KME-702

LCF and TMF crack growth in cast nickel-based Superalloys

Johan Moverare

LINKÖPING UNIVERSITY

SIEMENS

Project group

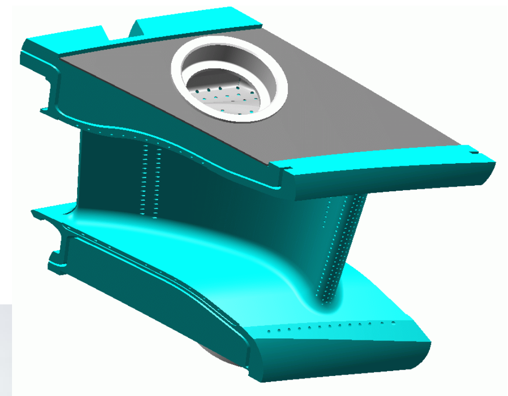
- Christian Busse, PhD student LiU
- Frans Palmert, Industrial PhD student Siemens/LiU
- Johan Moverare, Project leader LiU
- Daniel Leidermark, LiU
- Mikael Segersäll, LiU
- Kjell Simonsson, LiU
- David Gustafsson, Siemens
- Per Almroth, Siemens
- Björn Sjödin, Siemens

Reference group

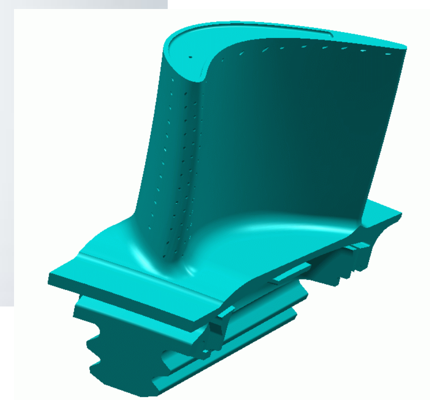
- Rikard Norling, Swerea
- Magnus Hörnqvist-Colliander, Chalmers

Focus of research

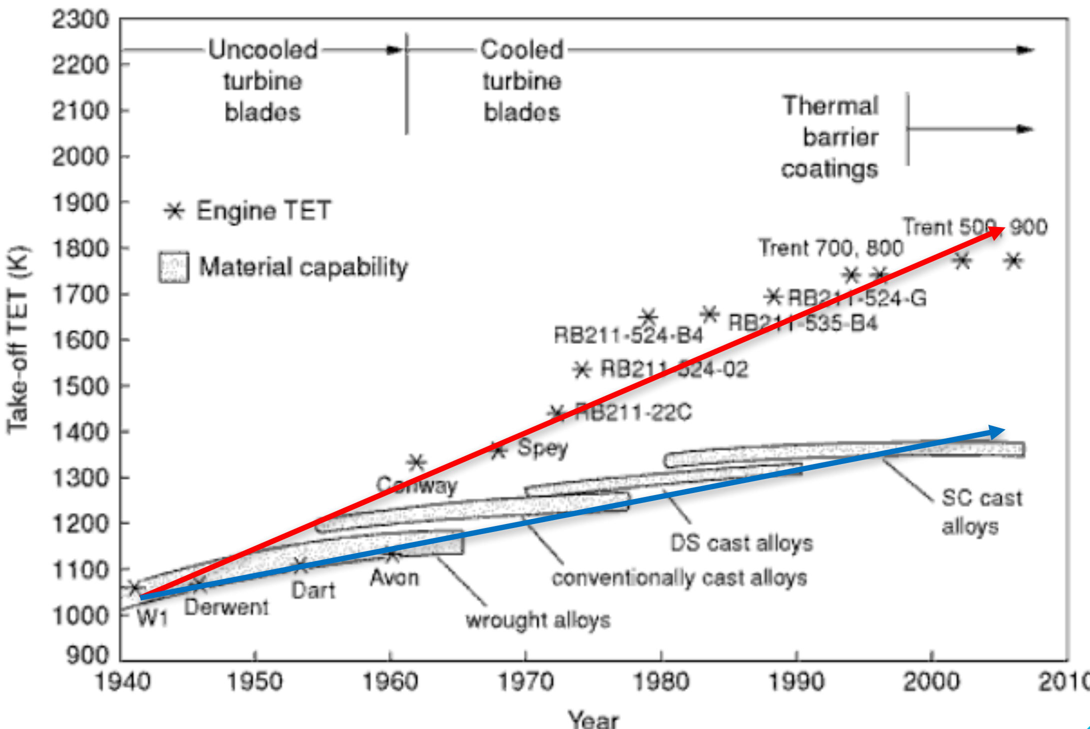
Efficient and robust gas turbines with high flexibility with respect to fuel and cyclic operation

