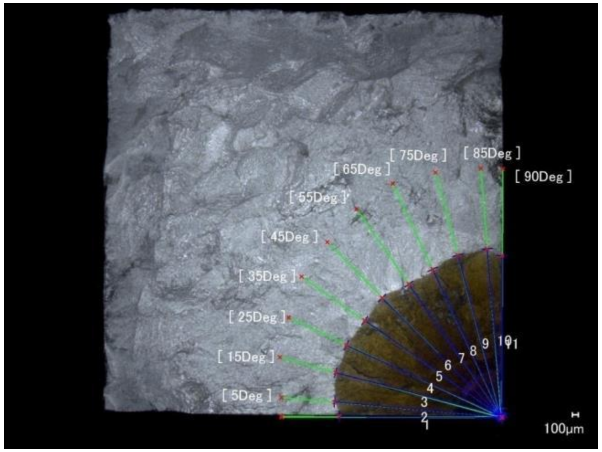


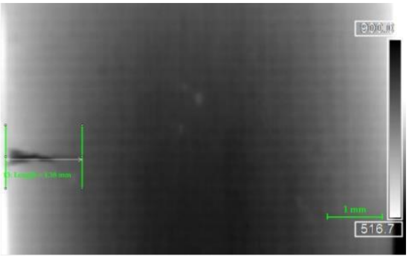


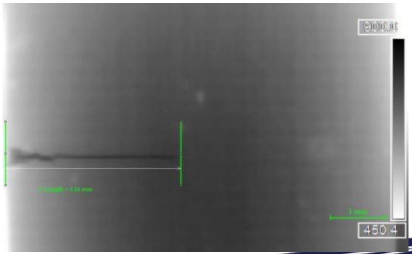
IR Crack Growth Measurements











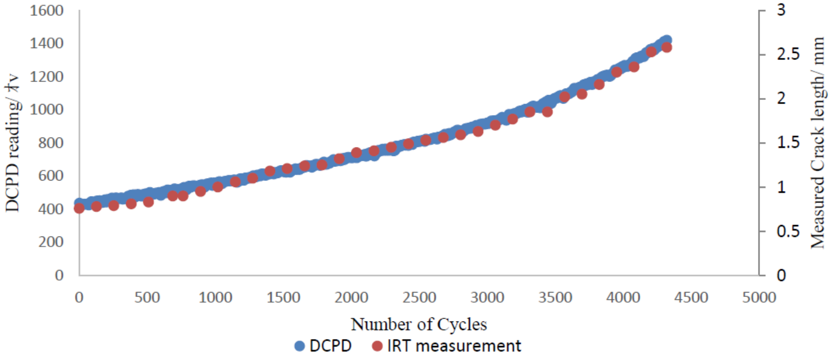
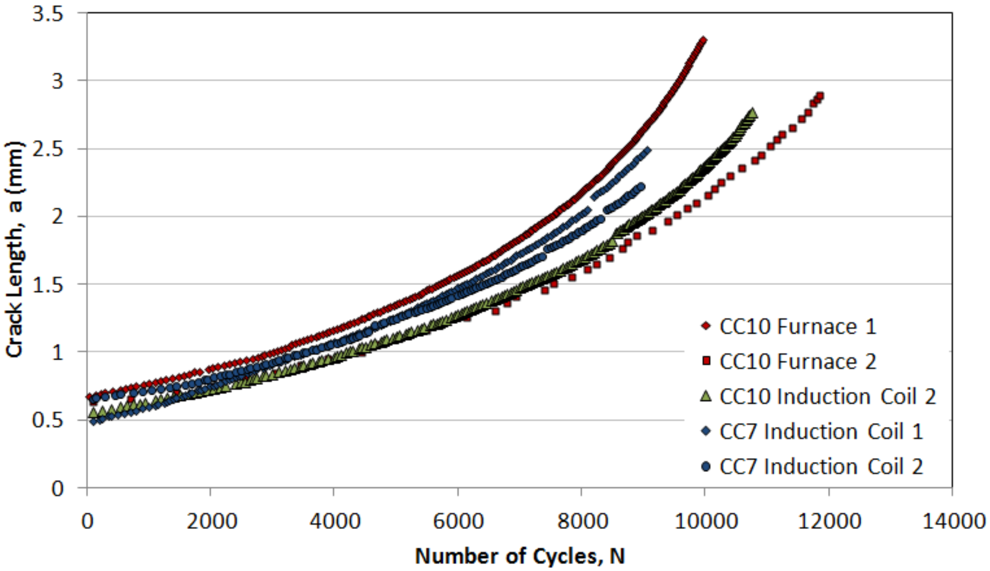


