



DEVELOPING THERMOMECHANICAL FATIGUE CRACK GROWTH TECHNIQUES

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Swansea University



Rolls-Royce®

Swansea University Bay Campus



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DevTMF Partners



Swansea University, Wales.
Testing and analysis

Nottingham University, England.
Modelling and round robin testing

Linköping University, Sweden.
Modelling and round robin testing

Rolls-Royce plc, UK.
Material and technical support



Introduction

Swansea University Background in TMF

TMFCG Test Development

Coils and Cooling

DCPD Measurements

Pre-Crack Procedure

TMFCG Test Results

Previous Work with Thermography

Rolls-Royce, MTOC

Swansea, ISM

TMFCG with Thermography

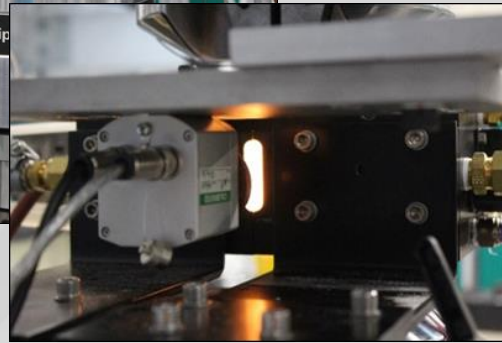
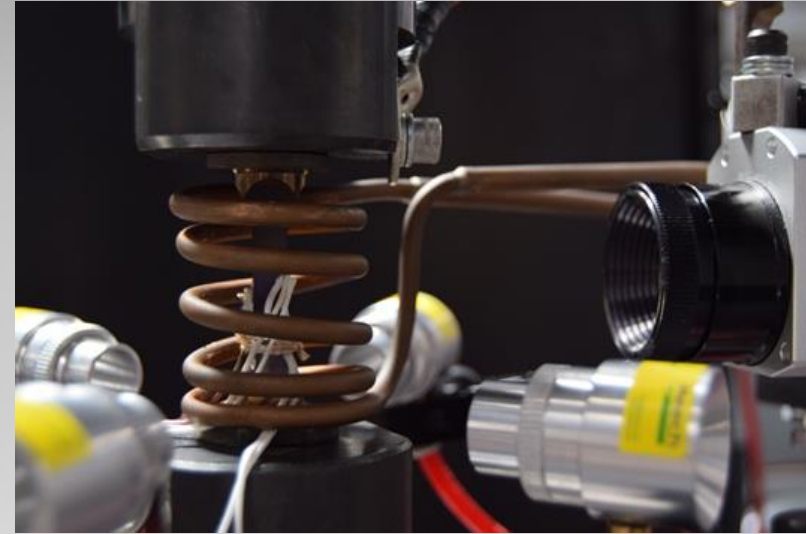
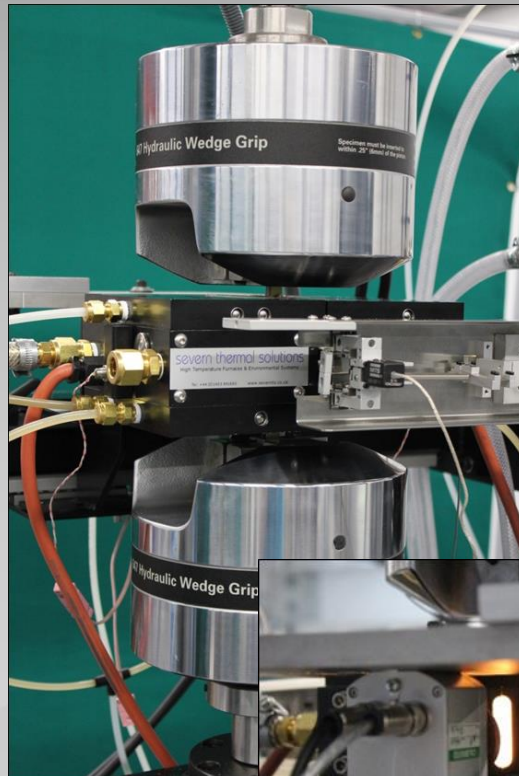
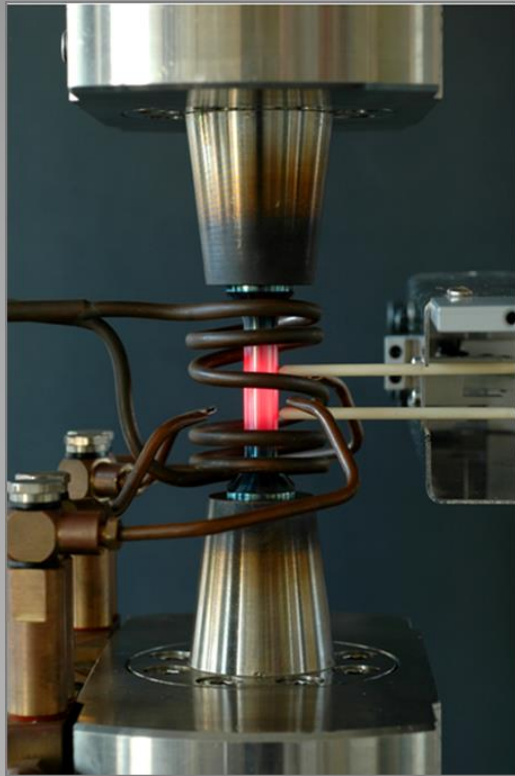
IR CG Measurements

Crack Tip Heating Investigations

Non-Invasive TMFCG



Background in TMF

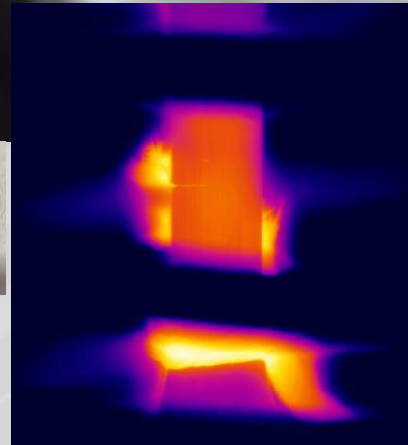
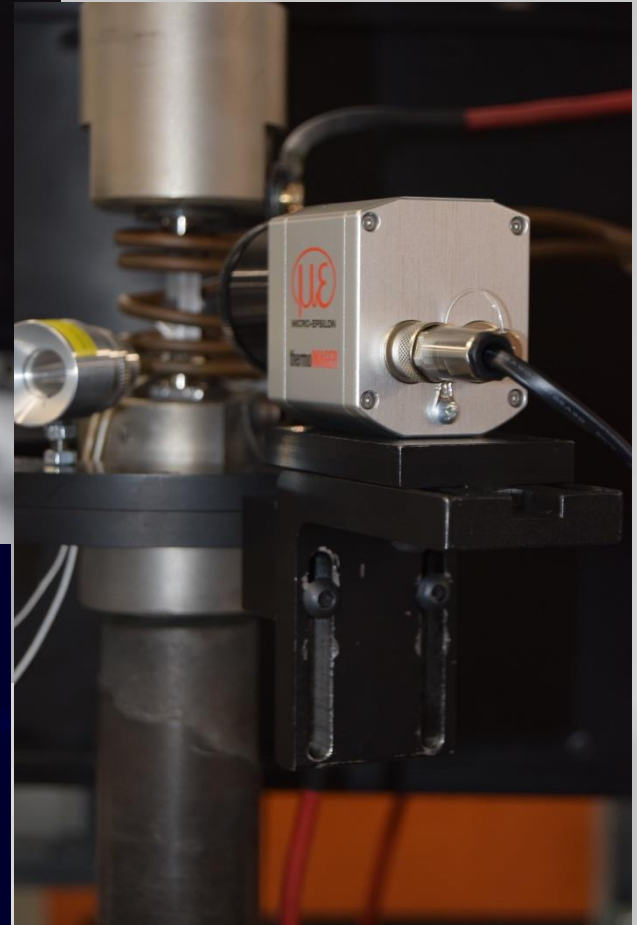
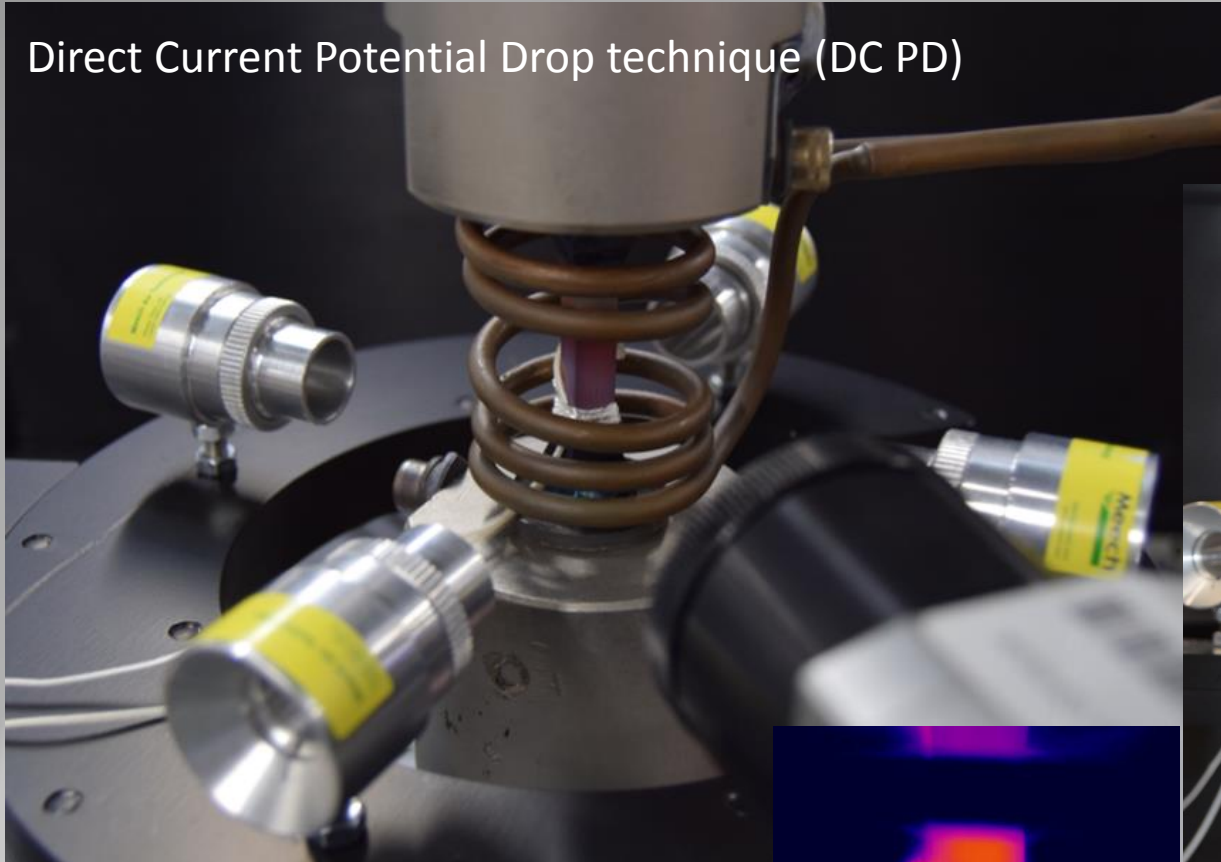


- ASTM E2368-10. Strain Controlled TMF Testing, 2010.
- ISO 12111:2011. Strain-controlled TMF Testing, 2011.
- BAM. CoP Force-Controlled TMF Testing, 2015.

