

KME-702:

LCF and TMF Crack Growth in Cast Nickel-Based Superalloys

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Energy Context

- Increasing renewable energy sources
- Intermittent
- Problem with energy storage



"One" solution = Gas turbines

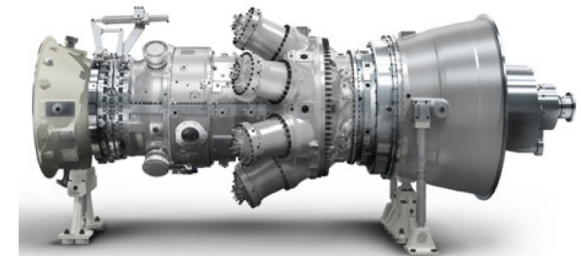
- Gas turbines traditionally designed for base load operation.
- Operational flexibility increases with introduction of renewable energy.
 - Balancing the power grid
 - Fast start-up and shut-down times
 - Fuel flexible
 - Cyclic load conditions, more starts and stops → fatigue



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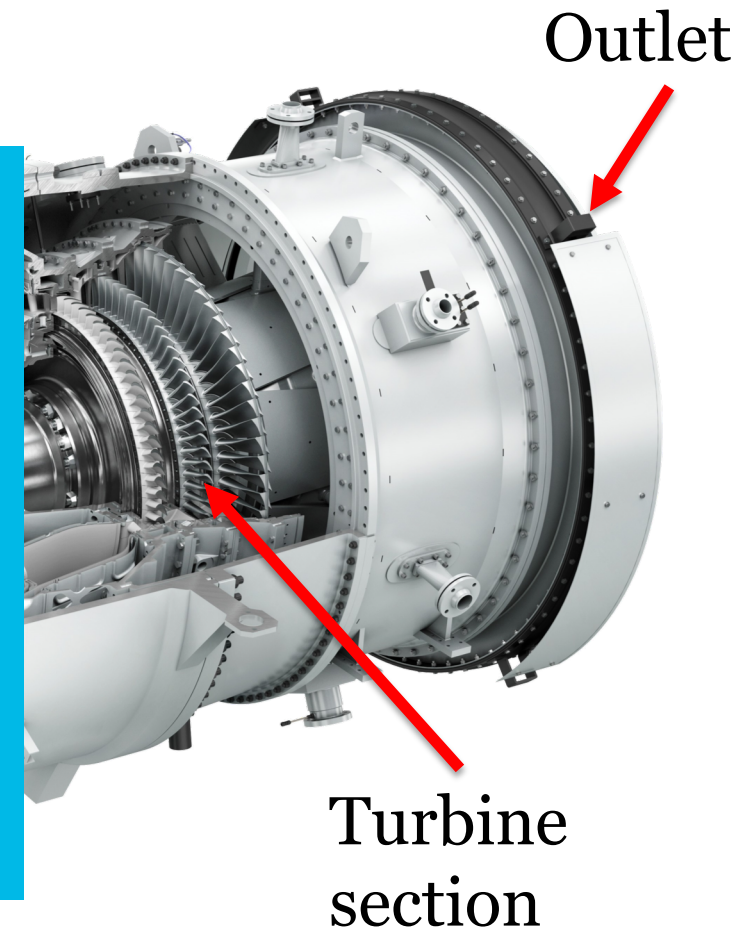


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Gas Turbines

- Highest temperature in turbine section
- Cast nickel-base superalloys, IN792, SX
- Improved creep and oxidations properties
- Complex material behaviour