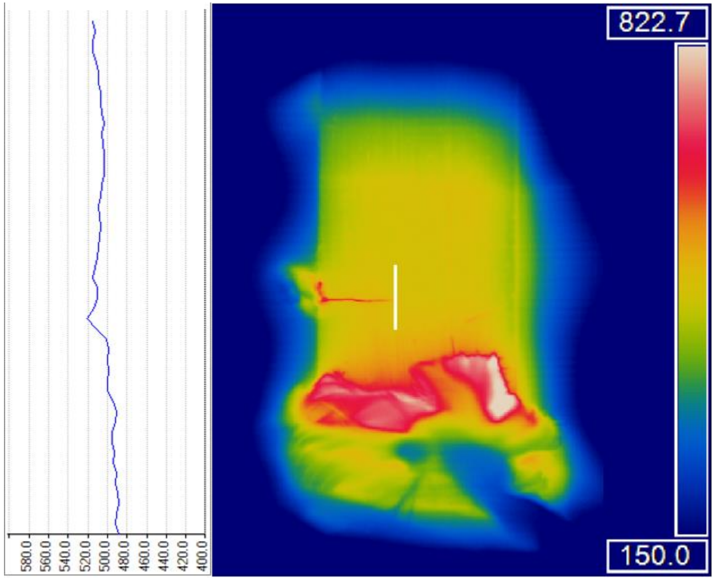
Image of surface crack length 3549 cycles

Image of surface crack length after 6549 cycles

Crack Tip Heating Investigations



Waspaloy crack length vs. number of cycles: furnace and induction coil comparisons at 650°C, 450MPa and R=0.1.



Ti6246 with crack plane at 500°C. Longitudinal profile indicates no effect of crack tip heating.

Non-Invasive TMFCG

A completely Non-Invasive TMF CP test method

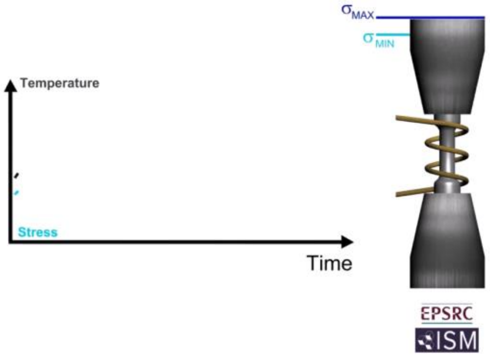
Advantages * Avoid complications with thermocouple control

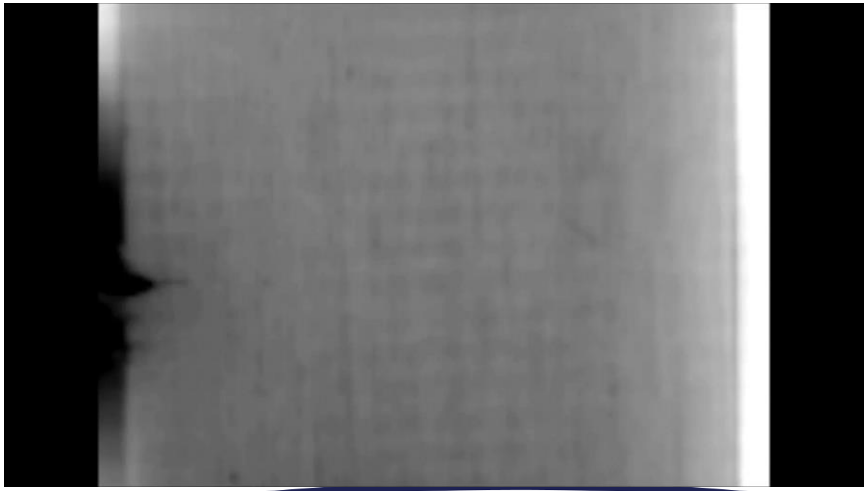
- Crack initiations at welds.
- Thermocouple shadowing and or over/undershooting

J. P. Jones, S. P. Brookes, M. T. Whittaker, R. J. Lancaster and B. Ward. “Non-Invasive Temperature Measurement and Control Techniques under Thermo-Mechanical Fatigue Loading”. Materials Science and Technology Journal. 2014.