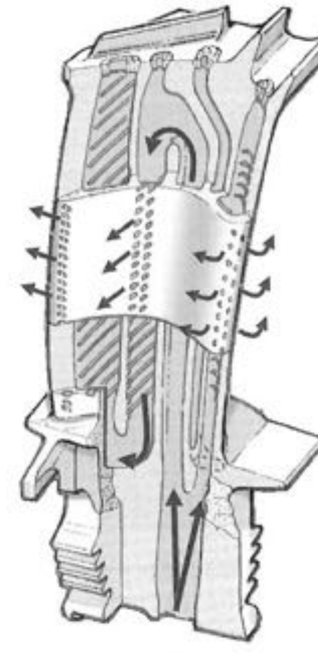


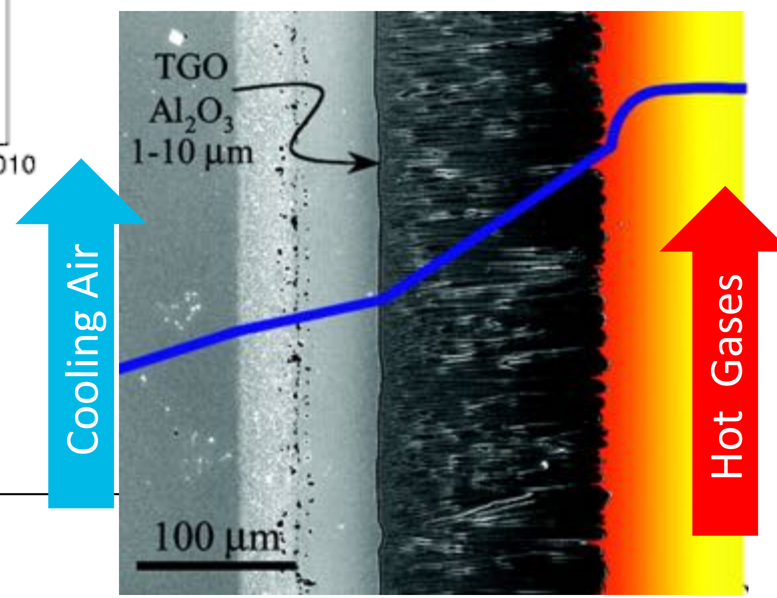
Siemens SGT-800



Engine development







Evolution of the turbine entry temperature (TET) capability of Rolls-Royce's civil aeroengines, from 1940 to the present day

How to achieve high durability of gas turbine blades

Possible failure modes	Possible solutions
• Oxidation	• Increased Al-content Use coatings
• Corrosion	• Increased Cr-content Use coatings
• Creep	• Hardening mechanisms Component design
• Fatigue	• How to improve alloys ?? Component design Operating condition

+

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Increased demand for cyclic operation

- Traditional gas turbines are originally designed primarily for base load operation
- Due to new market conditions and the introduction of more intermittent energy sources (e.g. wind and solar power) the **operational flexibility** of gas turbines must increase.

➔ More start and stop cycles
➔ Fatigue problems

Alloys of interest for KME-702

IN792

Traditional industrial gasturbine alloys

12.5 wt%Cr

3.4 wt%Al

+ more

STAL15SX

New alloy design for industrial gasturbines

15.5 wt%Cr

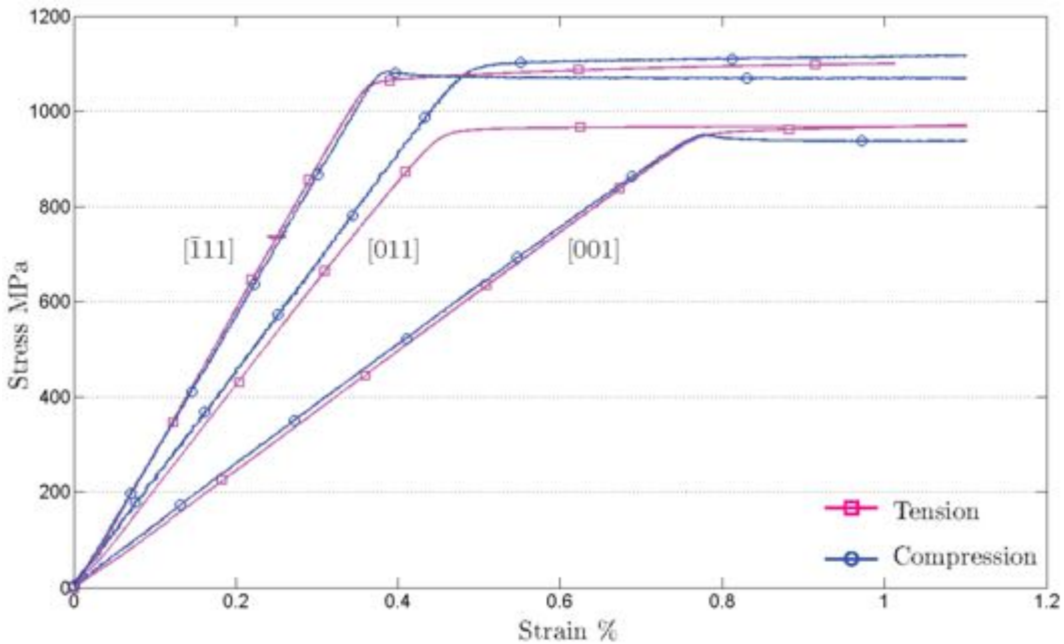
4.6 wt%Al

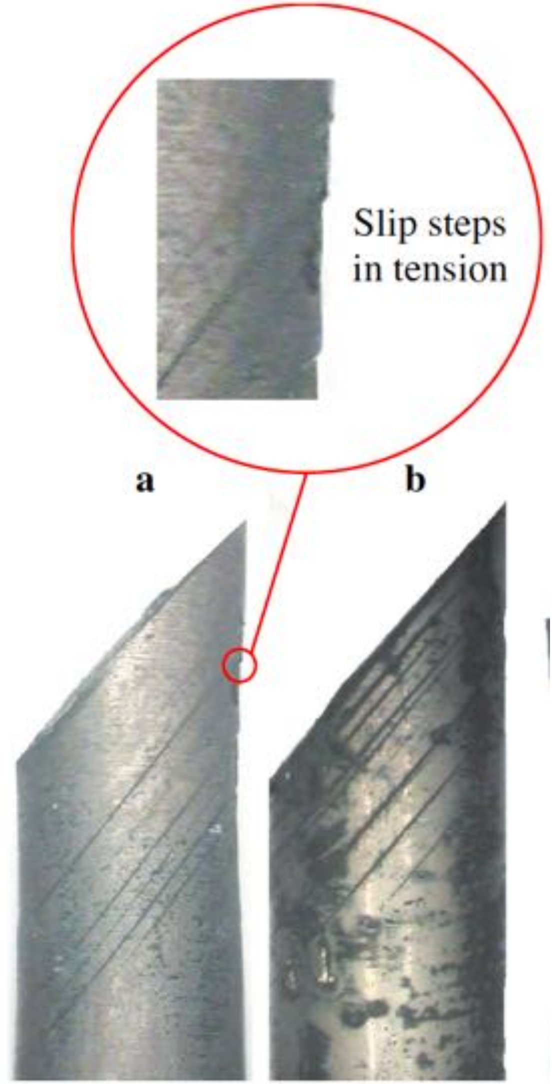
0.25 wt%Si + more

Thus an alloy that enables fuel flexibility and higher operating temperatures

Single crystal superalloys

- Elastic anisotropy
- Plastic anisotropy
- Tension/compression-asymmetry
- Crystallografic deformation and failure