Inlet

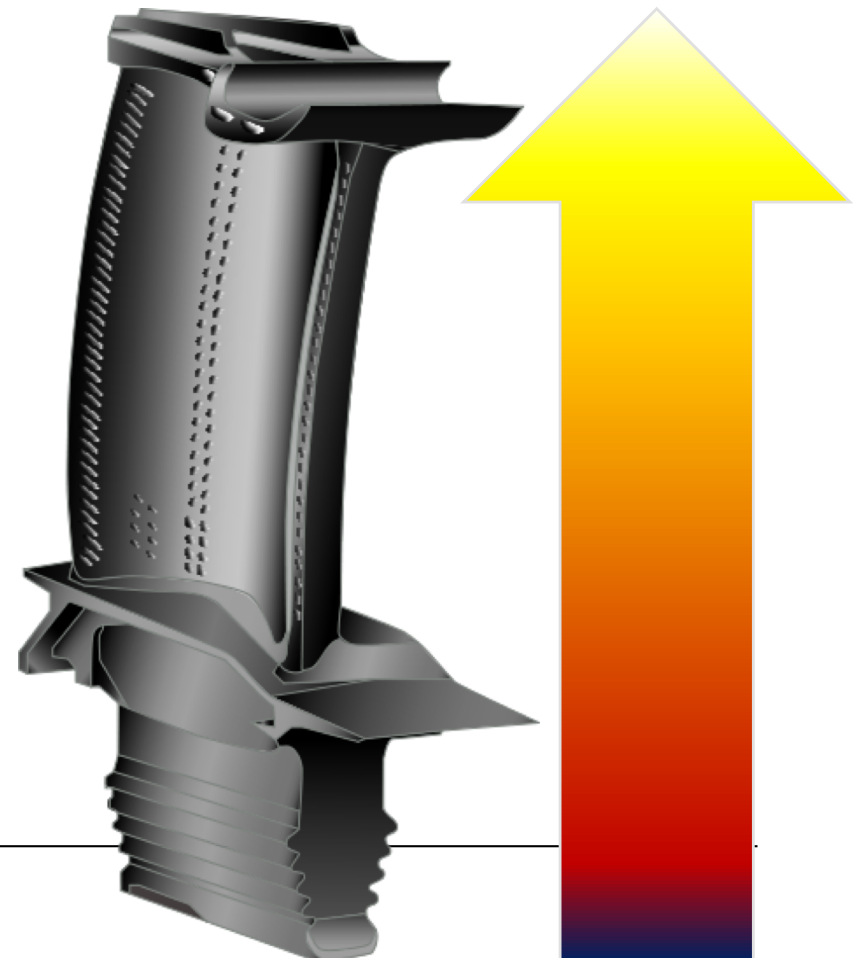
Turbine
section

Turbine section

Turbine disc

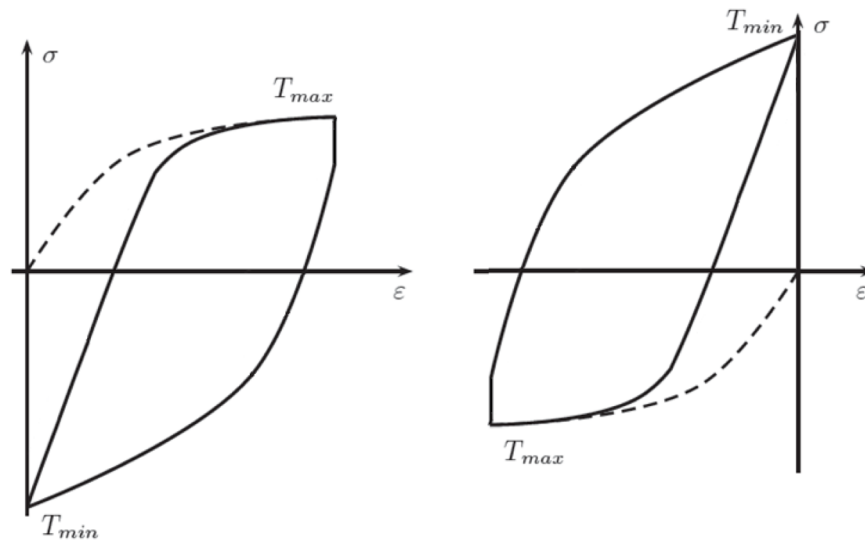
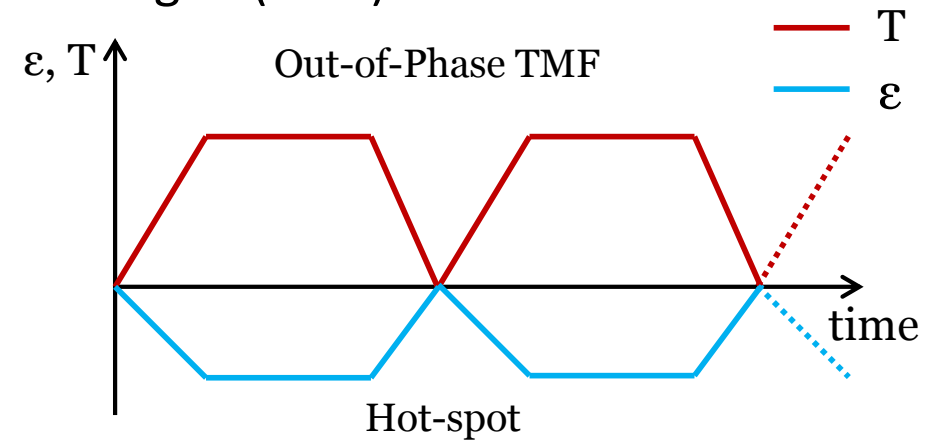
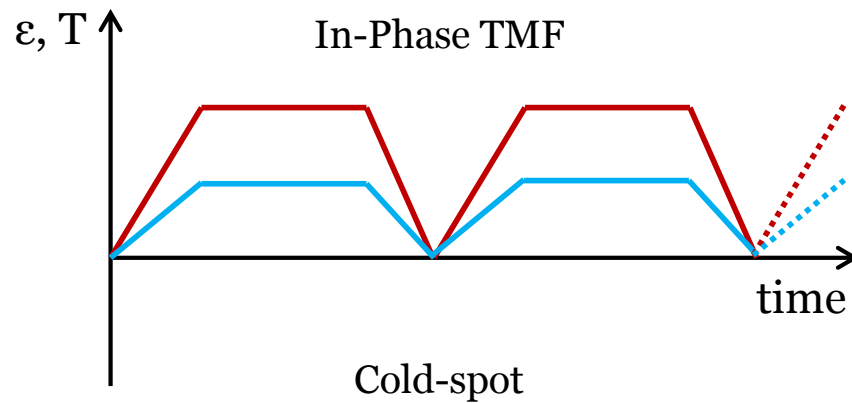


Turbine blade

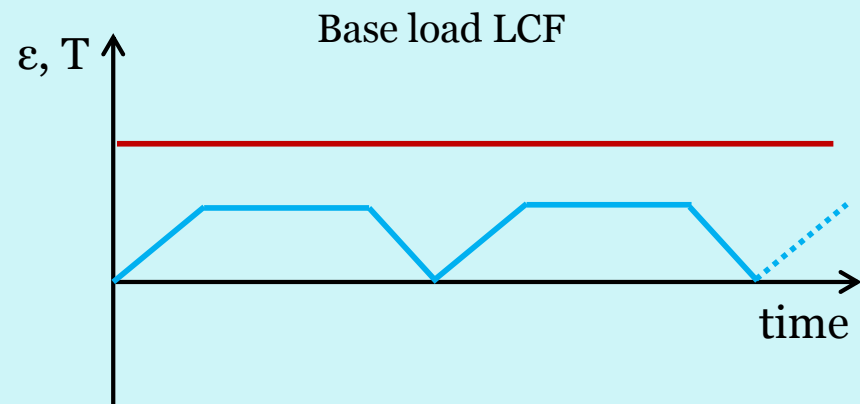


Cyclic conditions

Thermomechanical fatigue (TMF)



Can be idealised as LCF in certain cases (locations)

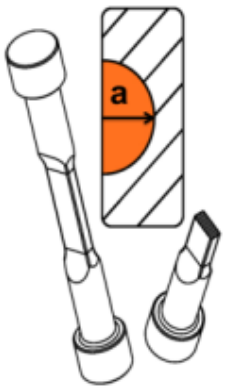
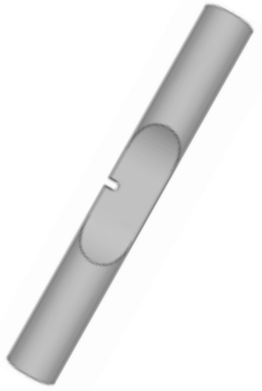
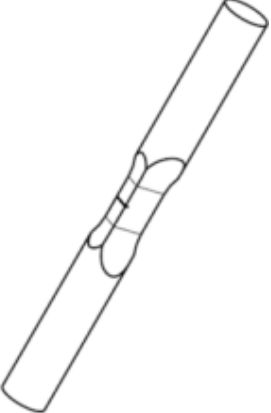
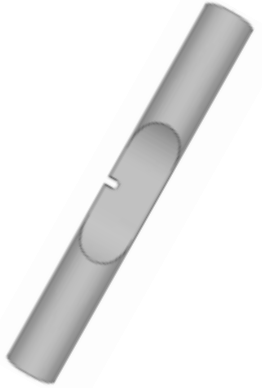
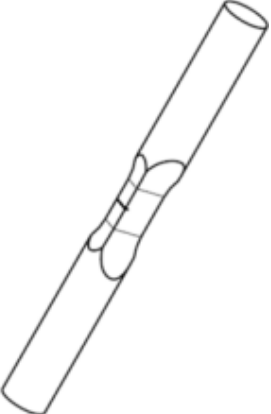