J. P. Jones, S. P. Brookes, M. T. Whittaker, R. J. Lancaster “Alternative Non-invasive temperature control and monitoring techniques”. ASTM, Fourth Symposium on the Evaluation of Existing and New Sensor Technologies for Fatigue, Fracture and Mechanical Testing, 2014.

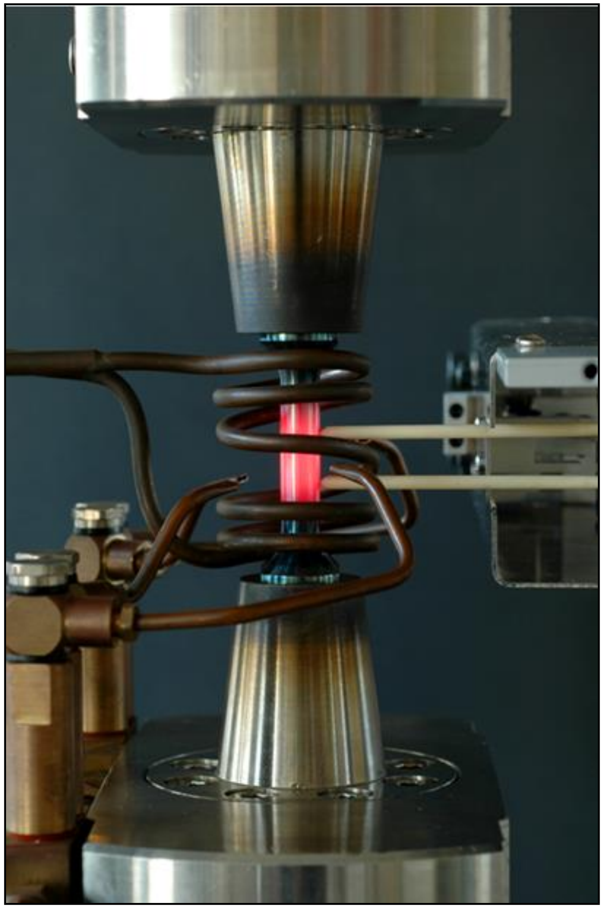
* Remove complications with PD probe attachments and coil interferences.