In KME-702 focus is on fatigue crack propagation

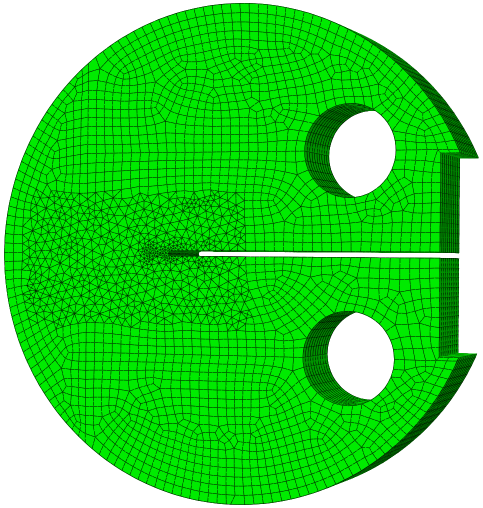
Key objectives of KME-702

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.

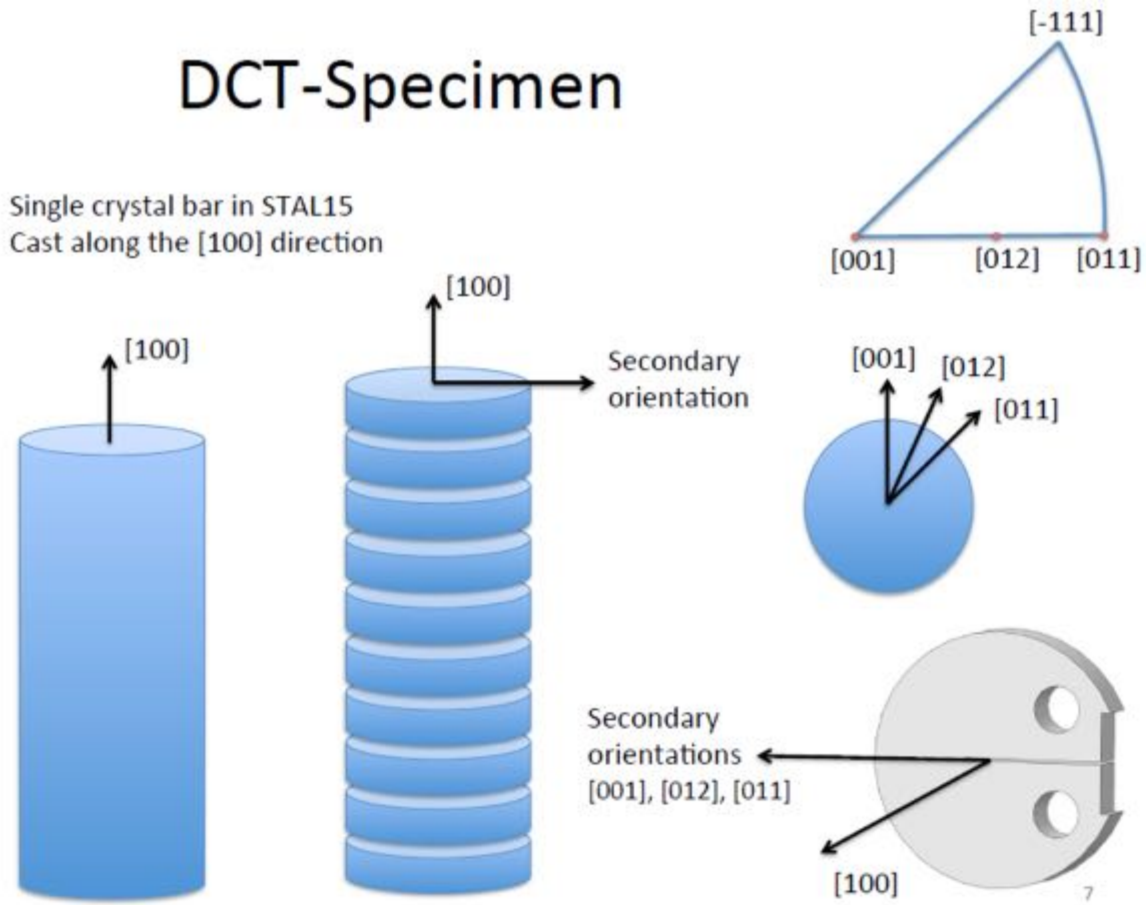