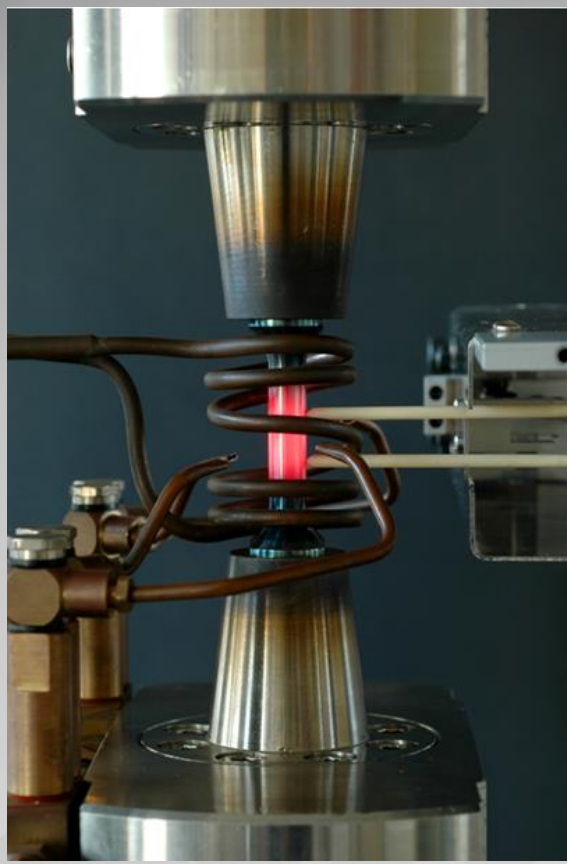


TMFCG Test Development

Direct Current Potential Drop technique (DC PD)

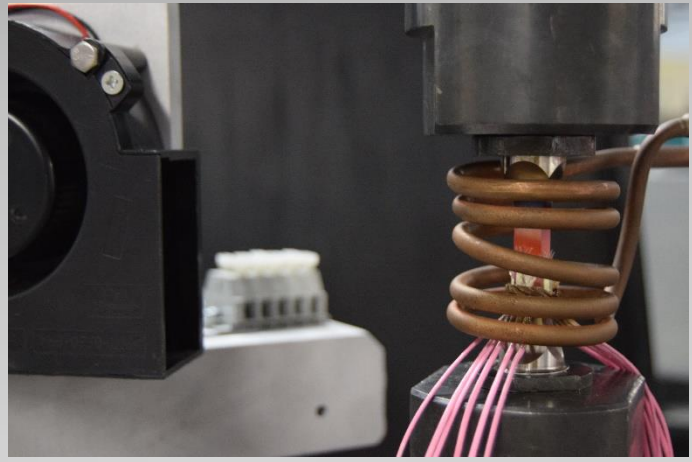


Forced Air Cooling

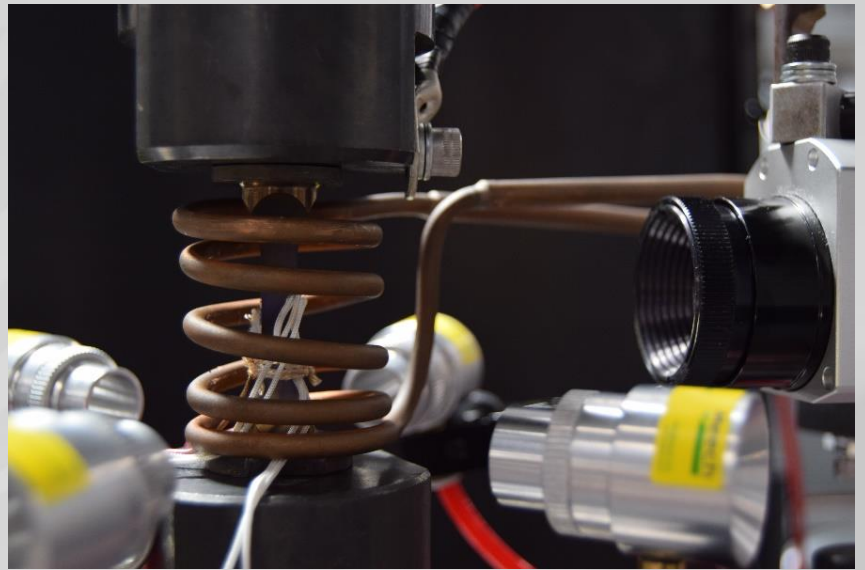


Localised/Focused Cooling

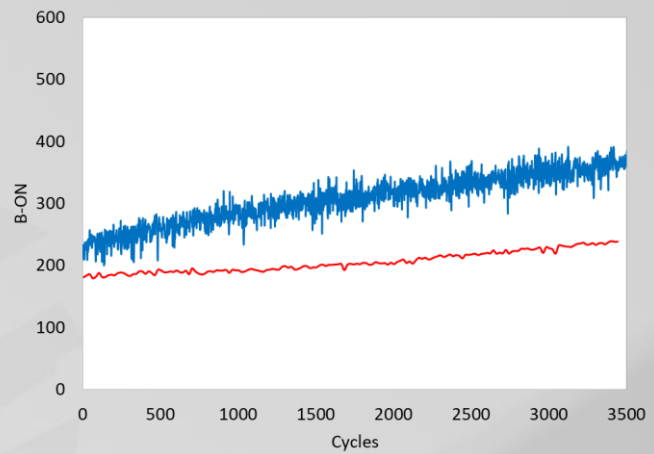
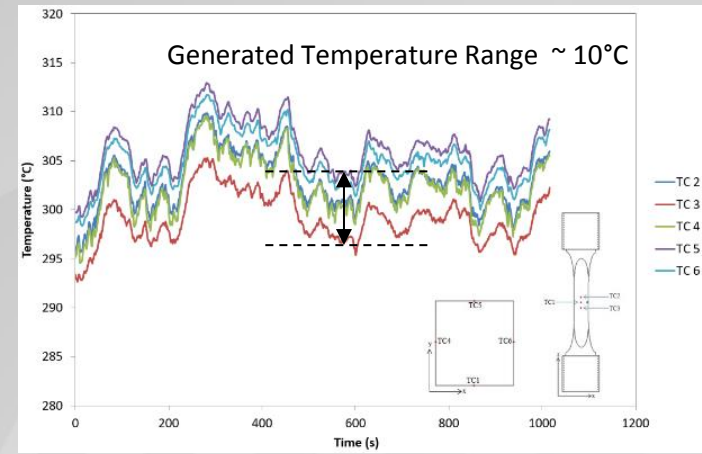
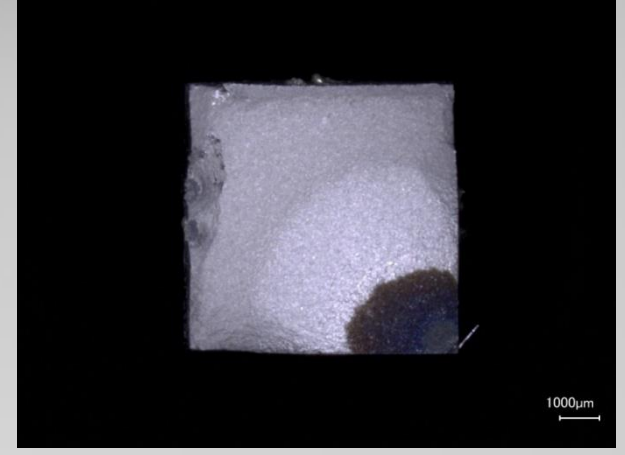
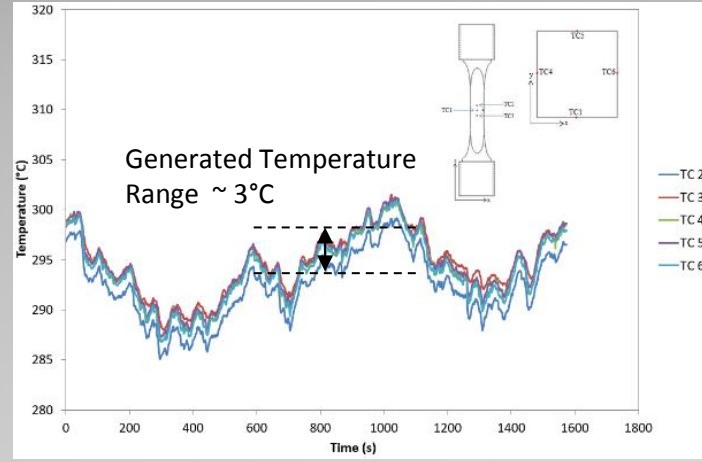
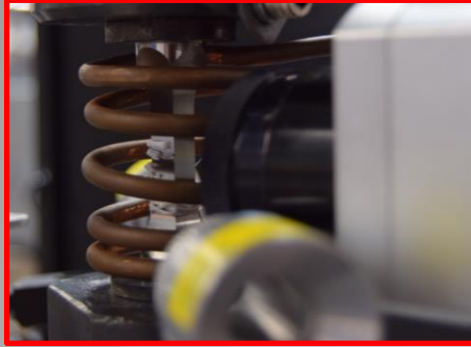
Basic Fan Cooling