DevTMF Rig Development

Previous Strain Control Setup



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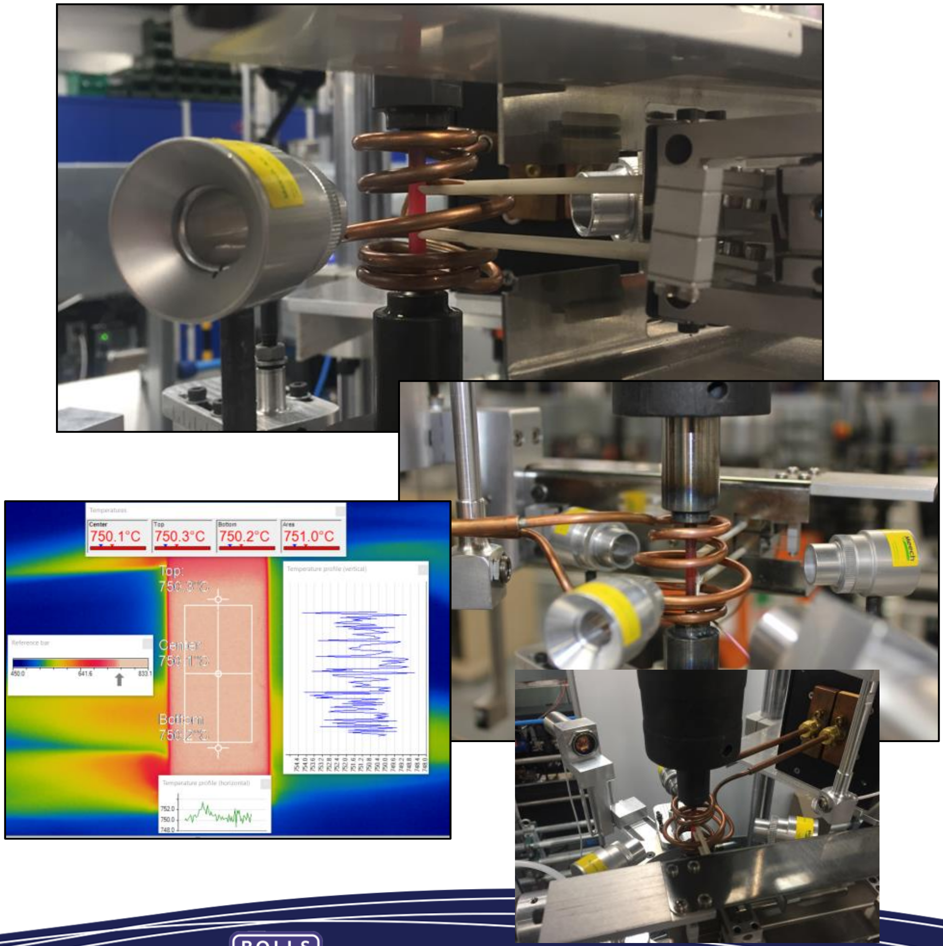
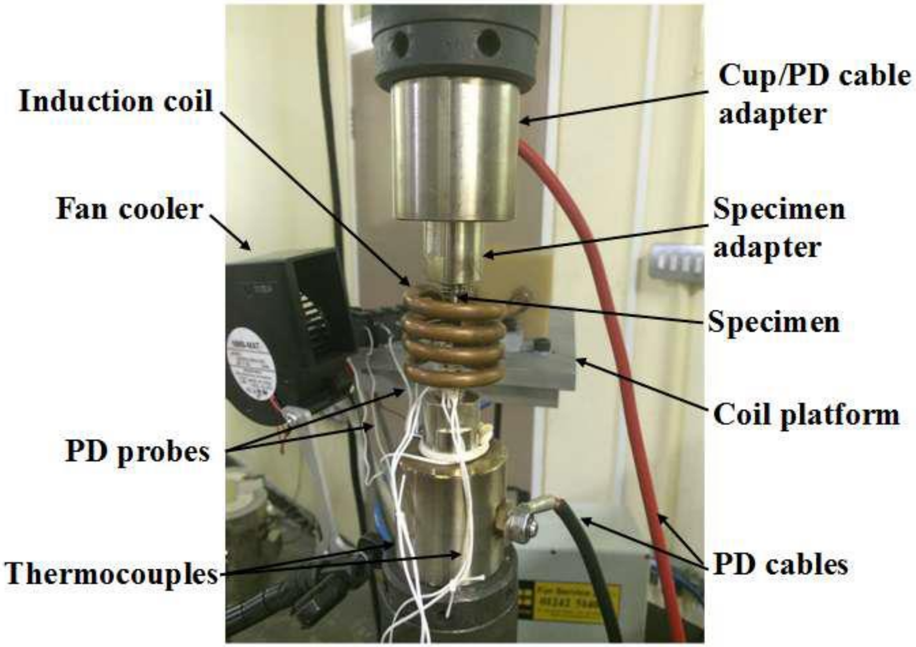
DevTMF Strain Control