Key objectives of KME-702

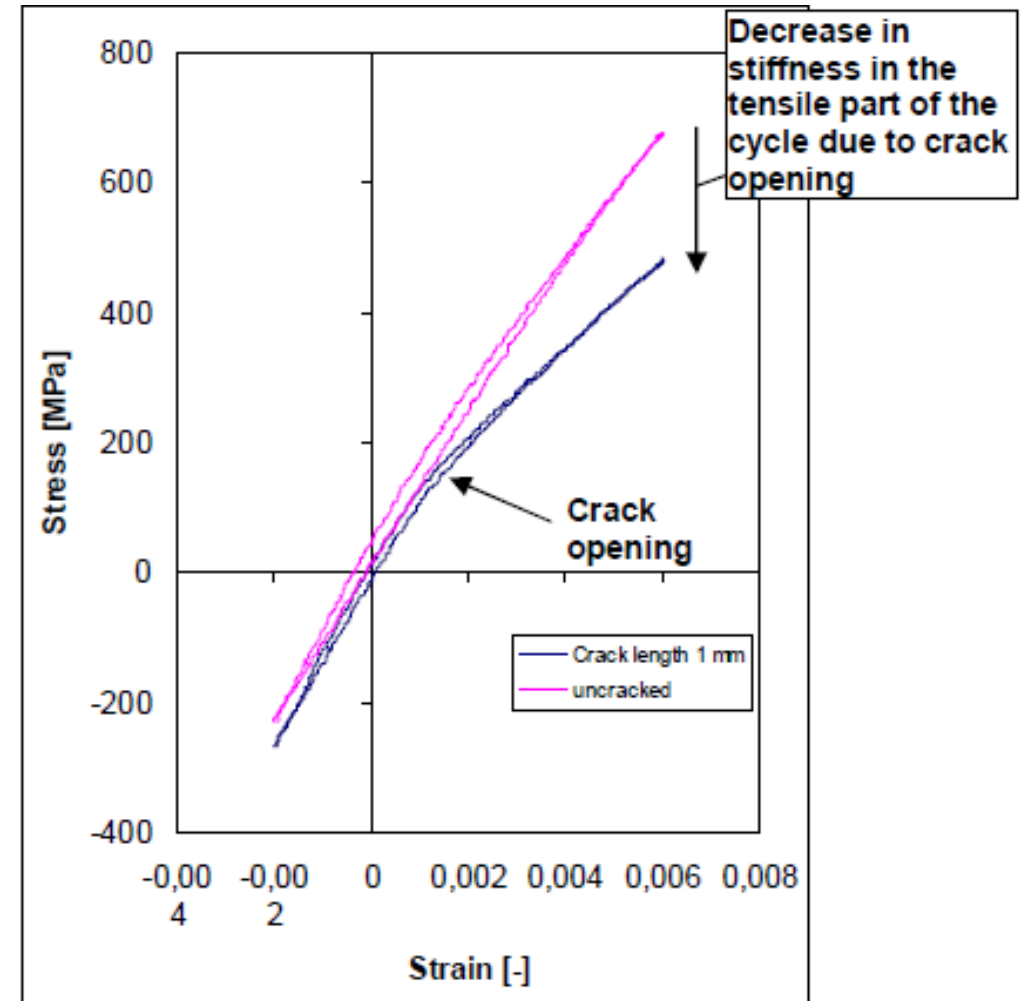
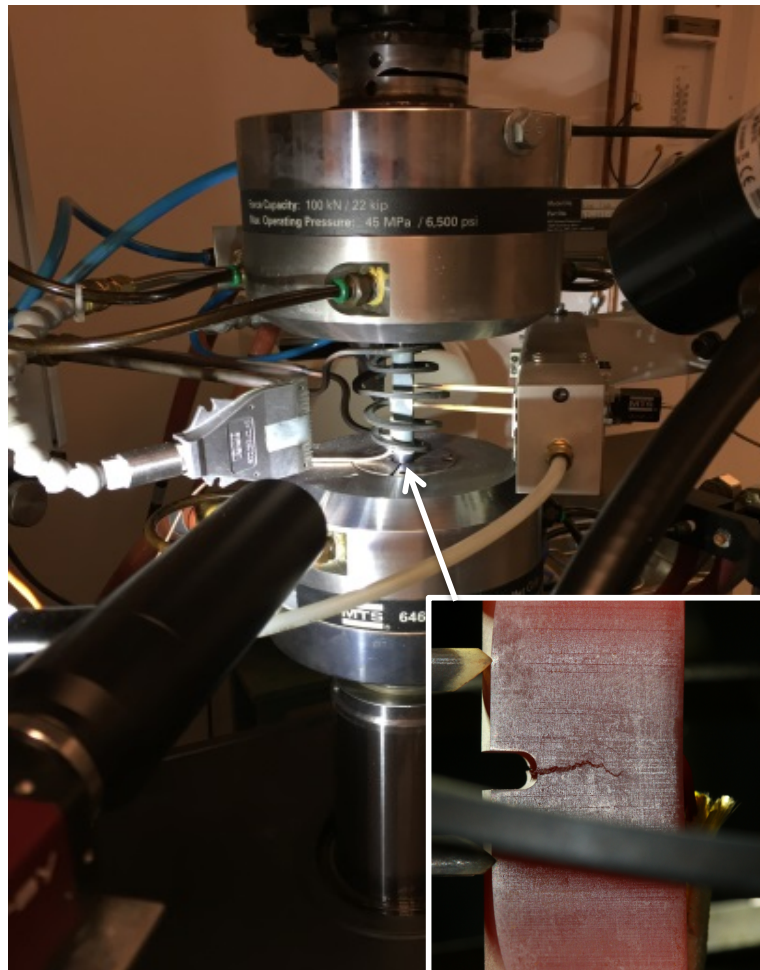
1. Validate a TMF crack growth test method that can be used to generate high quality data for cast nickel-based superalloys, including single-crystals.
2. Generation of high quality test data for TMF crack growth in the corrosion resistant single-crystal superalloy STAL15.
3. Improve the knowledge regarding the mechanisms that controls the crack growth rate in single-crystal superalloys.
4. Develop TMF crack growth models and life prediction methodologies that will reduce the need for high safety margins.
5. Validate the models for component near conditions.

Efficient and robust gas turbines with high flexibility with respect to fuel and cyclic operation

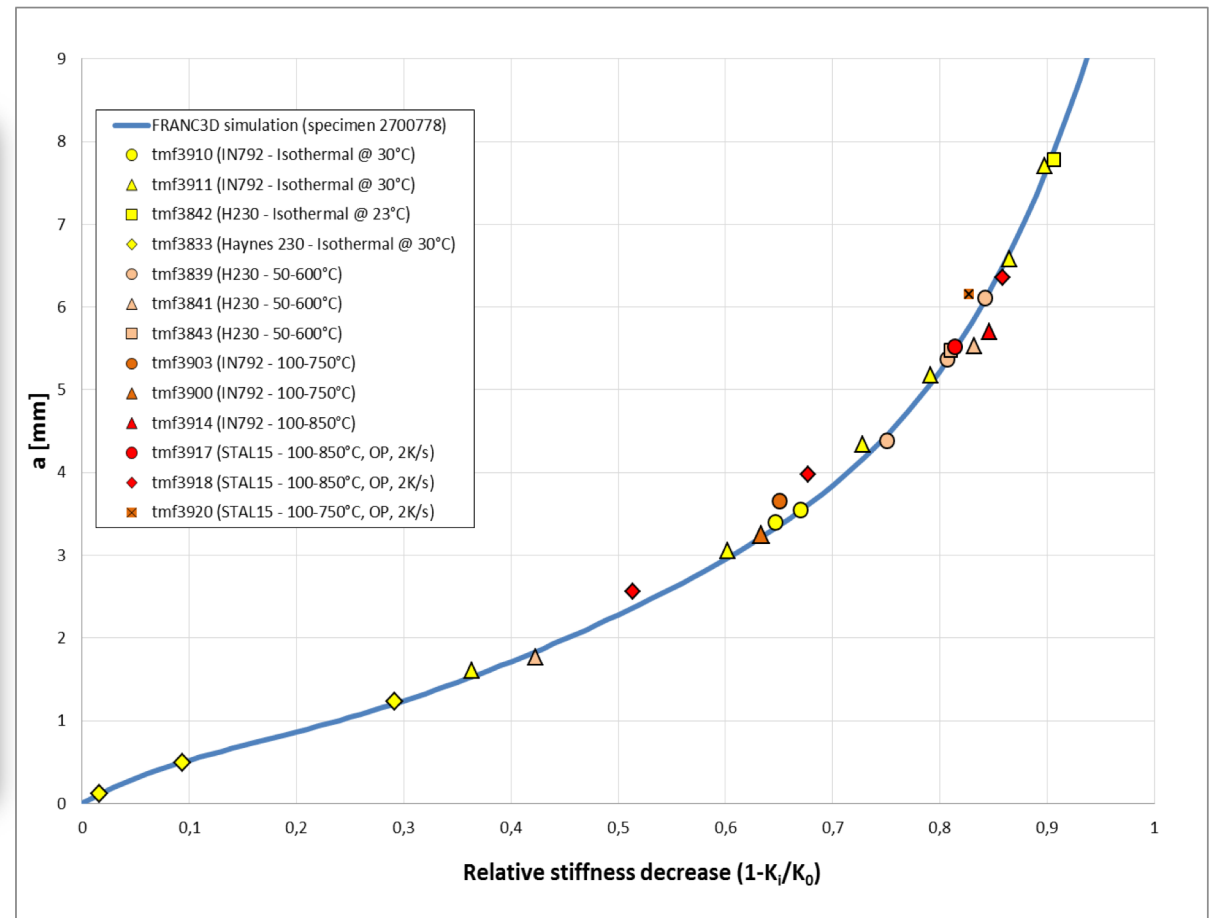
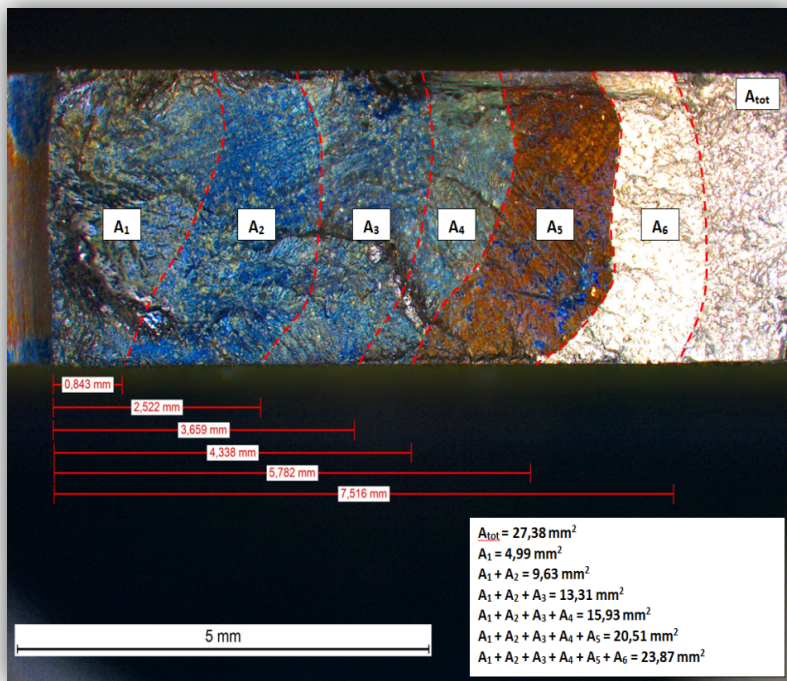
Testing methods - Overview