Diffuse uniform cooling through air amplifiers



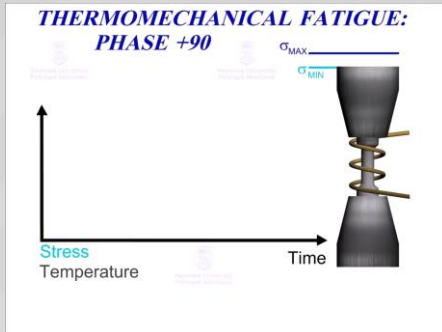
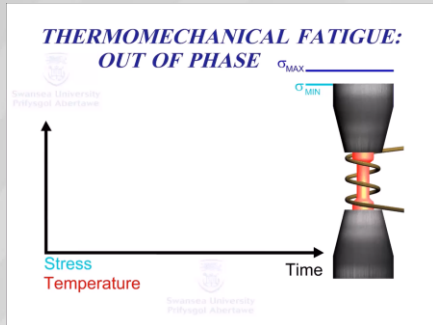
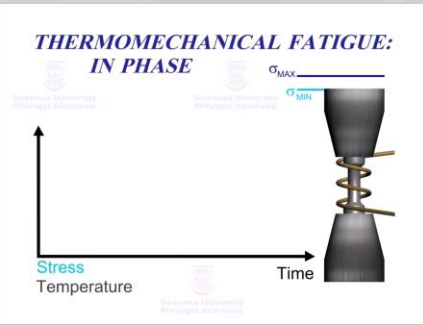
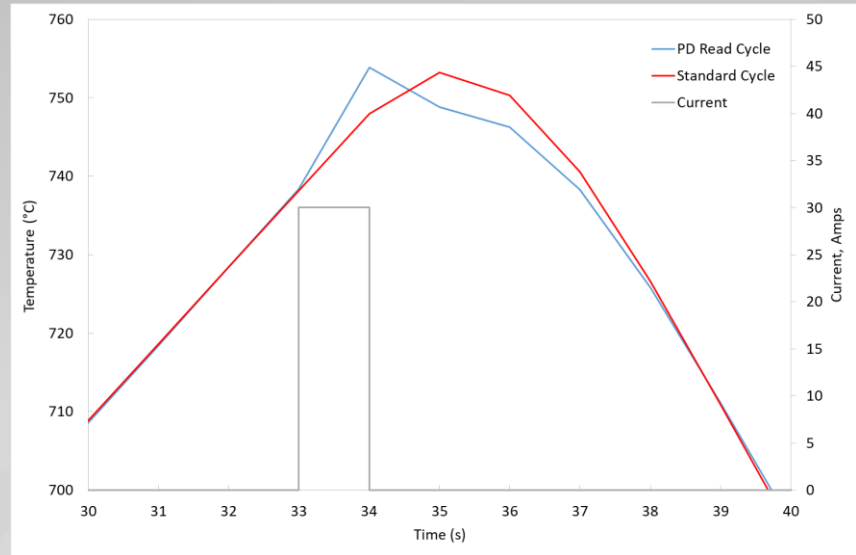
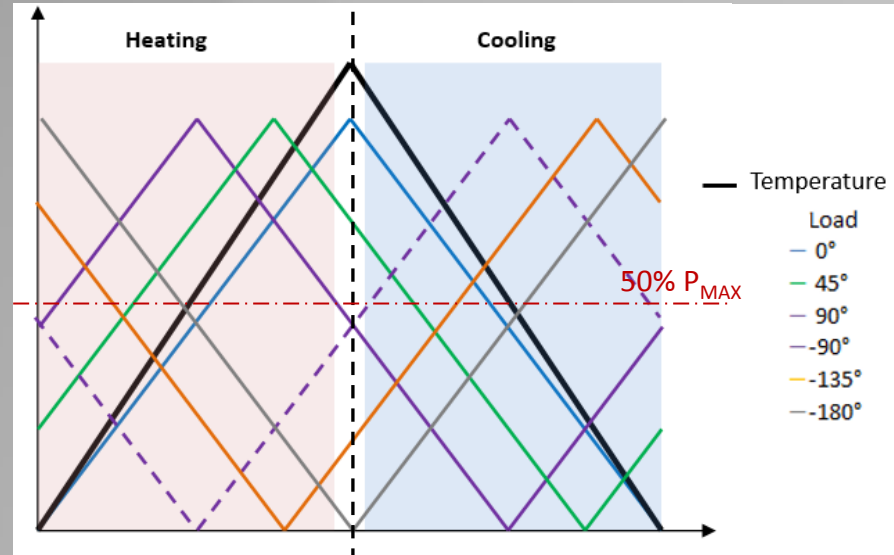
Induction Coil Designs



DCPD Measurements

PD read times across different phase angles.

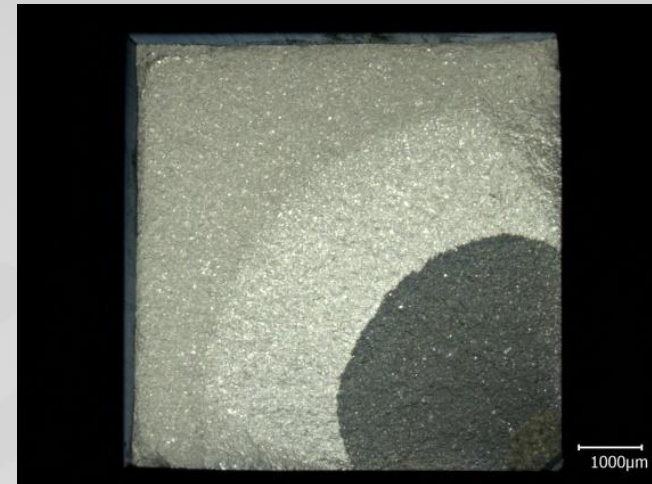
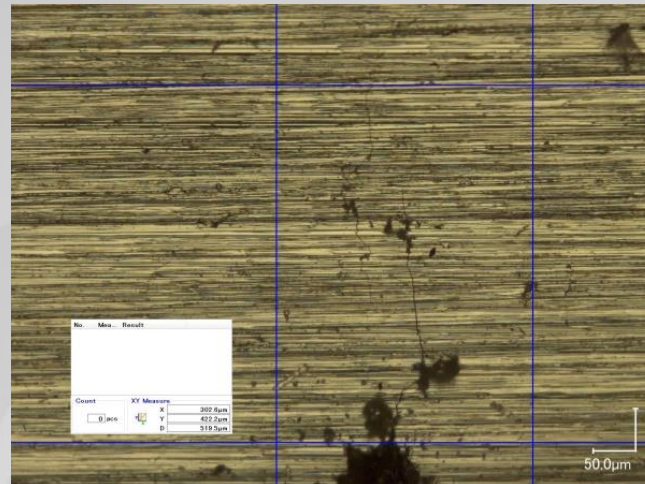
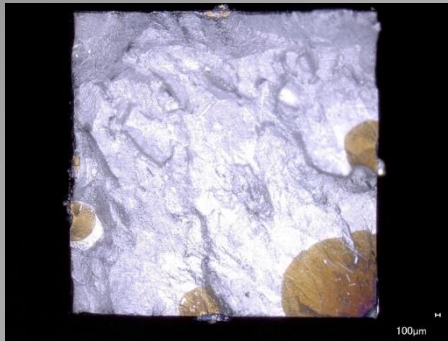
Noise in DCPD generated by - Cooling Air / Induction heating (high power outputs) / Applied load / Applied Current



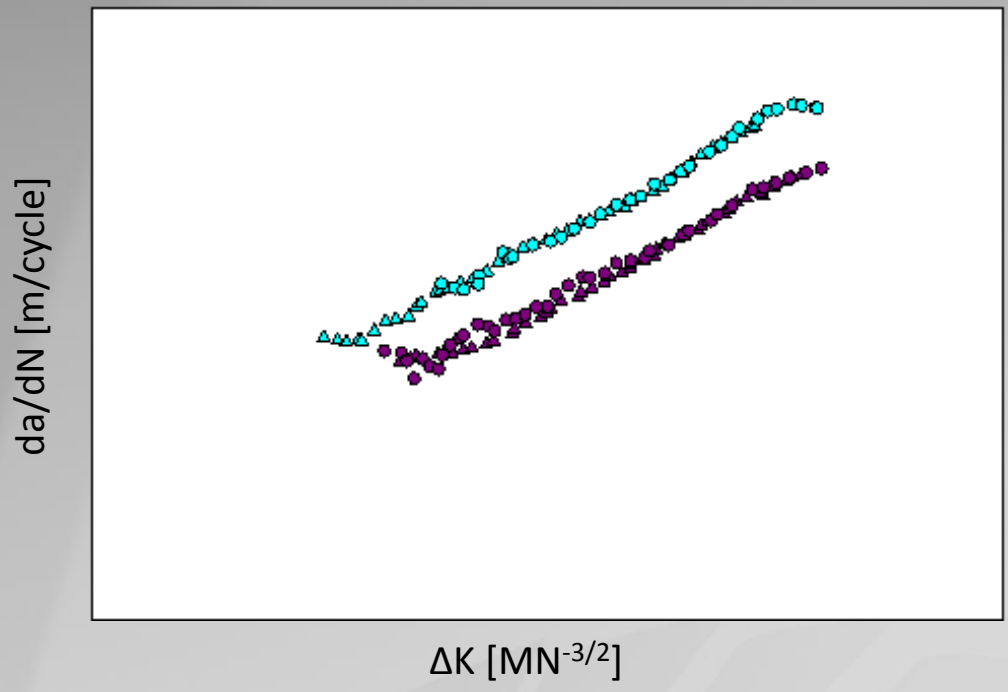
Pre-Crack Procedure

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

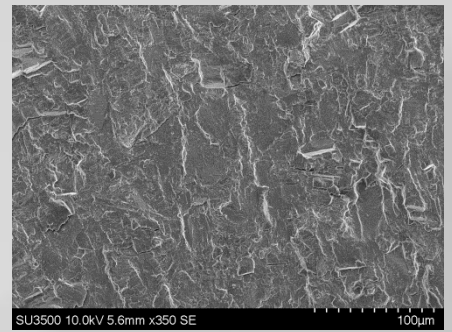
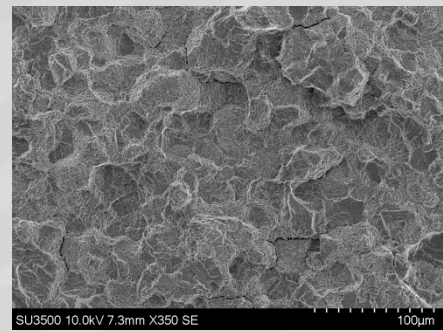
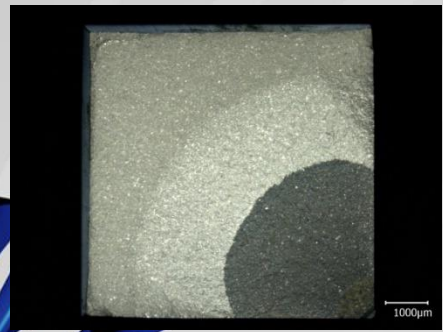