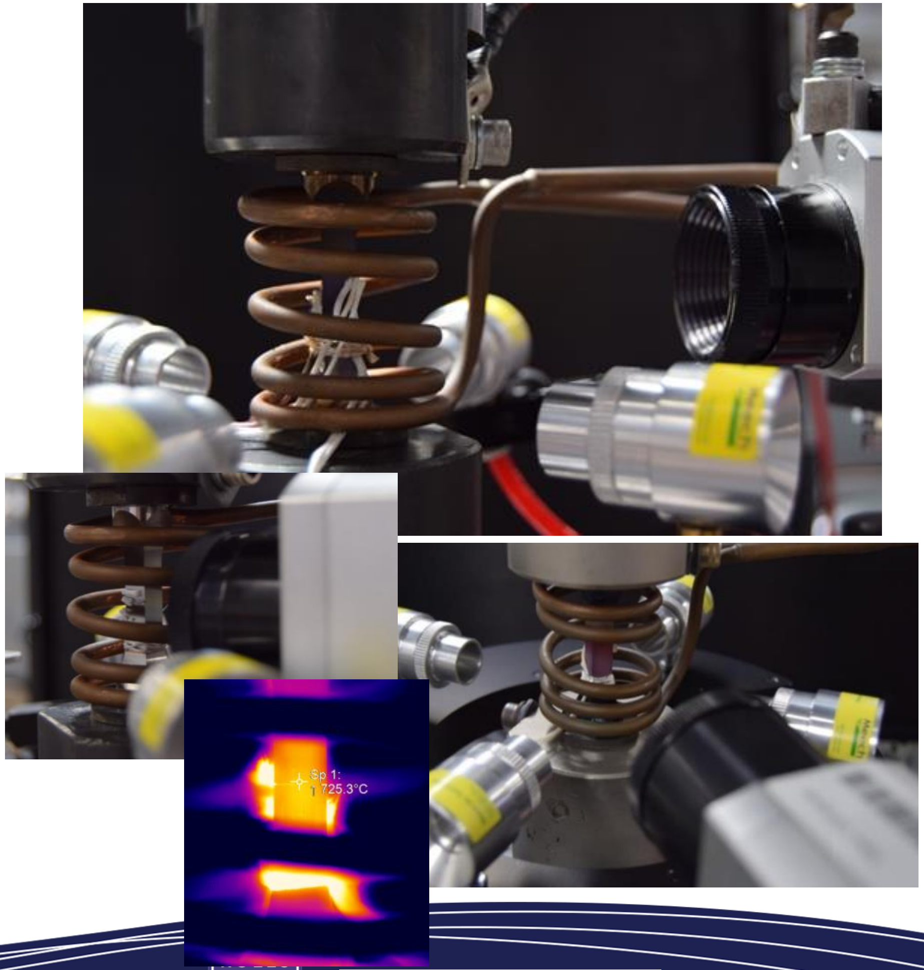


DevTMF Rig Development

DevTMF Strain Control



DevTMF Crack Growth



This project has received funding from the European Union's Horizon 2020 research and innovation programme and Joint Undertaking Clean Sky 2 under grant agreement No 686600.

The provision of materials and technical support from Rolls-Royce plc is gratefully acknowledged. A special mention must be paid to Turan Dirlik, Steve Brookes, Veronica Gray and the ISM/SMaRT staff.

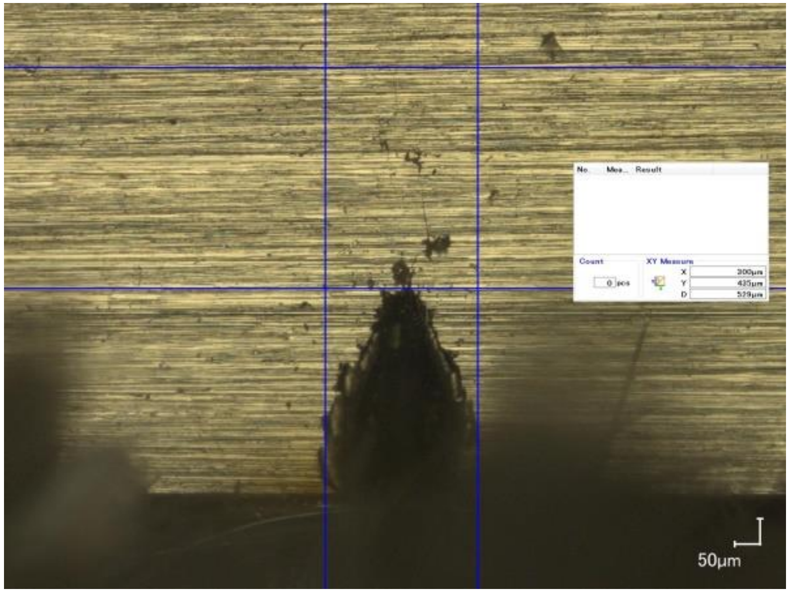
Email contact: jonathan.p.jones@swansea.ac.uk