Isothermal testing and modeling

DCT

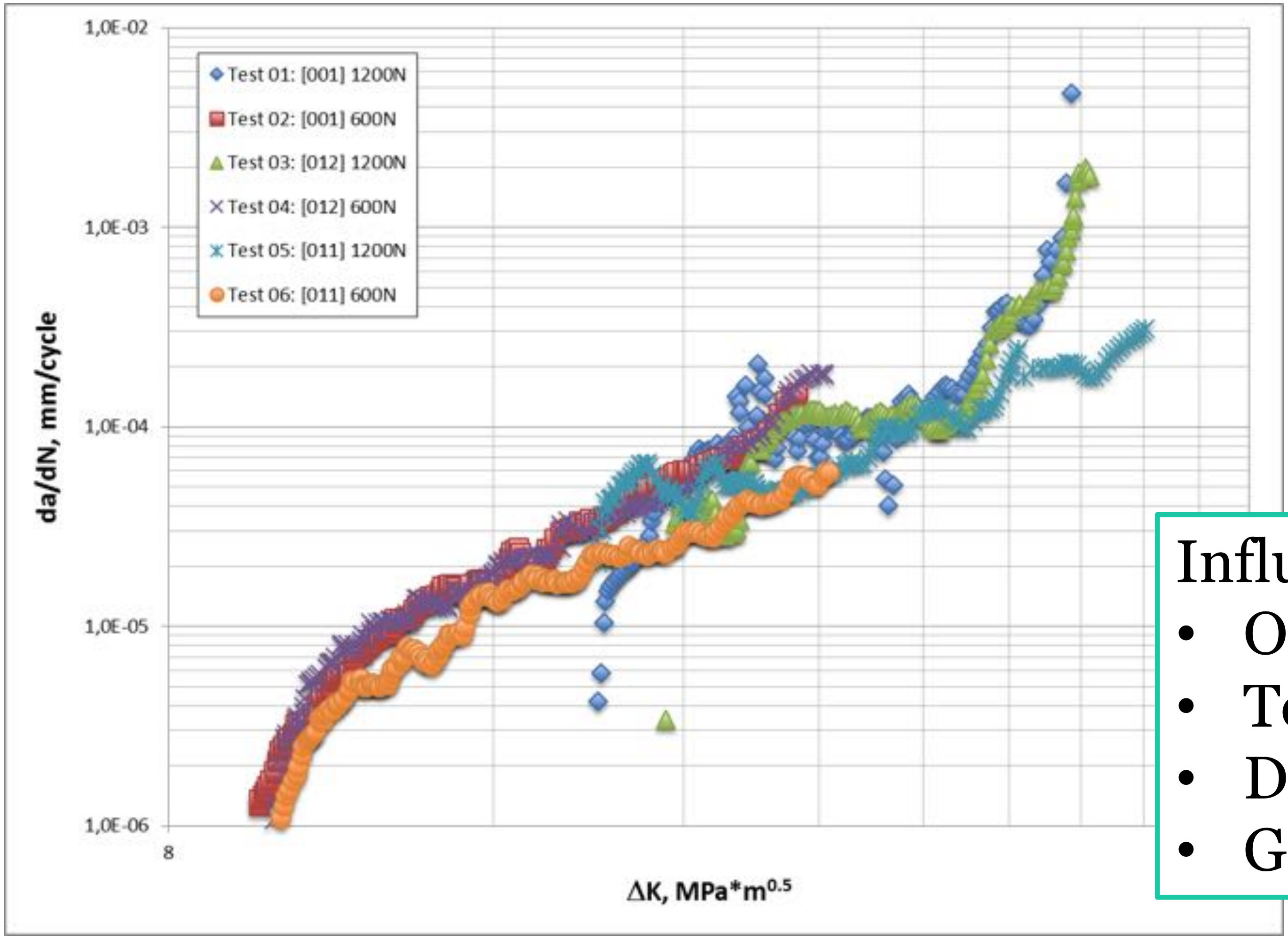
Kb



Crack growth testing using DCT-specimens



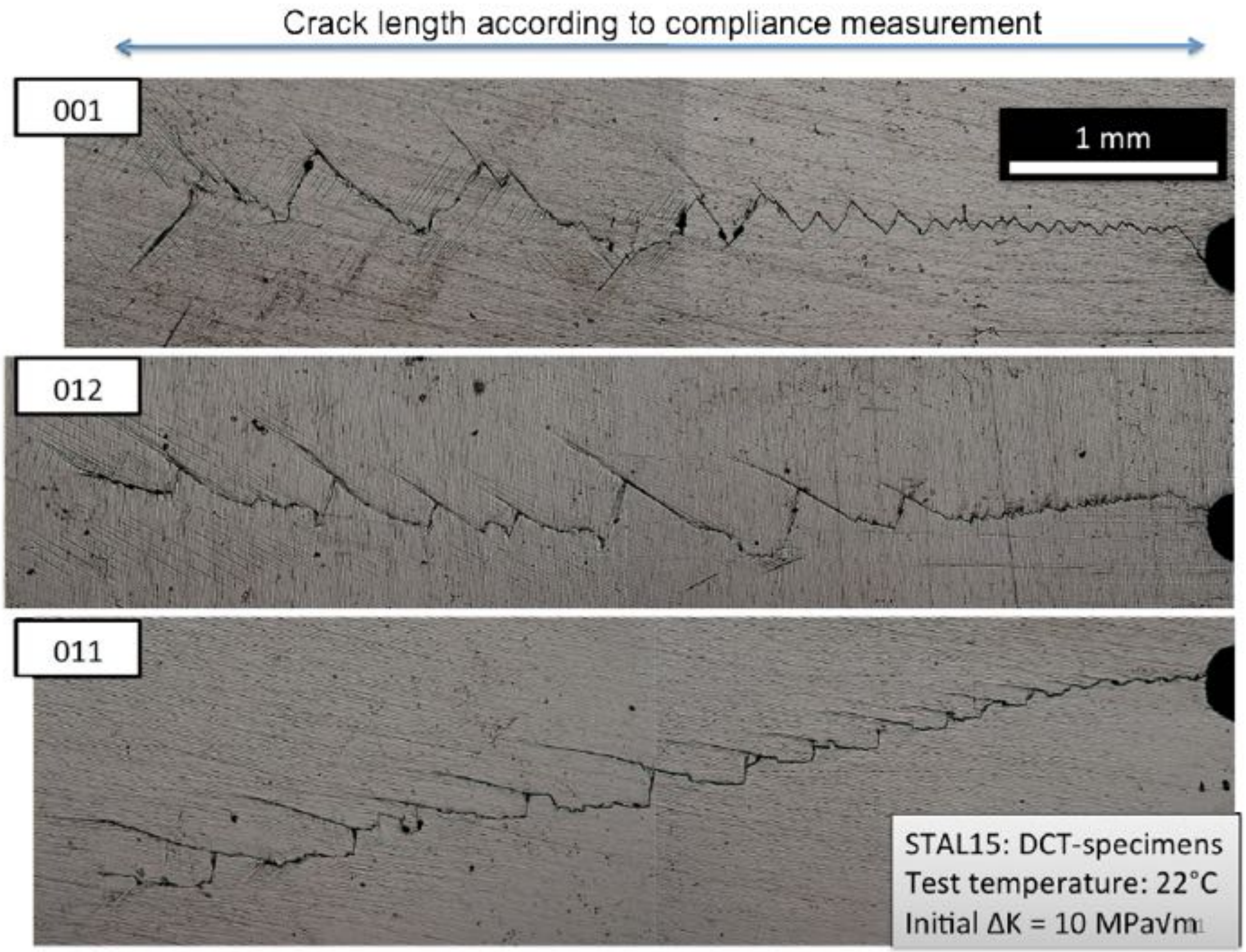
Crack propagation data has been generated