TMFCG Test Results

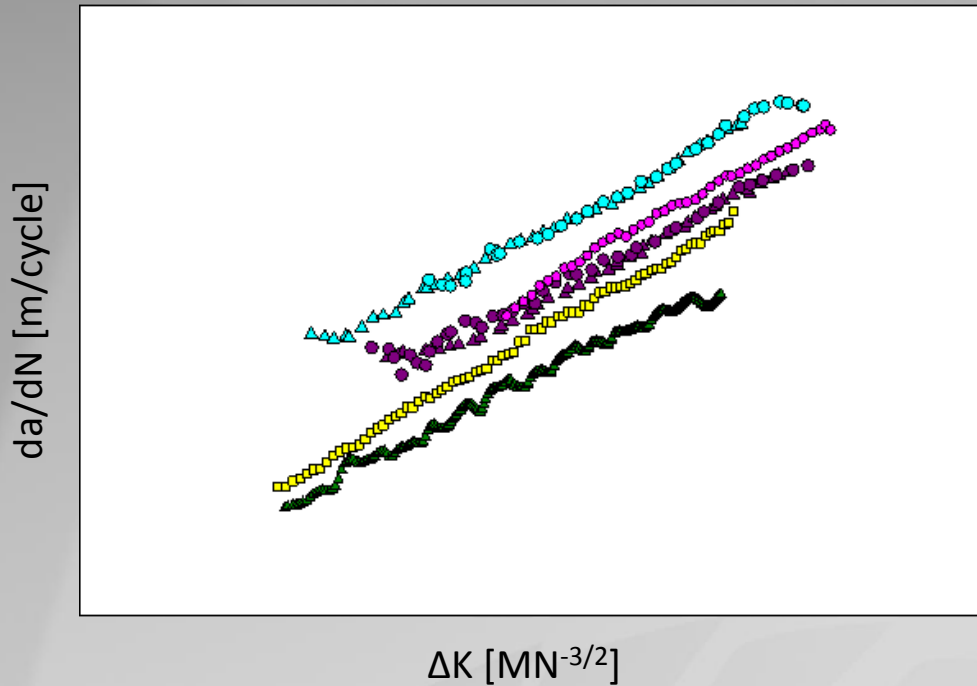


TMF Condition

- In Phase
- Out of Phase



TMFCG Test Results

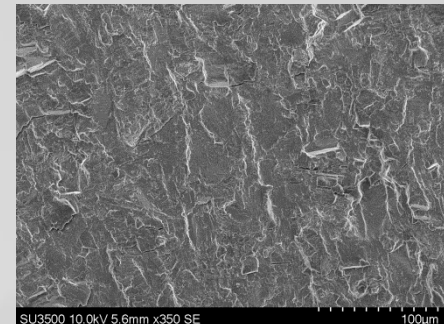
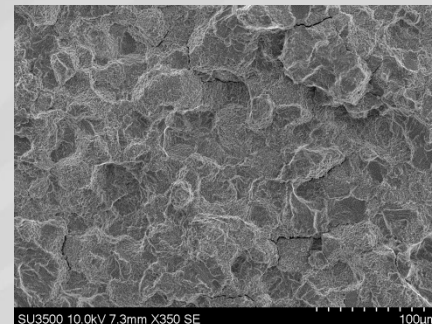
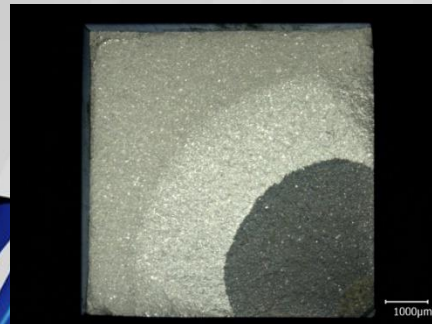


TMF Condition

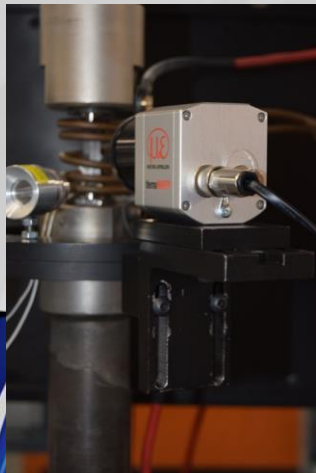
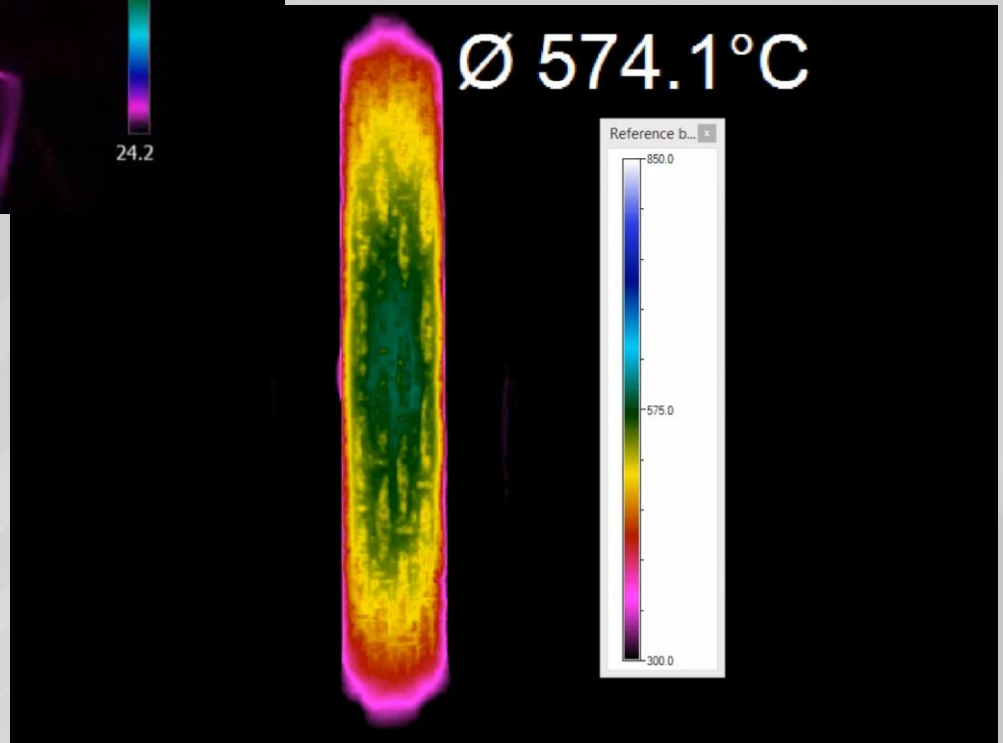
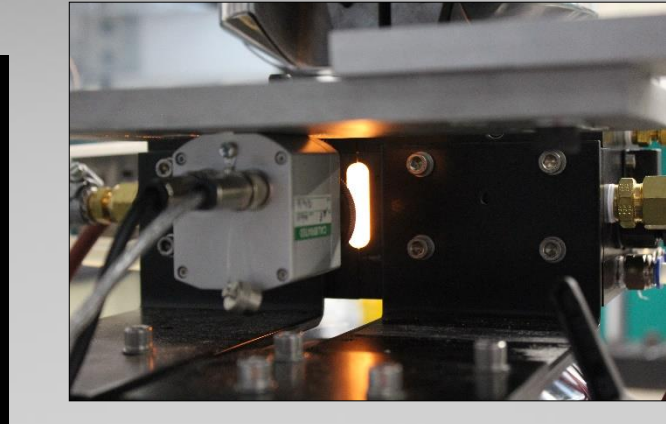
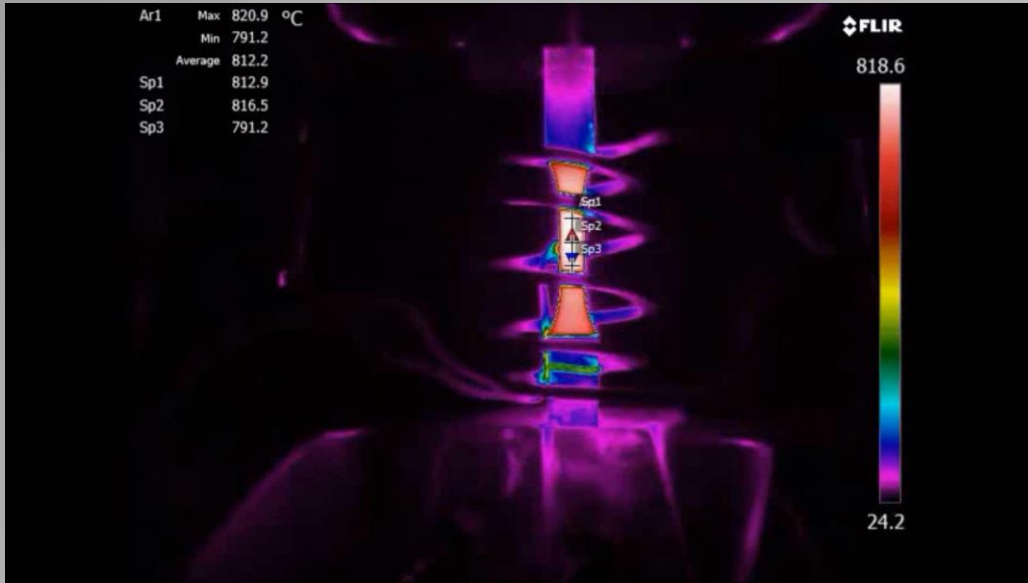
- In Phase
- Out of Phase