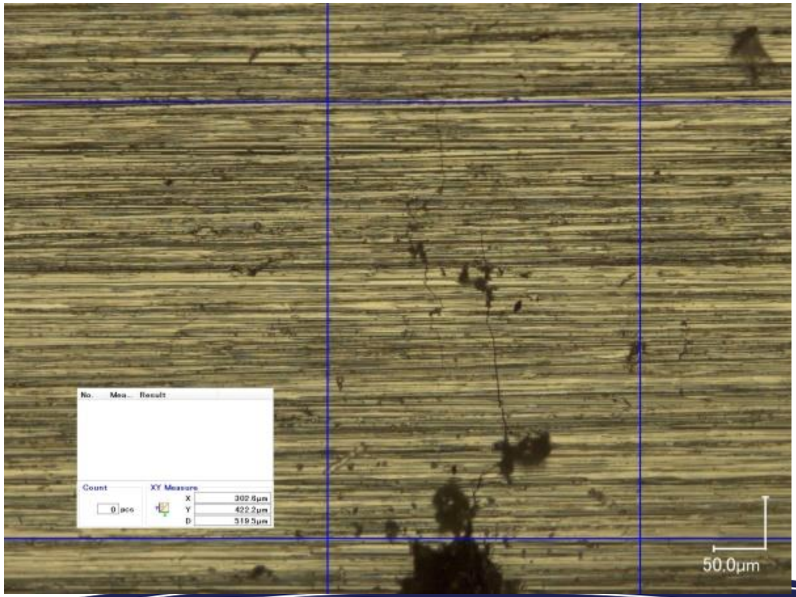
Any Questions?

TMF Crack Growth Standardisation

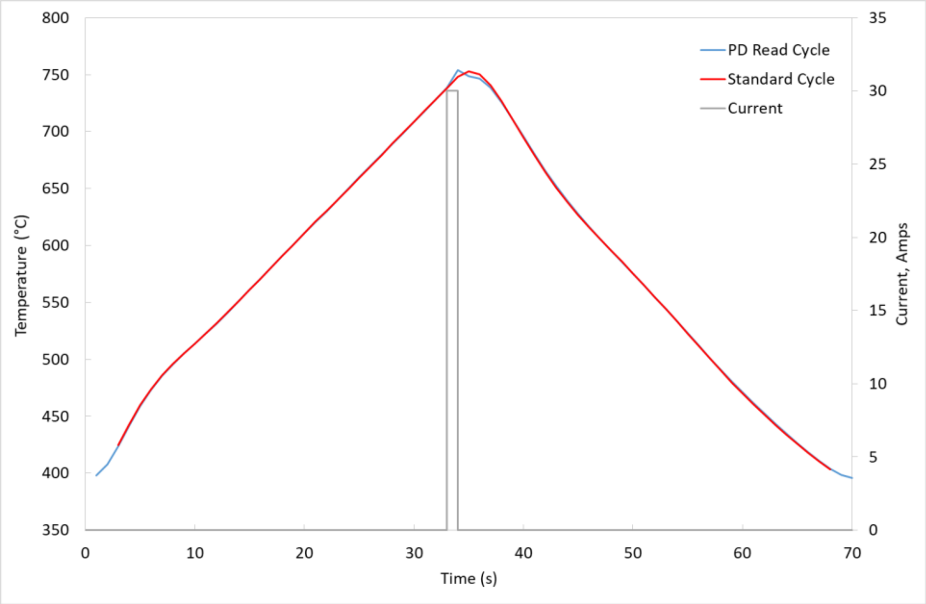
Thermo-Mechanical Fatigue Crack Growth Pre-Cracking

Stage	Temperature (°C)	Waveform	Frequency (Hz)	Stress (MPa)	Duration (µv)
1	Ambient	Sine	5	600	25
2	Ambient	Sine	5	500	50
3	Ambient	Sine	1	500	75