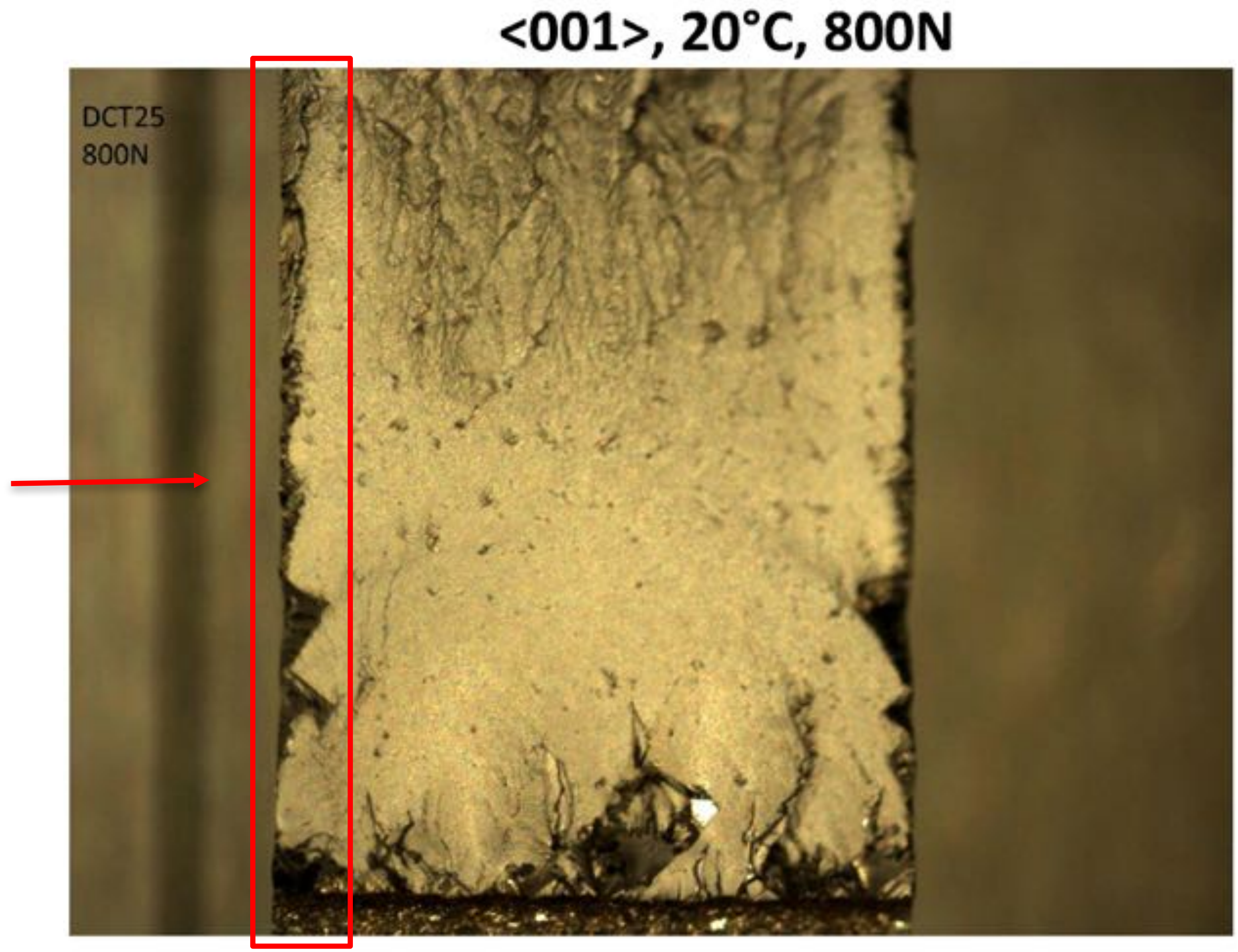
Influence of:

- Orientation
- Temperature
- Dwell type
- Geometry

Crack appearance

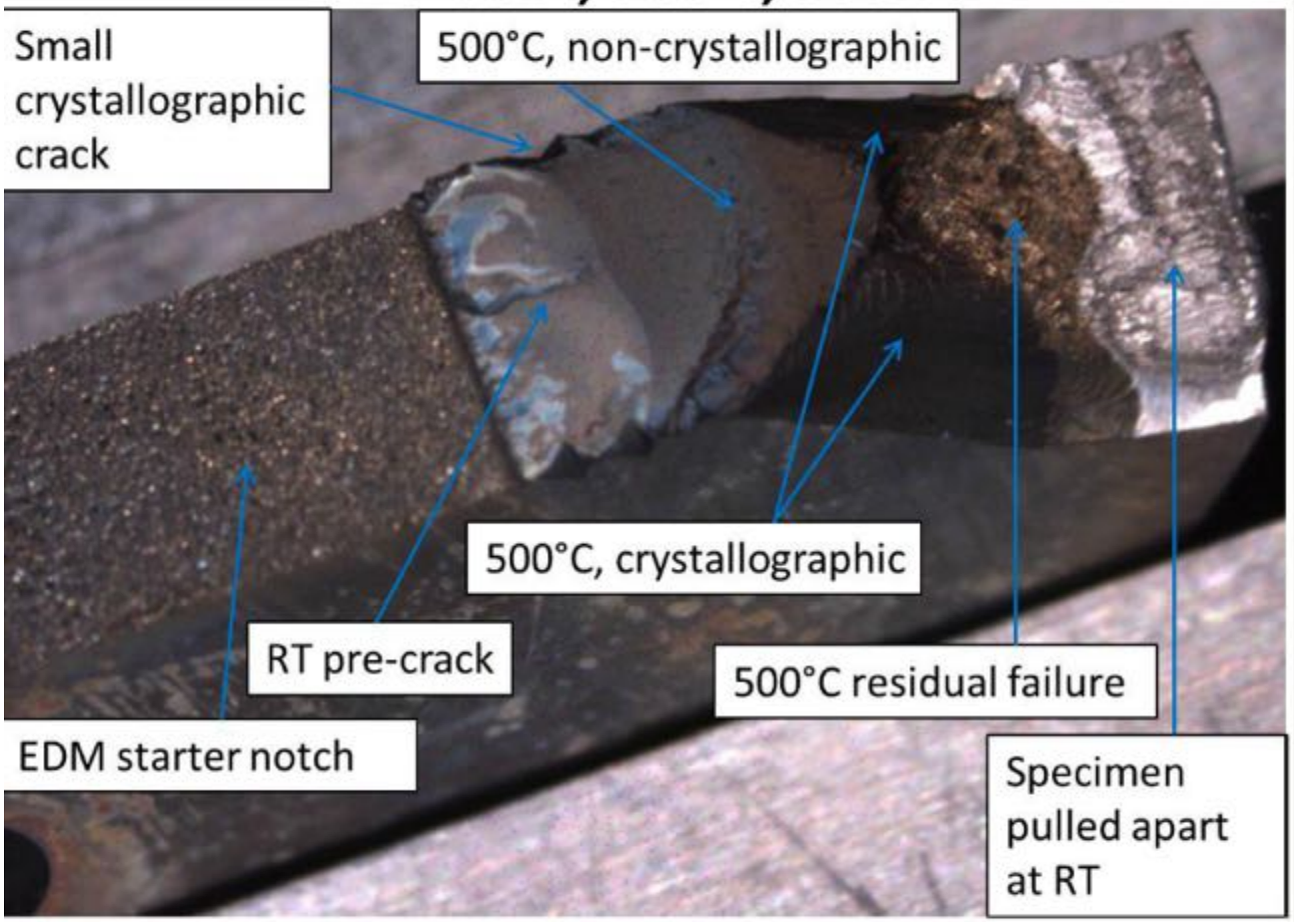


Fracture appearance

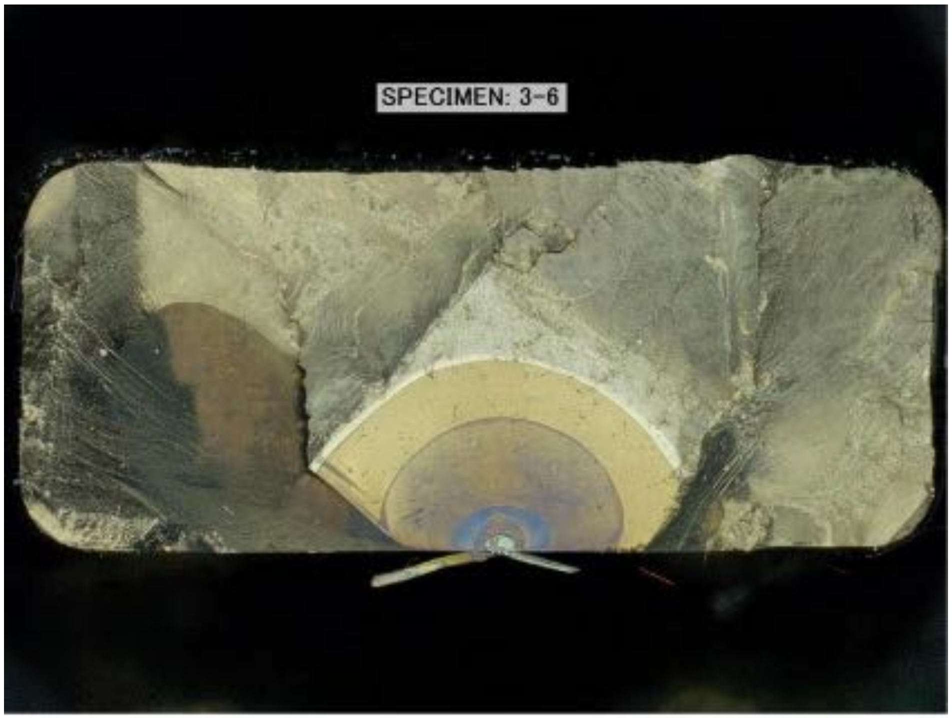


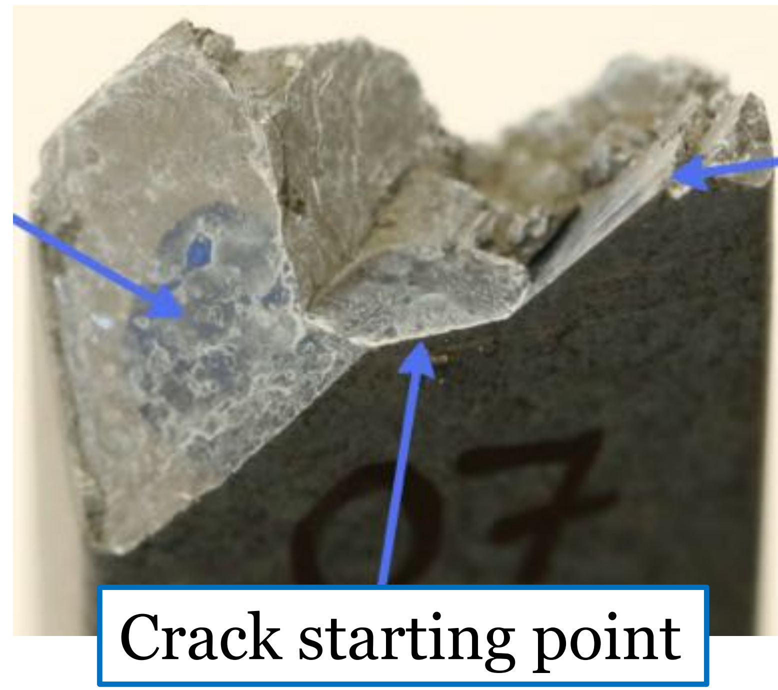
Fracture appearance

<001>, 500°C, 900N

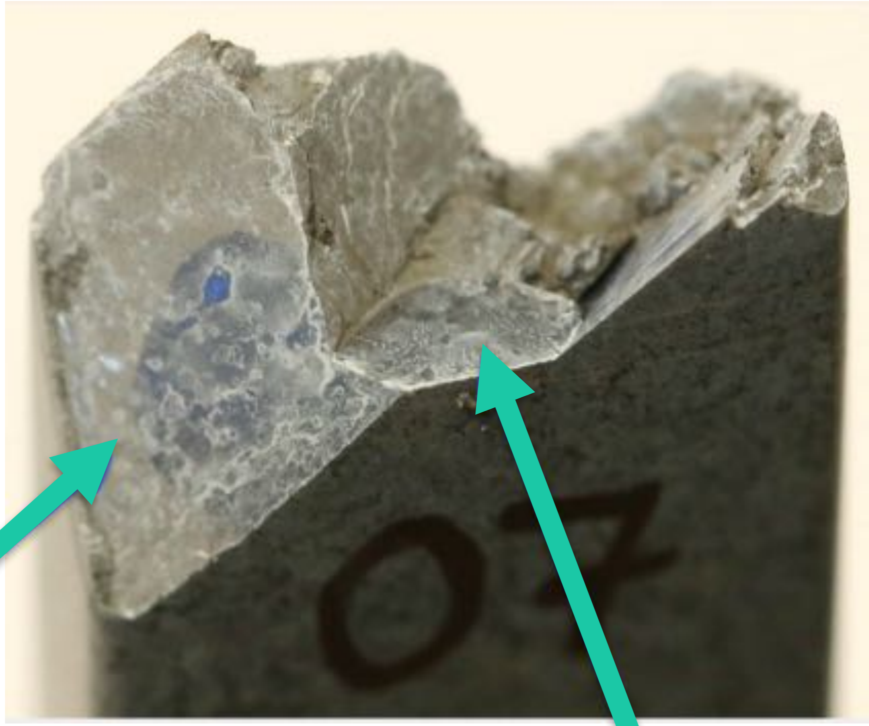


Fracture appearance in for the Kb specimens