Isothermal Condition

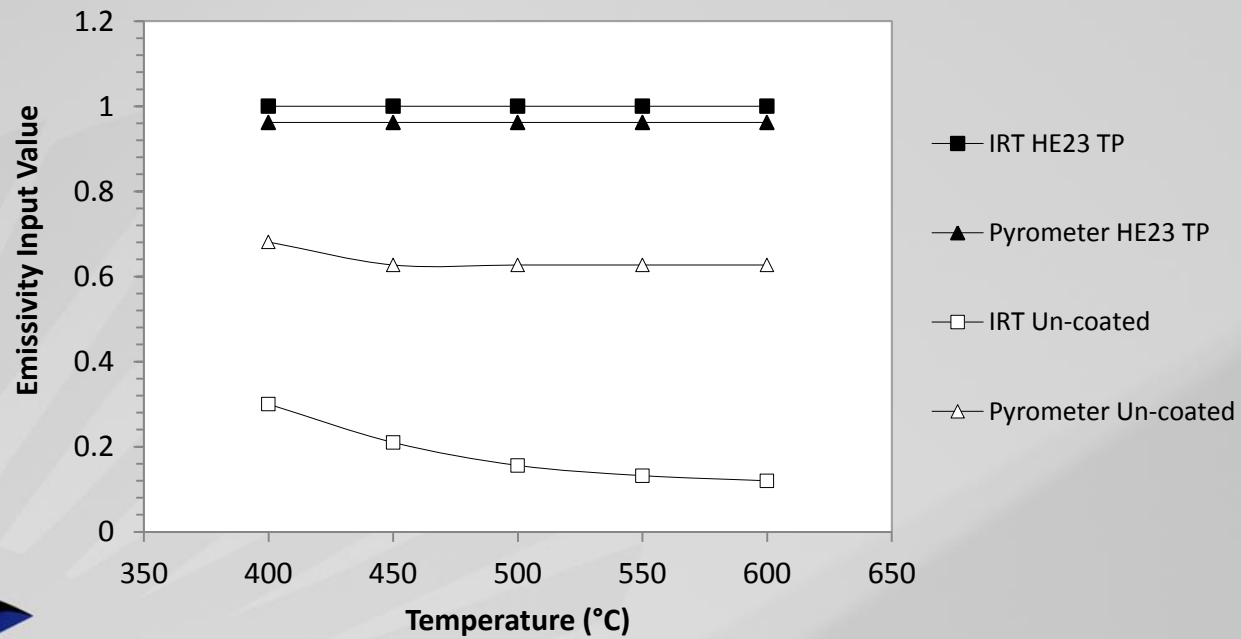
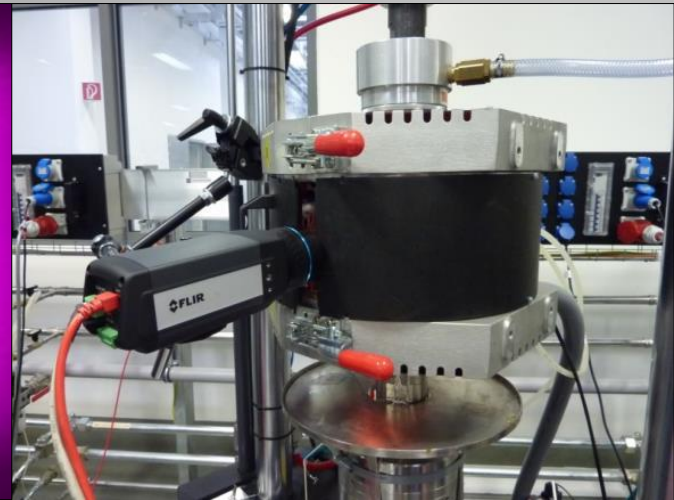
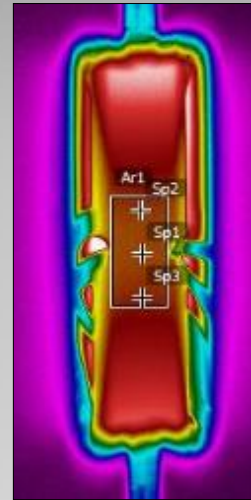
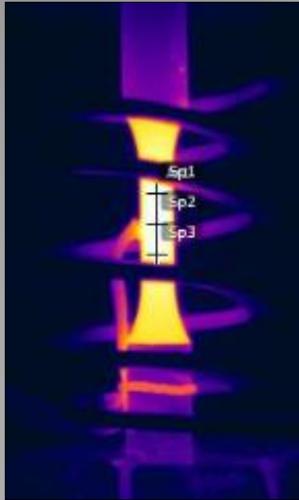
- T_{MAX} TMF Test
- T_{MAX} TMF Test (Vacuum)
- T_{MIN} TMF Test