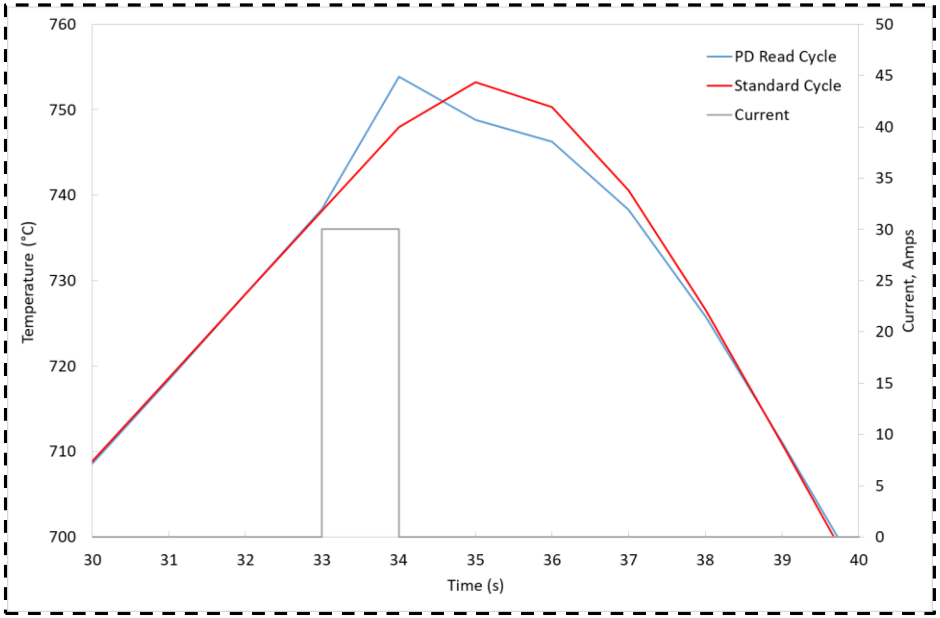


TMF Crack Growth Standardisation



Direct Current Potential Drop technique (DC PD).

- Previously 30amps
- Now 10amps

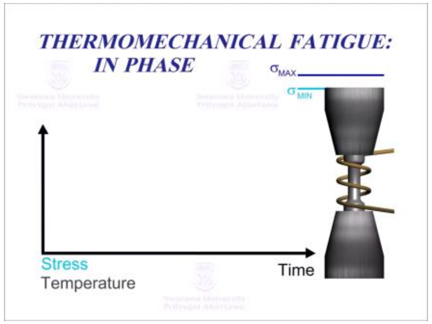


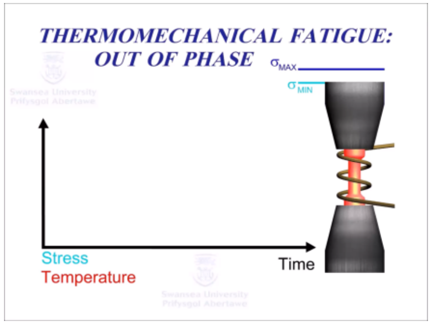
Applied current above 10amps, causes interferences with temperature controlled by thermocouples.