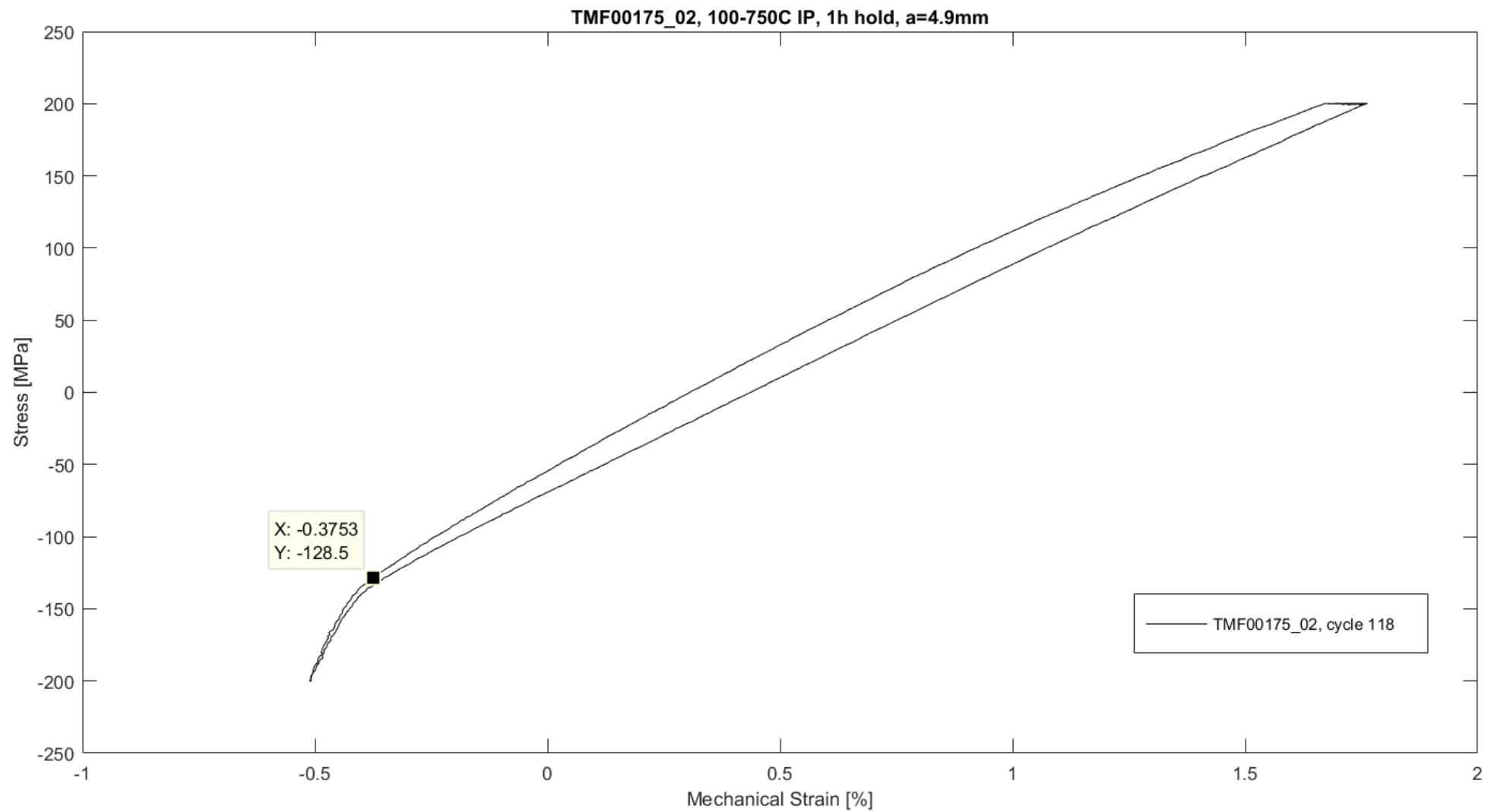
	Kb	DCT	SEN-FSP	SEN-ORL
Isothermal				
TMF				

TMF testing - setup



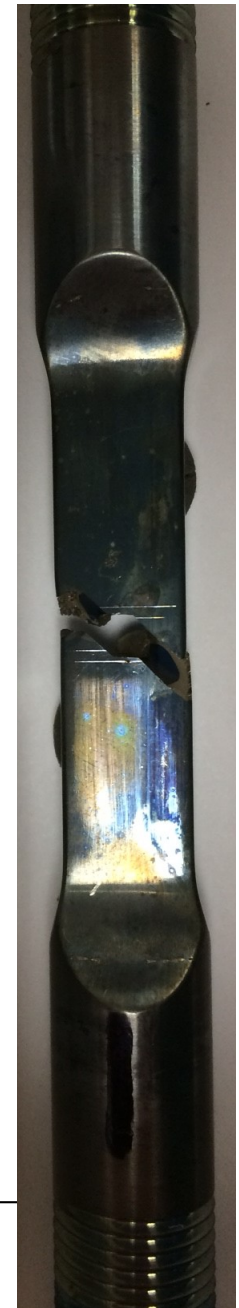
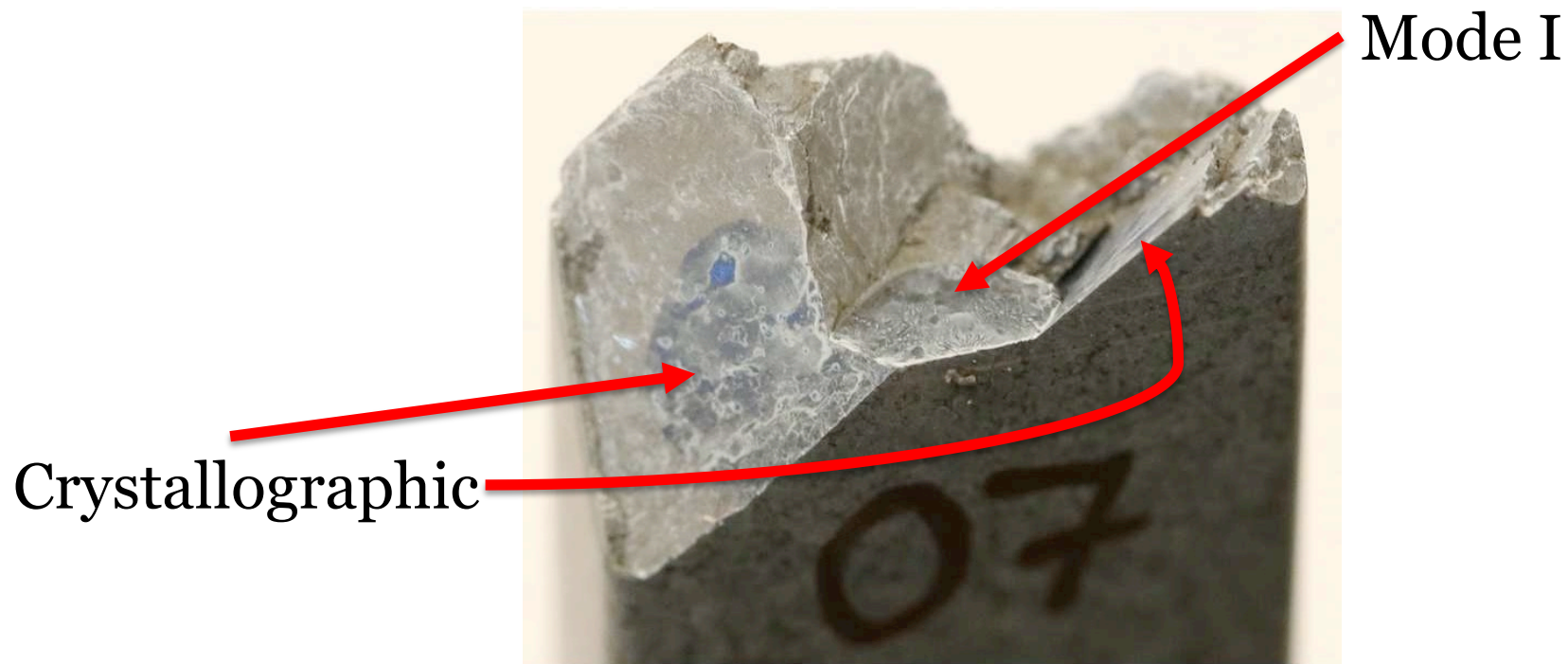
TMF testing – crack length measurement