Two types of cracking behaviour

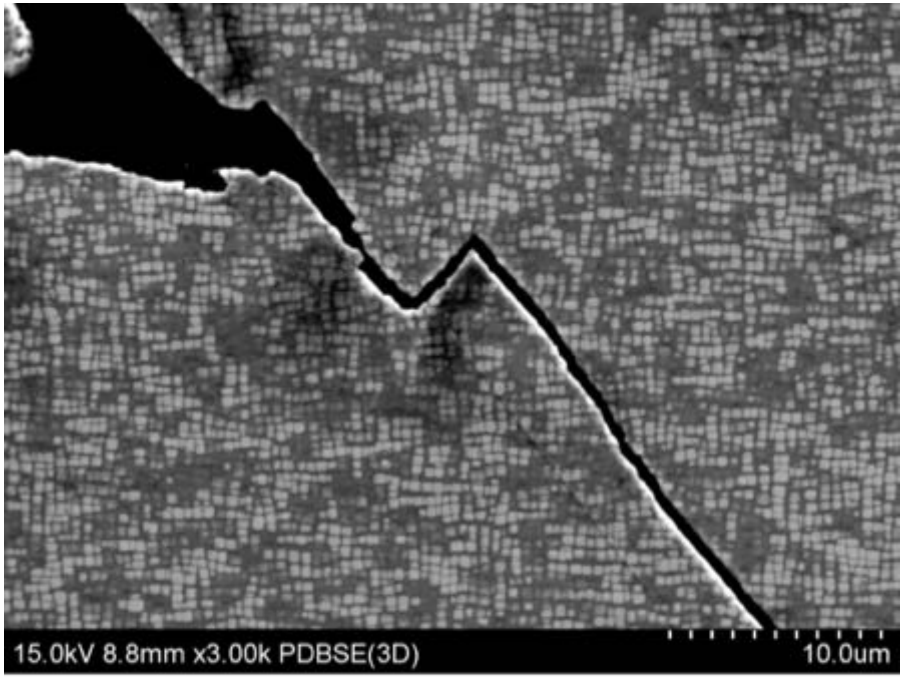


Crystallographic

Mode I

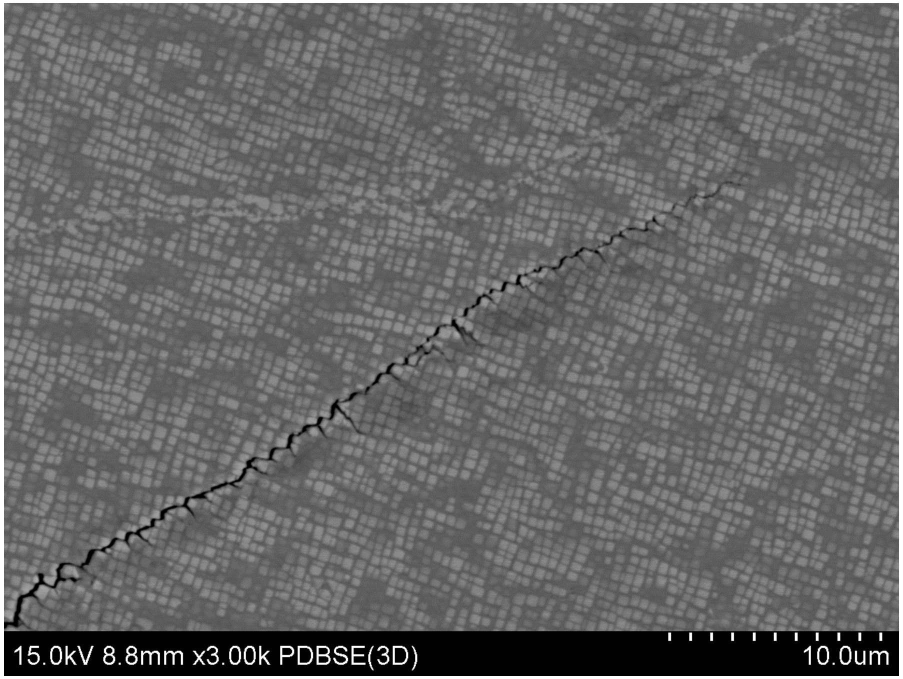
Crystallographic cracking

- Primarily at lower temperature
- Or higher stress
- Cutting through the precipitates
- Particles are weak



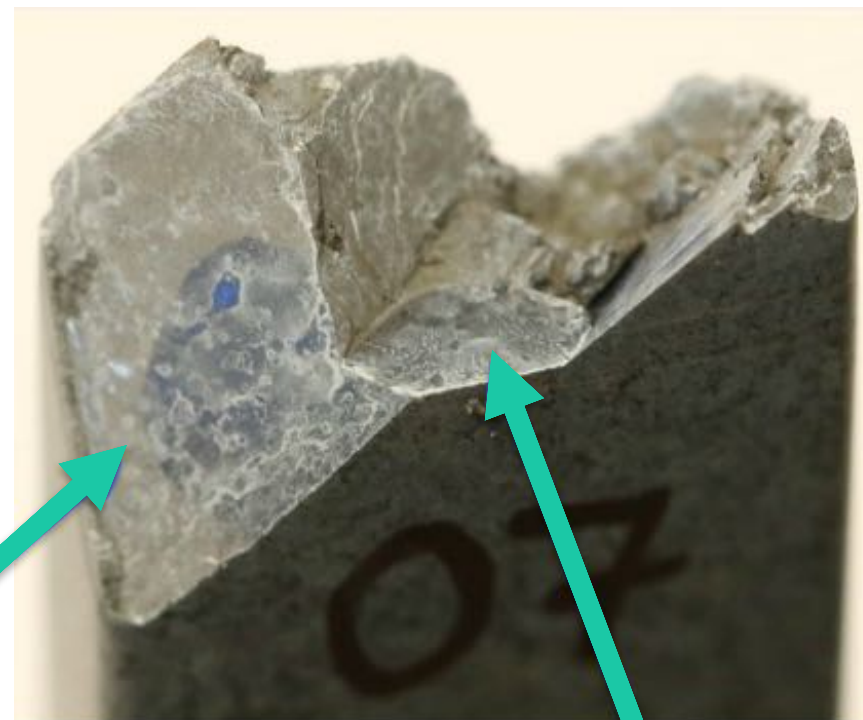
Mode I cracking