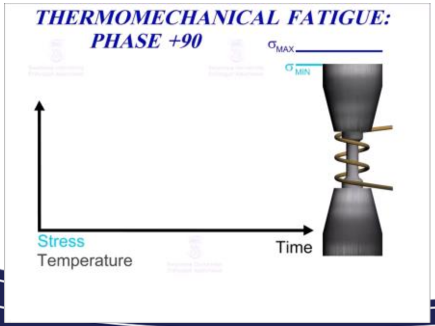
TMF Crack Growth Standardisation

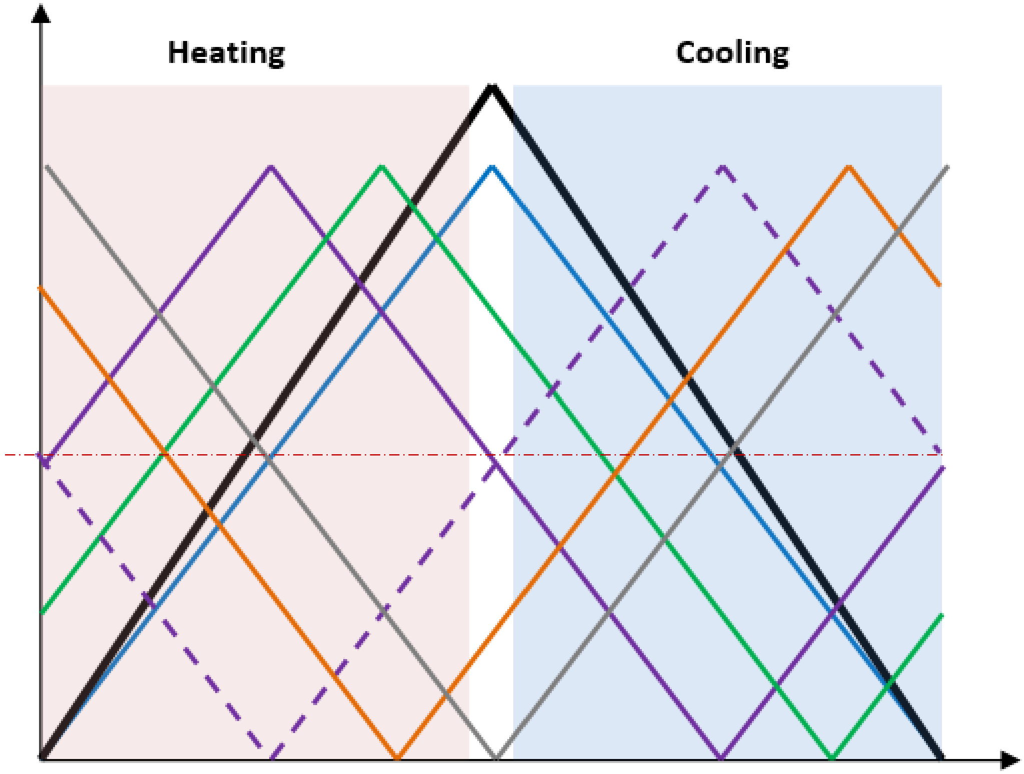
PD read times across different phase angles.

Noise in DCPD generated by - Cooling Air / Induction heating (high power outputs) / Applied load

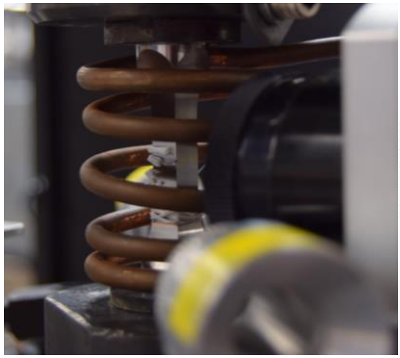


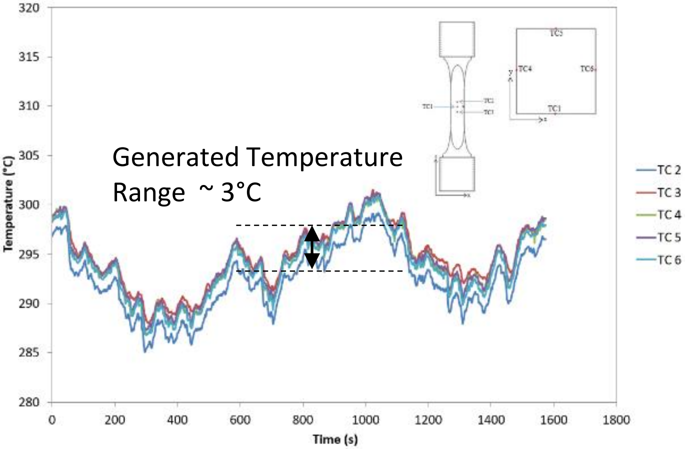


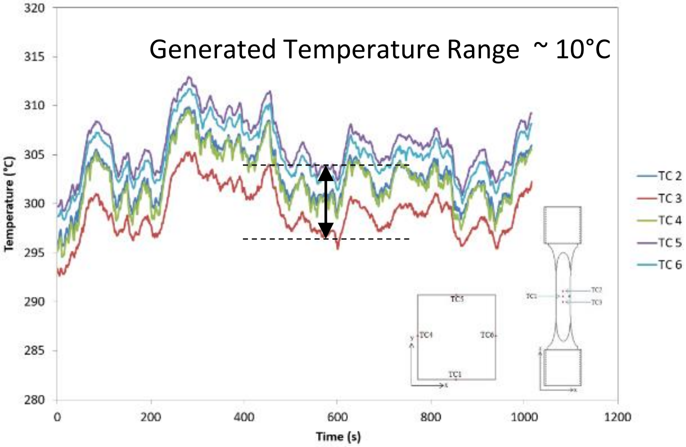




TMF Crack Growth Standardisation




Generated Temperature Range ~ 3°C


Generated Temperature Range ~ 10°C