Fracture Behaviour

- Cracks tend to transition from Mode I cracking to crystallographic cracking



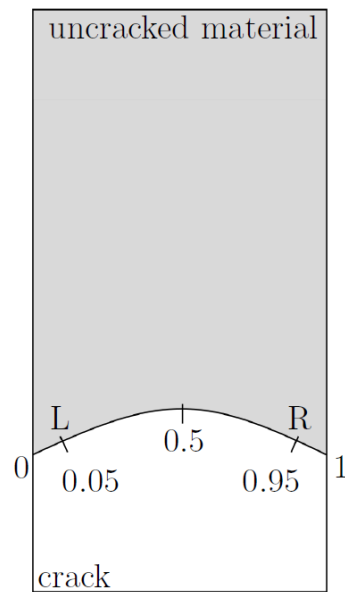
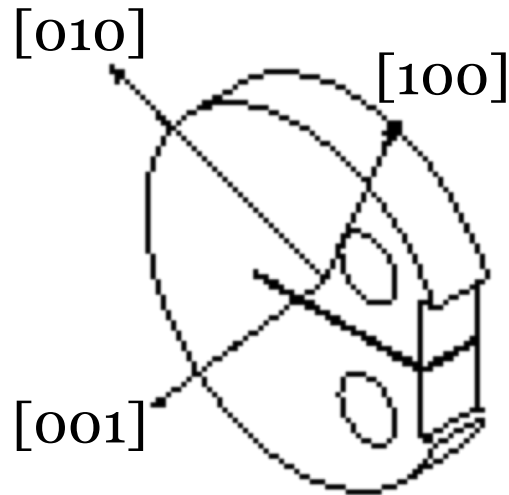
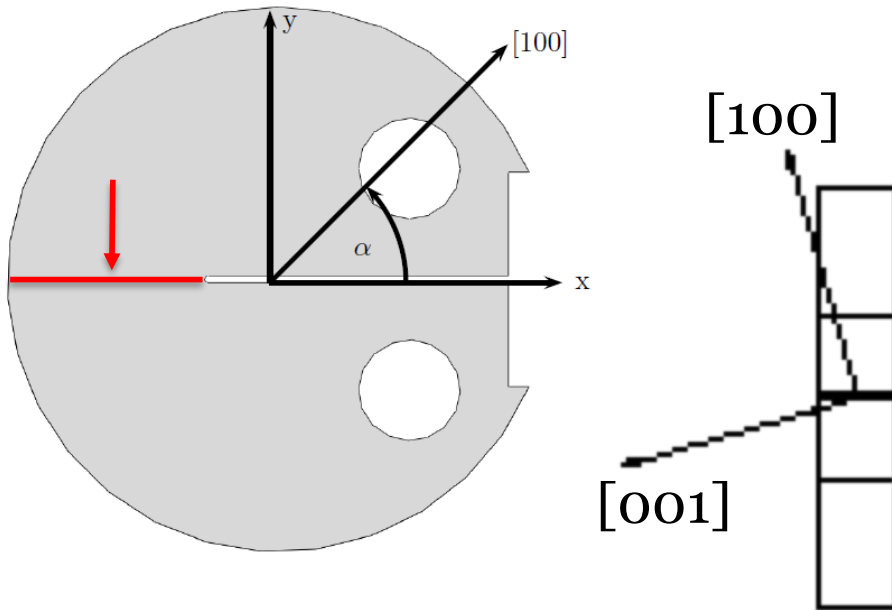
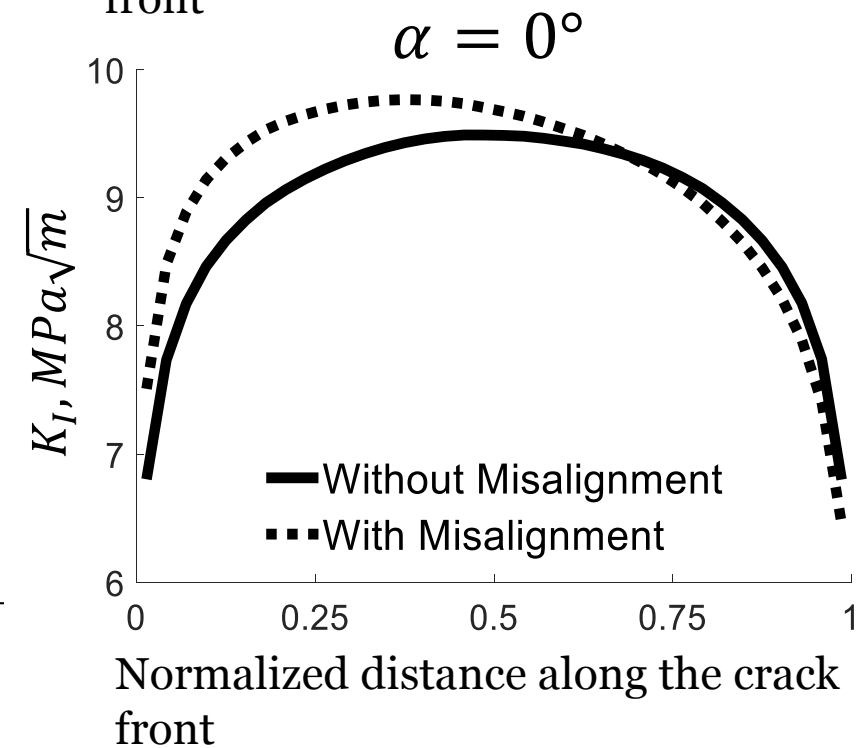
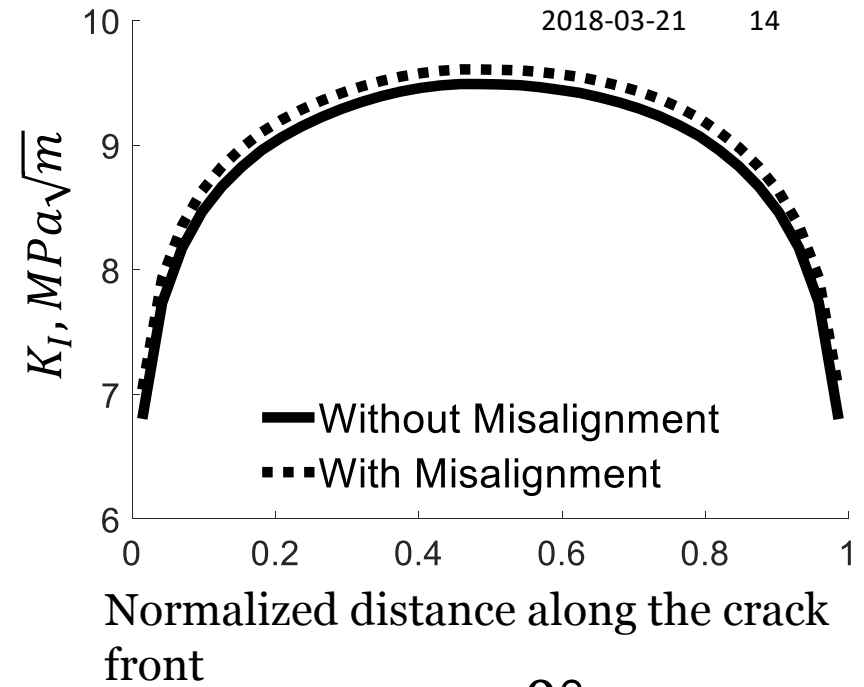
Modelling