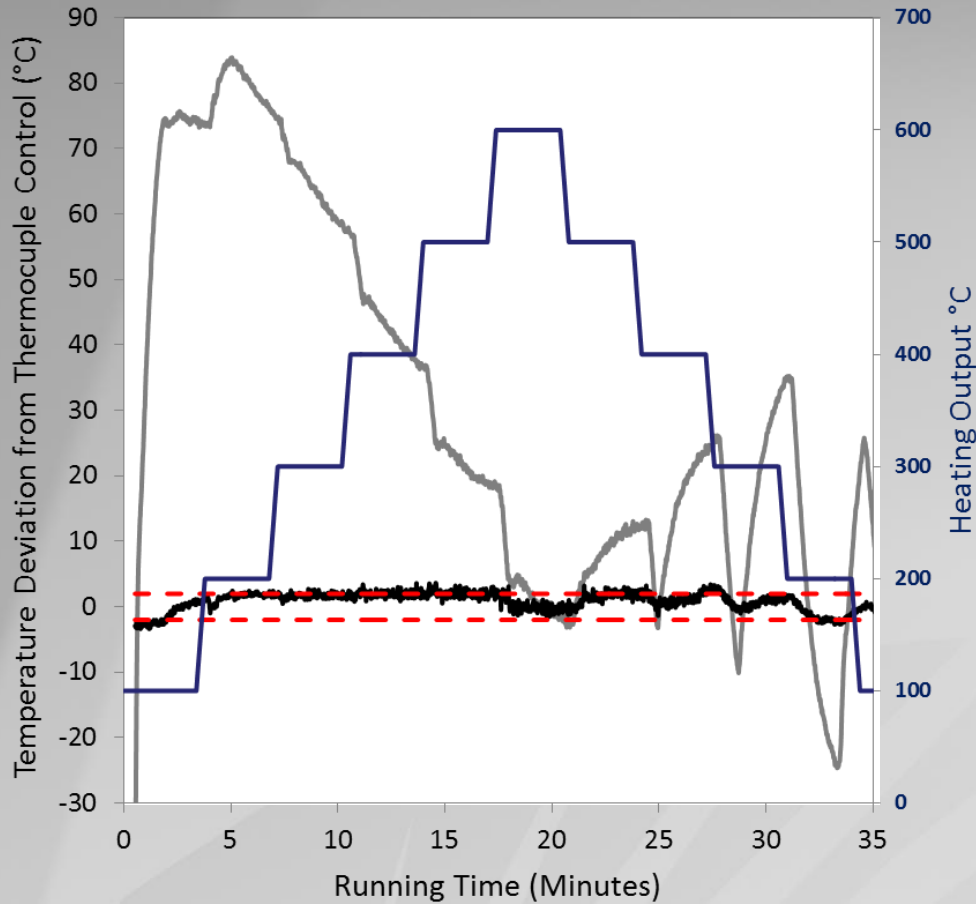
Previous Work with Thermography



Previous Work – Rolls-Royce, MTOC

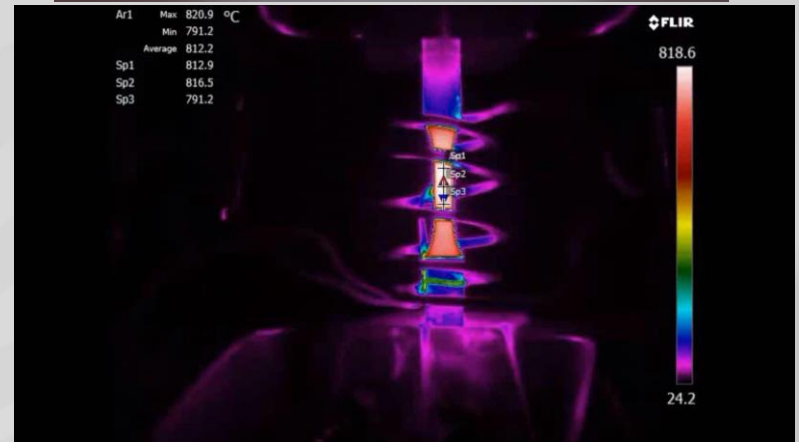


Previous Work – Rolls-Royce, MTOC

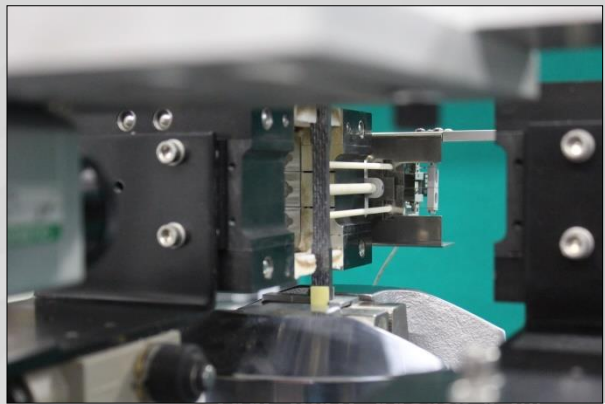
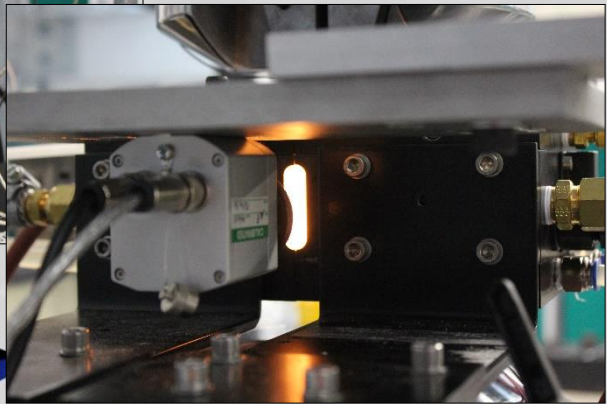
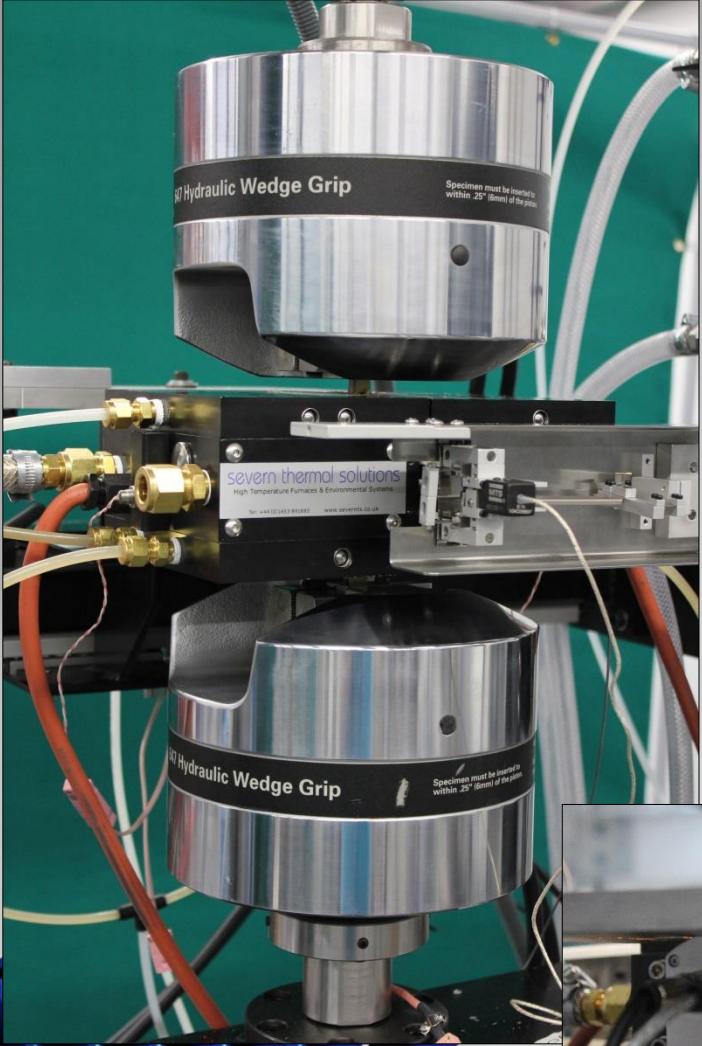


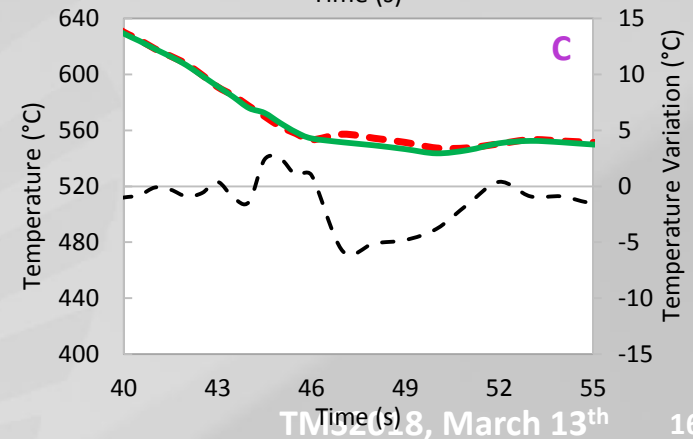
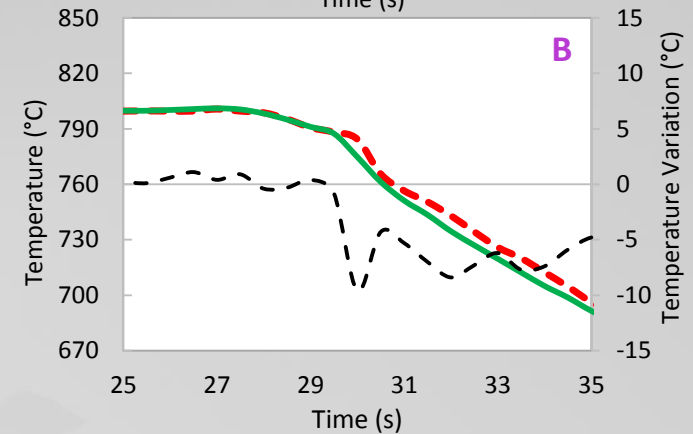
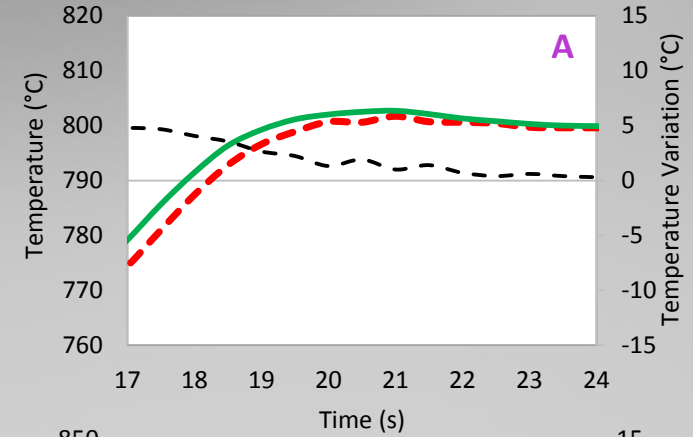
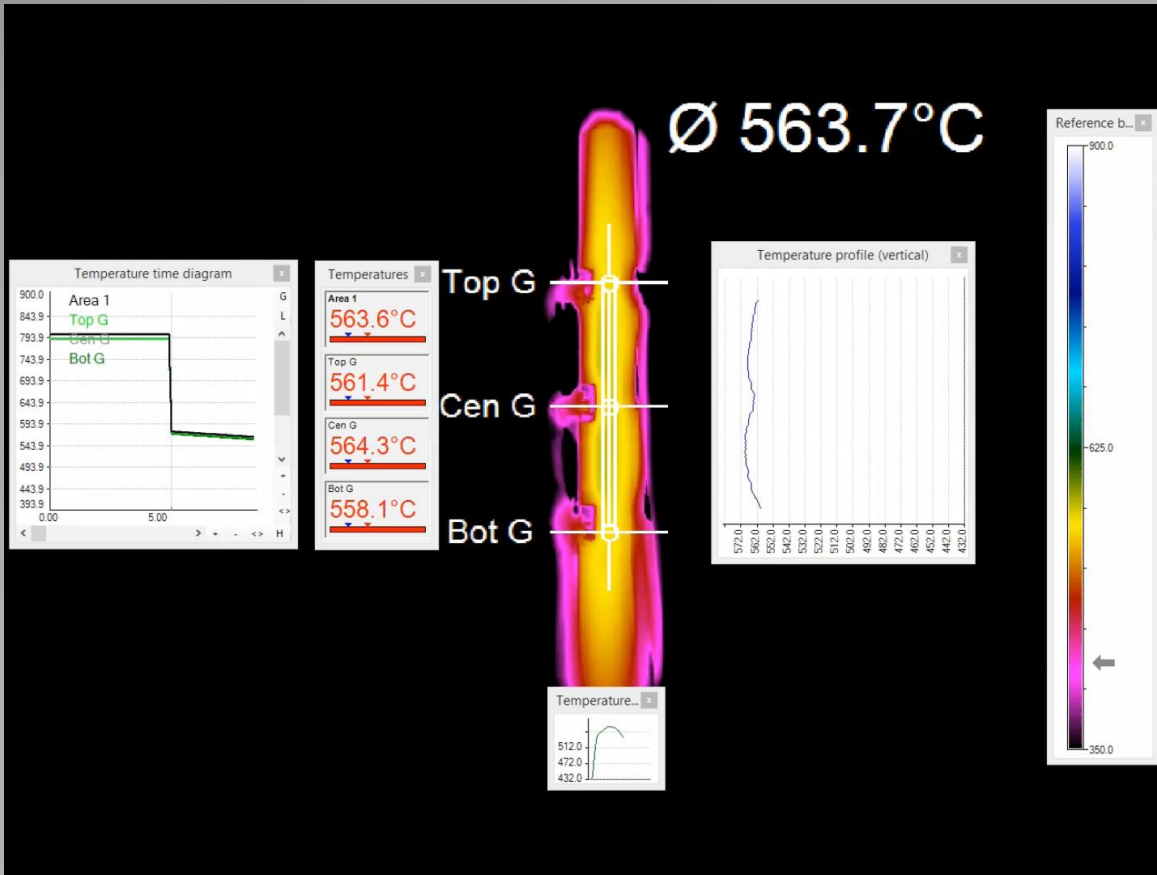
- IR Thermography Monitor
- IR Thermography Monitor HE23
- - - Thermocouple Control Target Temperature $\pm 2^{\circ}\text{C}$
- Heating Output

Coated Test Piece



Previous work – ISM, Swansea

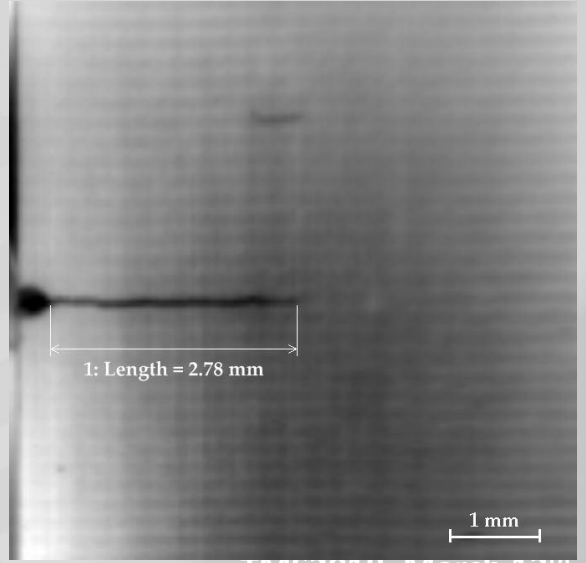
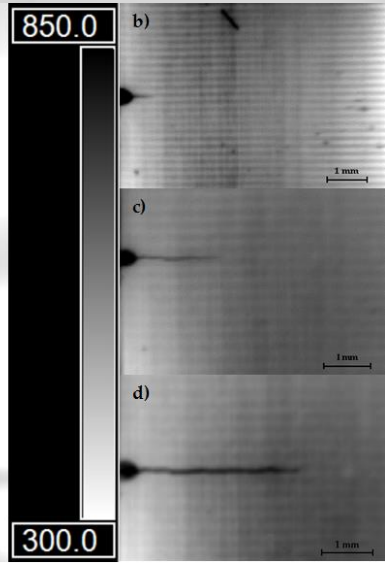
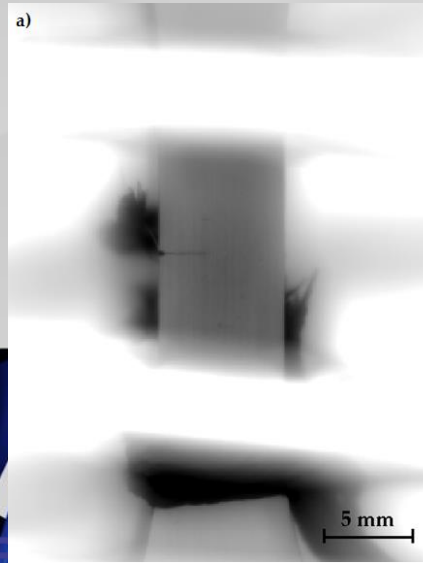
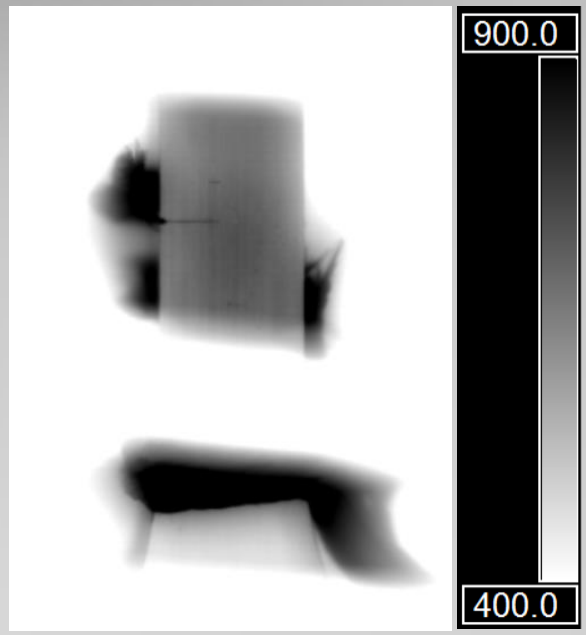
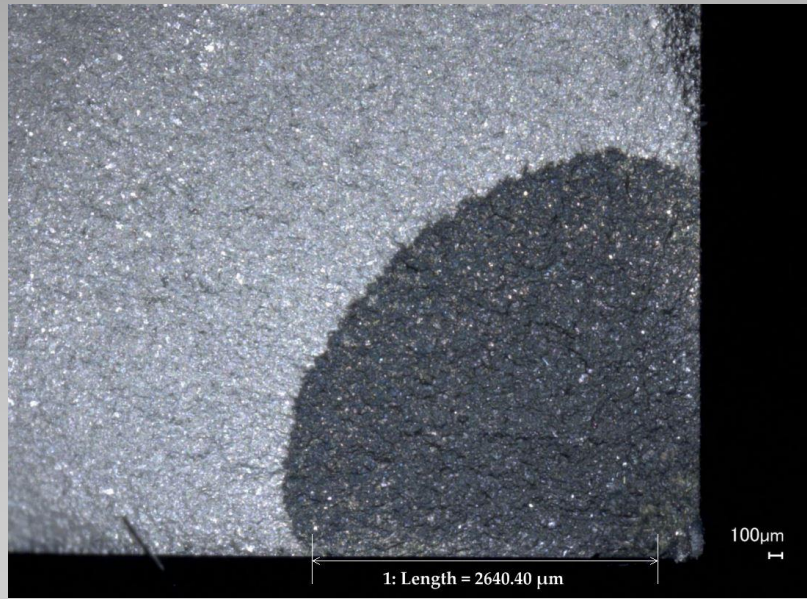
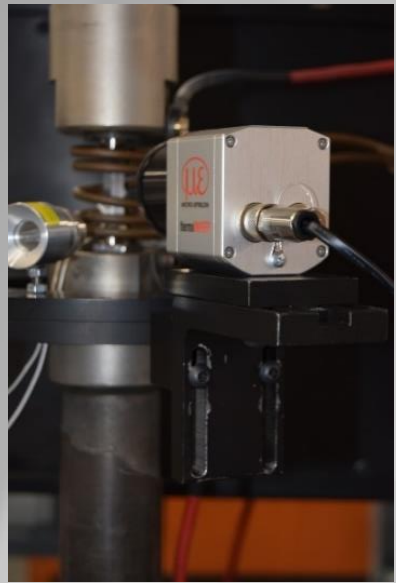




- IR Area Control
- TC_Center
- - - Temperature Deviation (°C)



IR Crack Growth Measurements



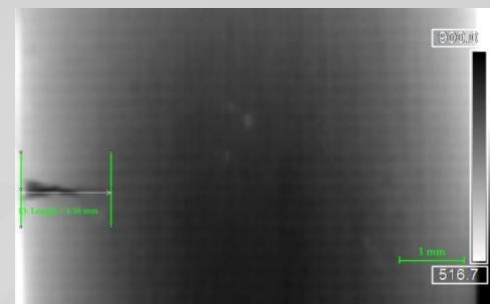
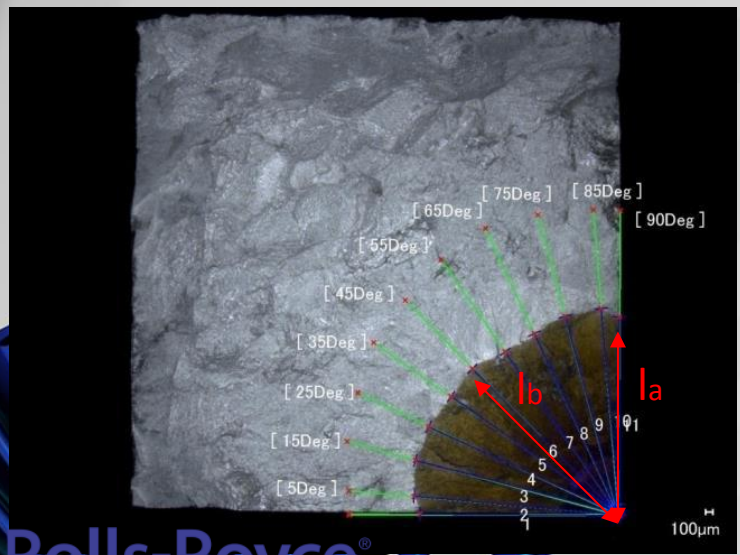
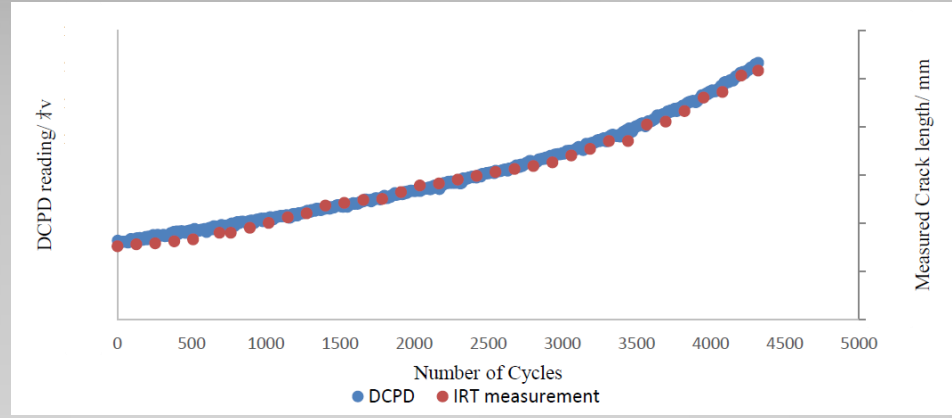
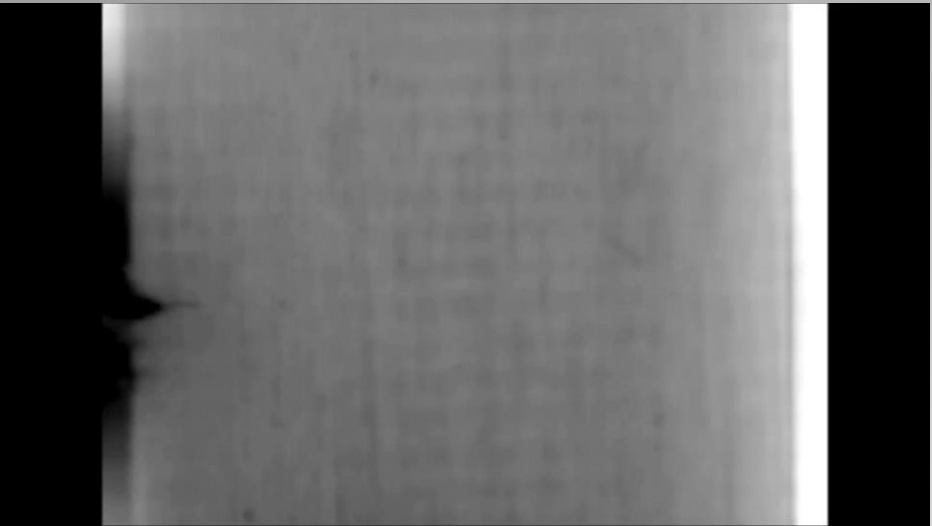