- Develop crack growth models and life prediction methodologies that will reduce the need for high safety margins
- Prediction of
 - **When** the cracking mode transition occurs
 - **Which** crystallographic plane it transitions to
 - **How** fast it grows on the crystallographic plane

$\alpha = 90^\circ$

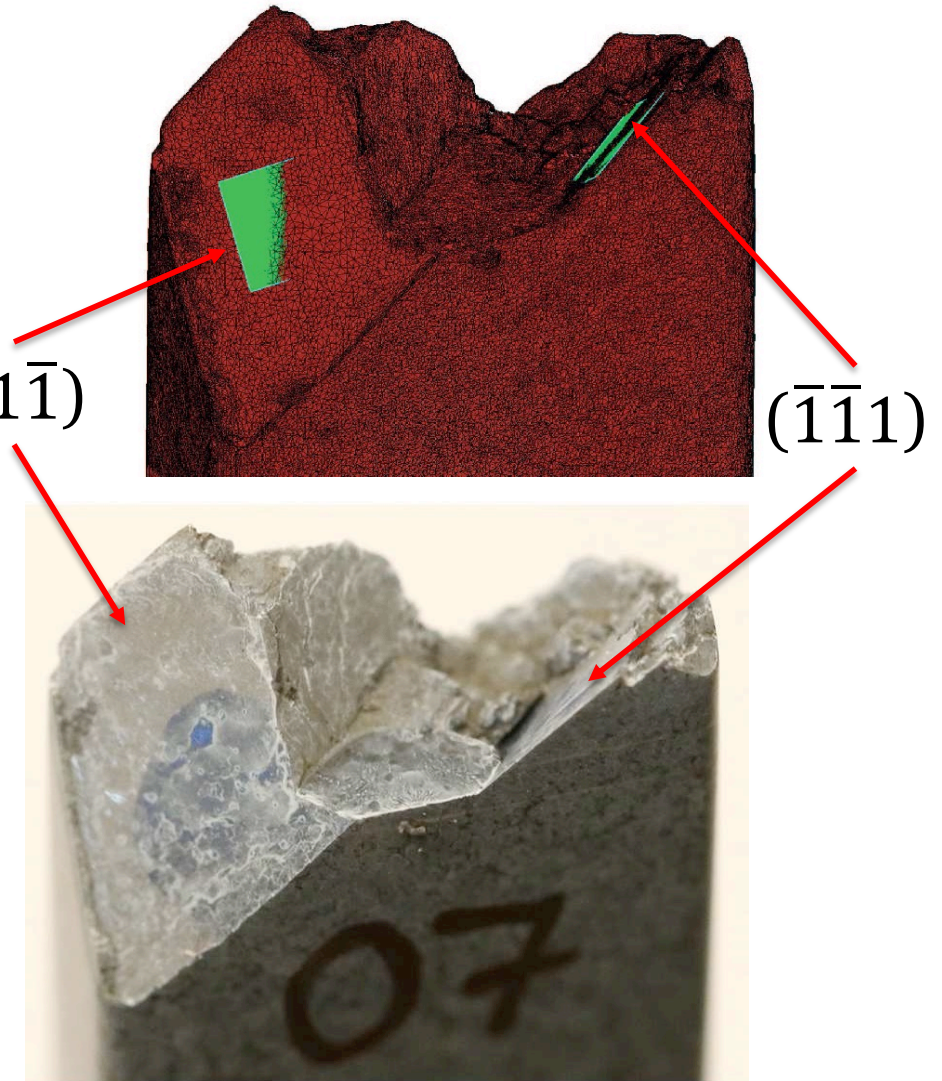
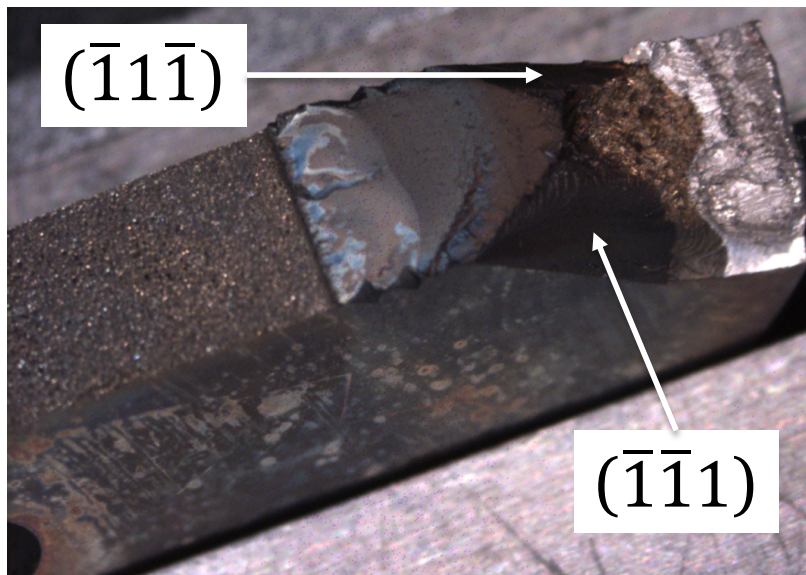
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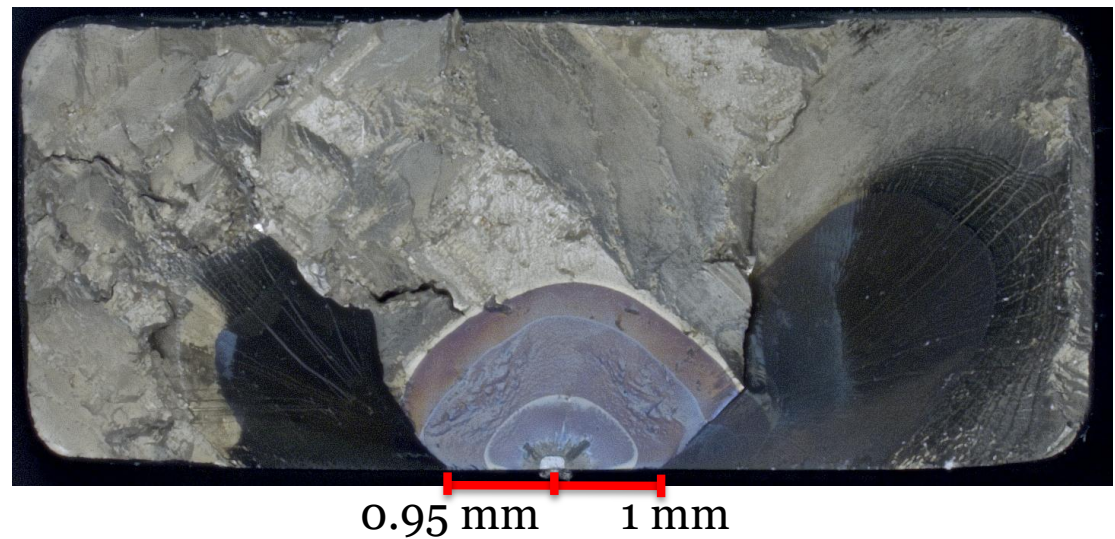
Fracture Surfaces