Image of surface crack length 3549 cycles

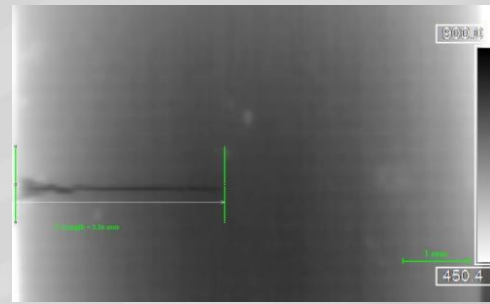
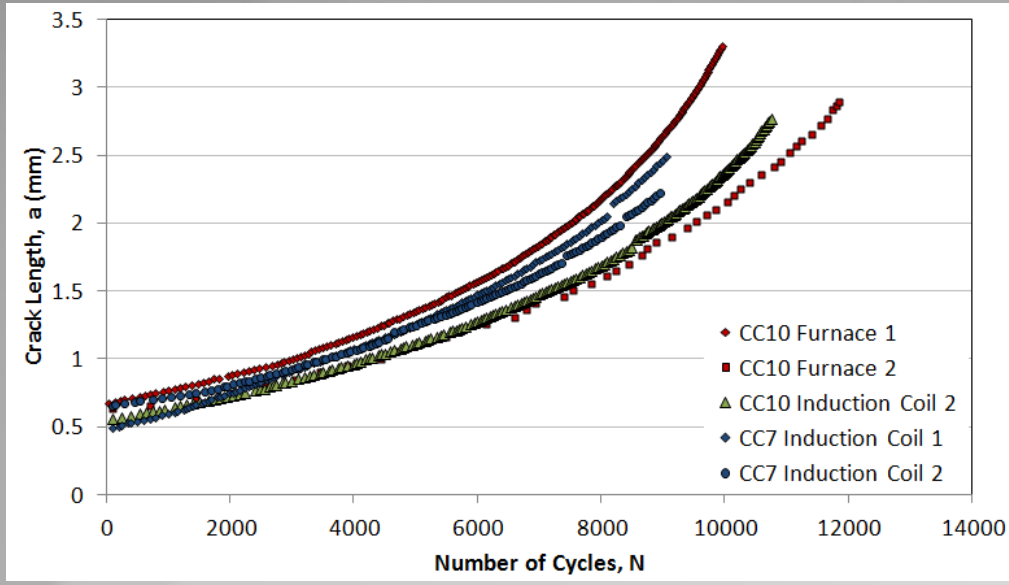
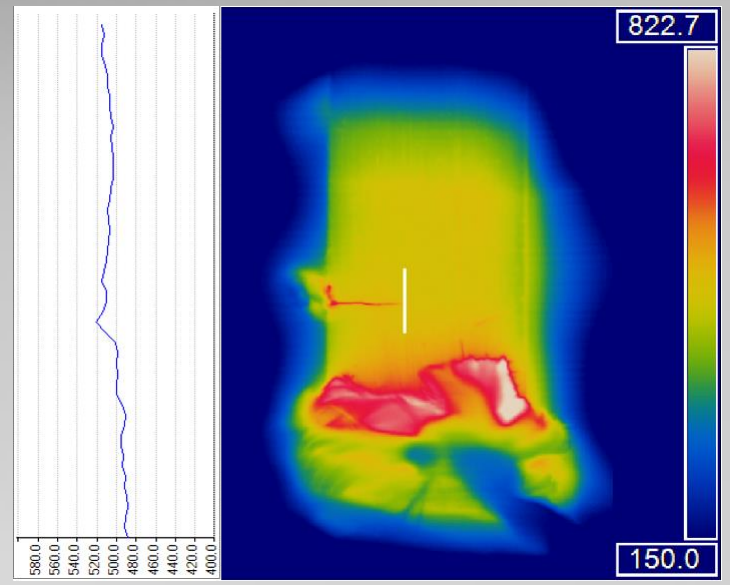


Image of surface crack length after 6549 cycles

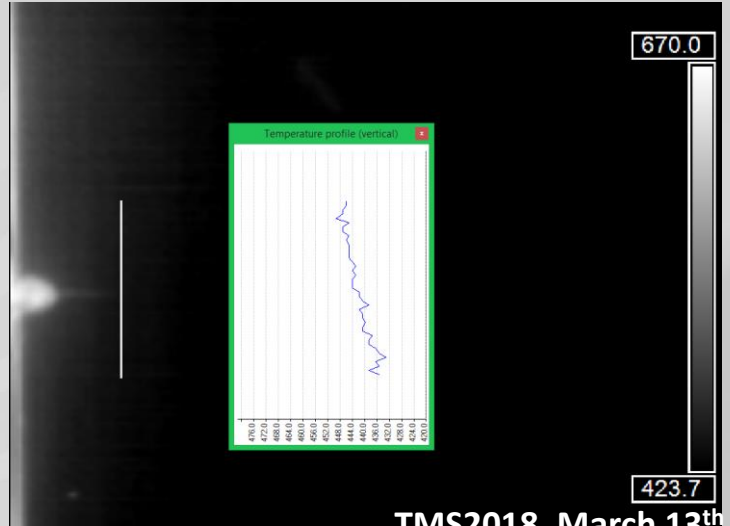
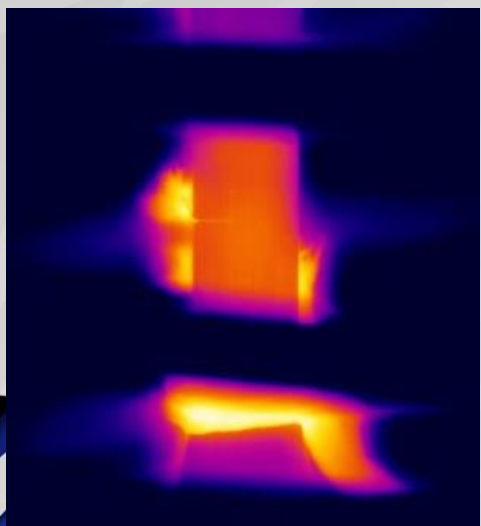
Crack Tip Heating Investigations



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 TMFCG test method

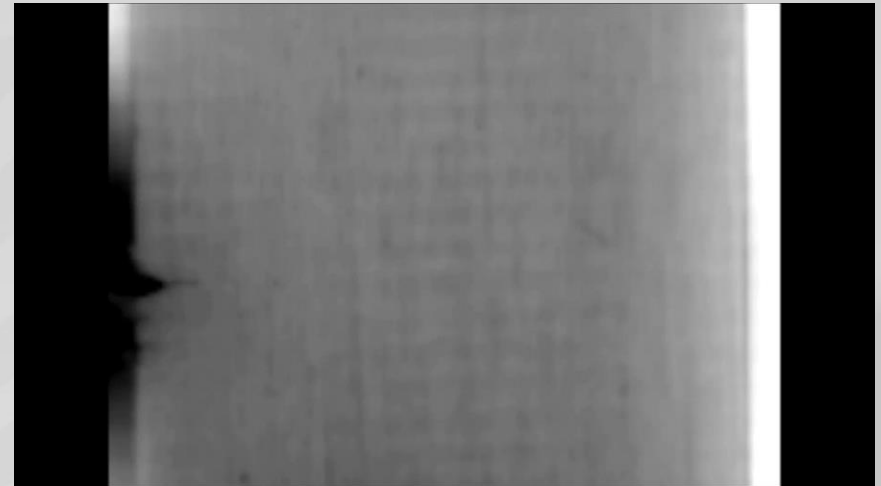
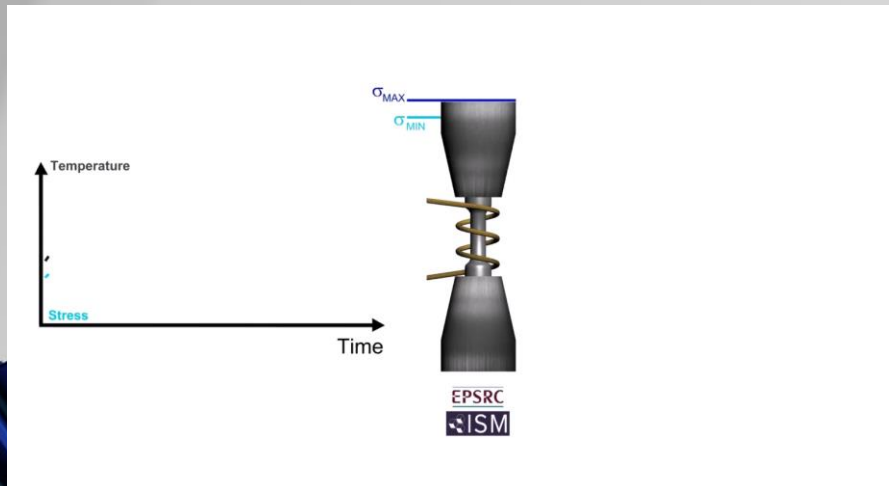
Advantages * Avoid complications with thermocouple control

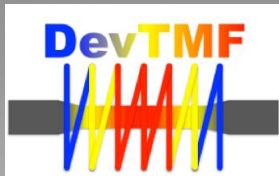
- Crack initiations at welds.
- Thermocouple shadowing and or over/undershooting

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.
- * Enables aggressive environmental testing to be carried out





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Any Questions?



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