- Determination of crystallographic planes $(\bar{1}1\bar{1})$



Transition crack lengths

- Transition crack lengths measurements
- First global crystallographic plane



Resolved Stress Intensity Factors

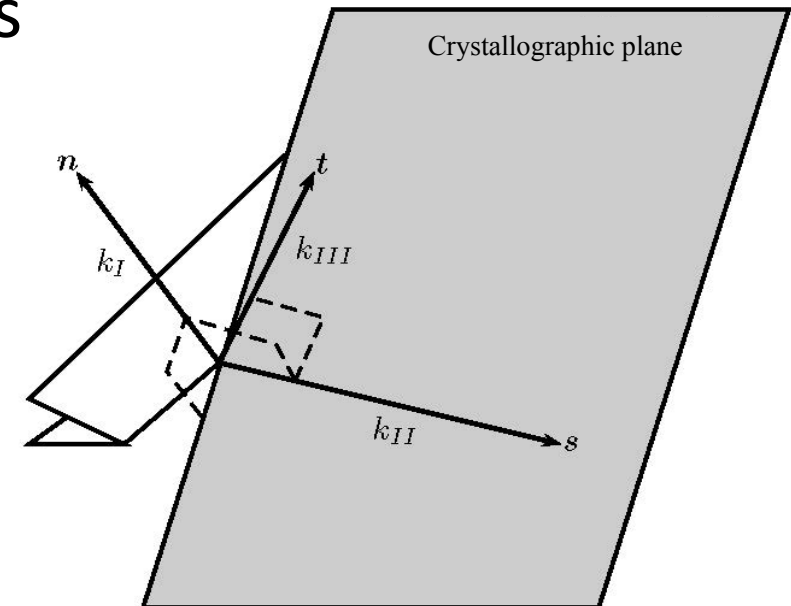
- Resolved SIFs

$$k_I(n, s) = \lim_{r \rightarrow 0} \sqrt{2\pi r} n \cdot \sigma(s) \cdot n$$

$$k_{II}(n, s) = \lim_{r \rightarrow 0} \sqrt{2\pi r} s \cdot \sigma(s) \cdot n$$

$$k_{III}(n, s) = \lim_{r \rightarrow 0} \sqrt{2\pi r} t \cdot \sigma(s) \cdot n$$

- $t = n \times s$
- s is taken to be the Burgers' directions
- Describing the three modes of fracture on an arbitrary plane



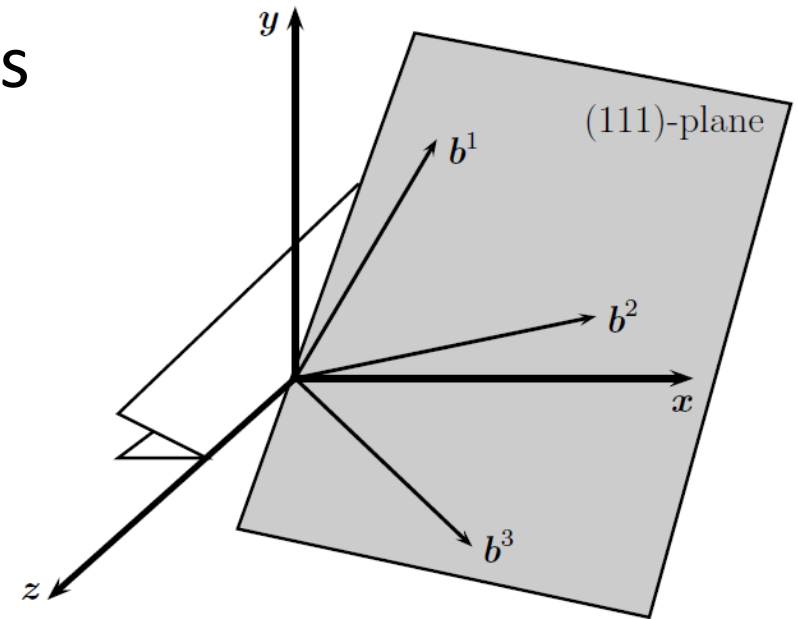
Resolved Stress Intensity Factors

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$$k_{III}(n, s) = \lim_{r \rightarrow 0} \sqrt{2\pi r} t \cdot \sigma(s) \cdot n$$



- Evaluation direction **s** to be in Burgers' directions **b**
 - Physically inspired by micromechanisms
 - Directions of least resistance to dislocation motion

Resolved Stress Intensity Factors

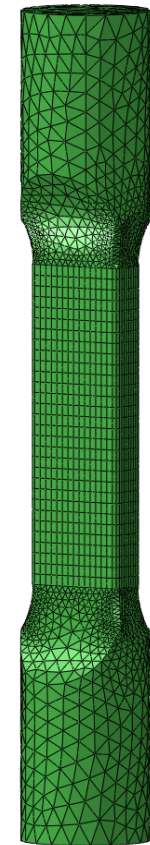
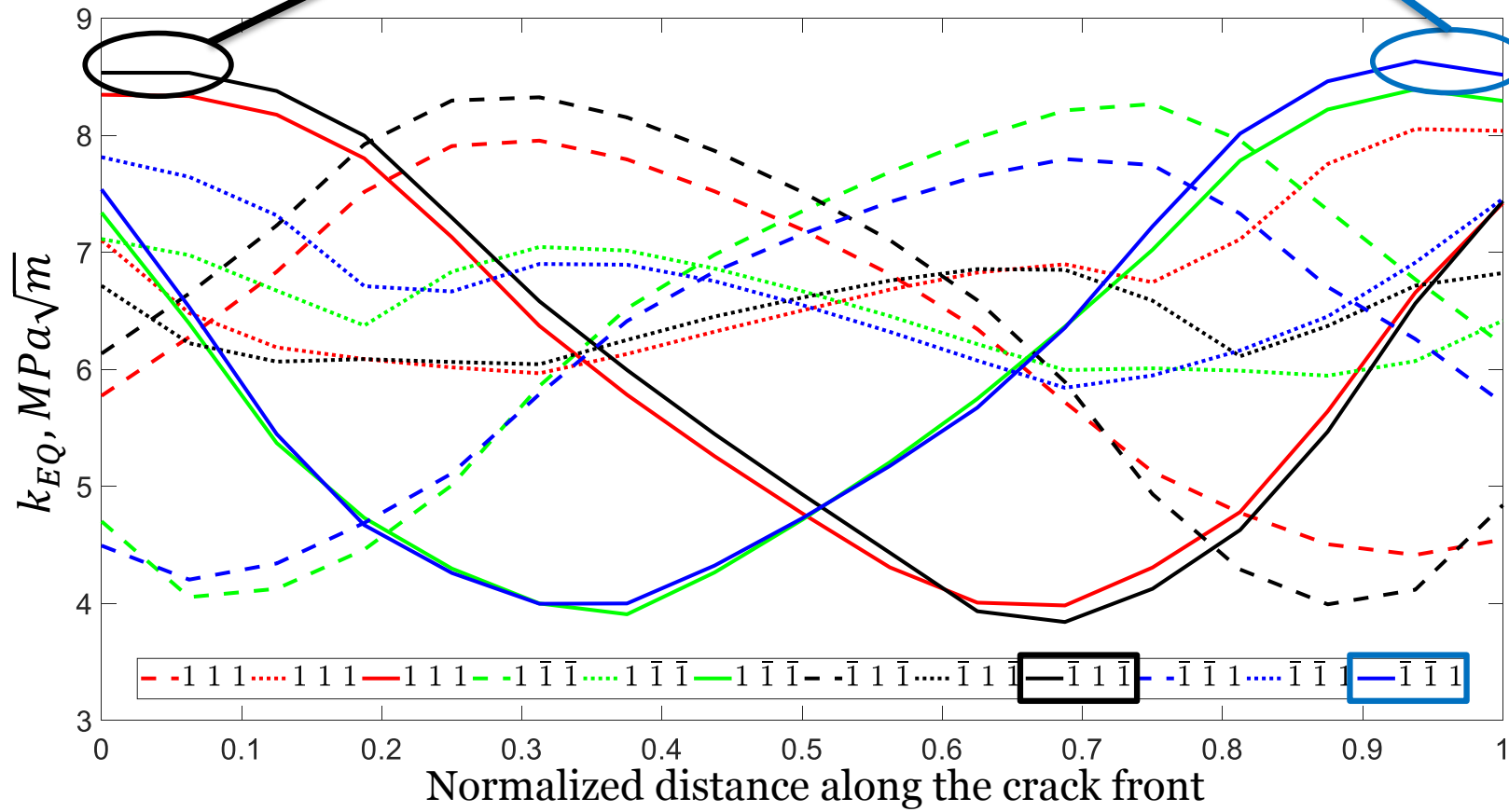
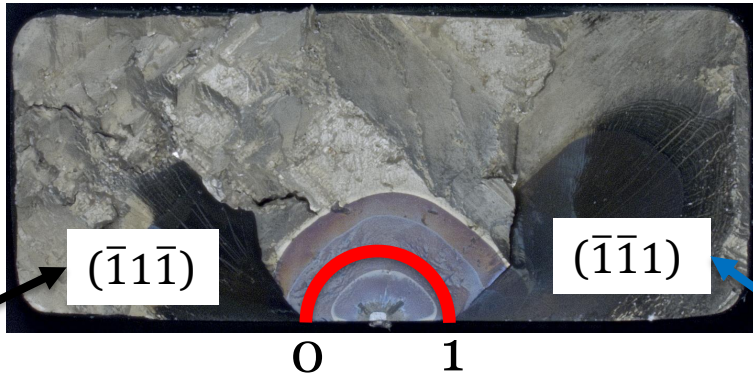
- Equivalent RSIF

$$k_{EQ} = \sqrt{\psi k_I^2 + k_{II}^2 + k_{III}^2}$$

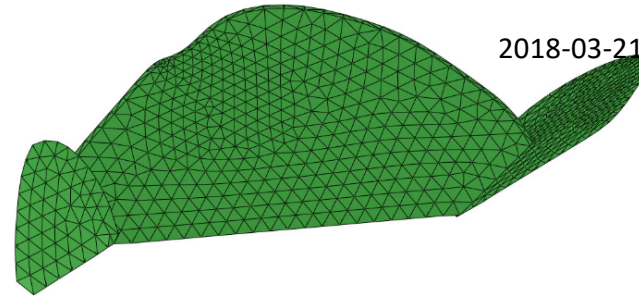
where ψ is a calibration parameters based on the experiments

- Resolved shear stresses weaken the crystallographic planes by dislocation motion
- Resolved normal stresses facilitate dislocation motion

RSIF results



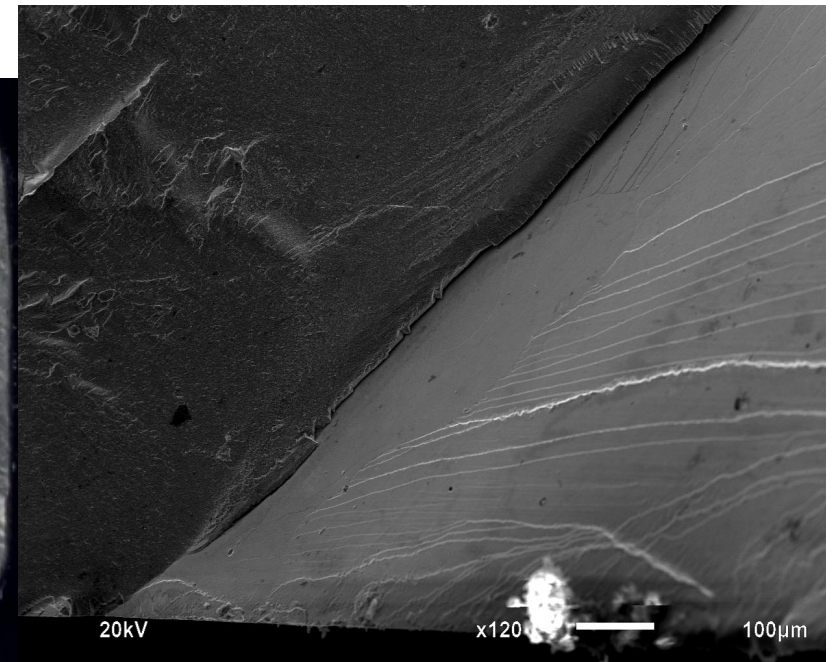
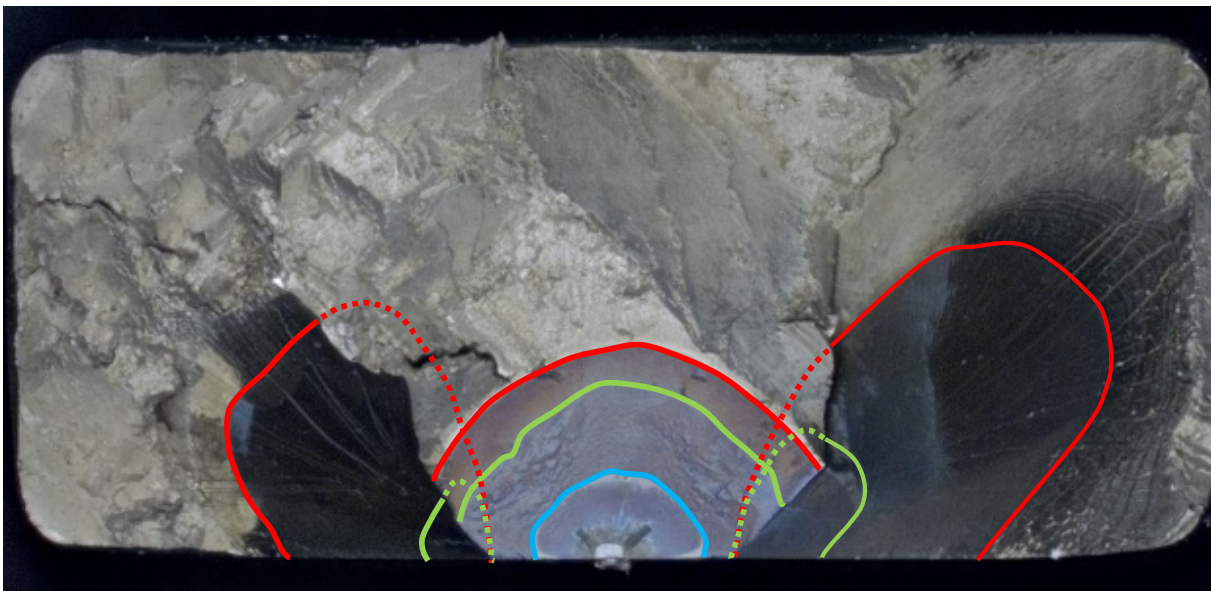
Crack propagation rate



- Evaluation of crystallographic crack growth rate

$$\frac{dL}{dN} = C_c (k_{EQ})^{n_c},$$

- RSIF used in crack growth model as proposed by Paris
- 3D crack geometry with three crack fronts



Conclusions

- A good prediction of the experiments was accomplished with the developed RSIF.
- The crystal orientation has a strong influence on the stress response and propensity for crystallographic cracking.
- The method to evaluate the TMF crack growth has been verified for different test conditions.
- The crack closure has a high impact on the crack growth rate at higher temperatures.

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