- Primarily at higher temperatures
- Or lower stress
- Cracking mainly in the matrix
- Particles are strong



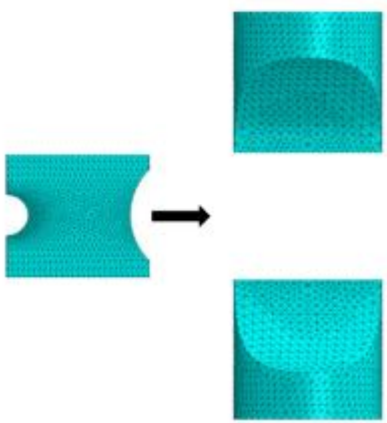
- What governs the transition from Mode I to crystallographic cracking and how can it be predicted?

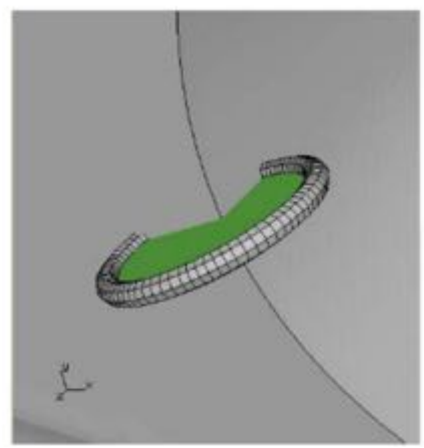
- How can we model the crack propagation?



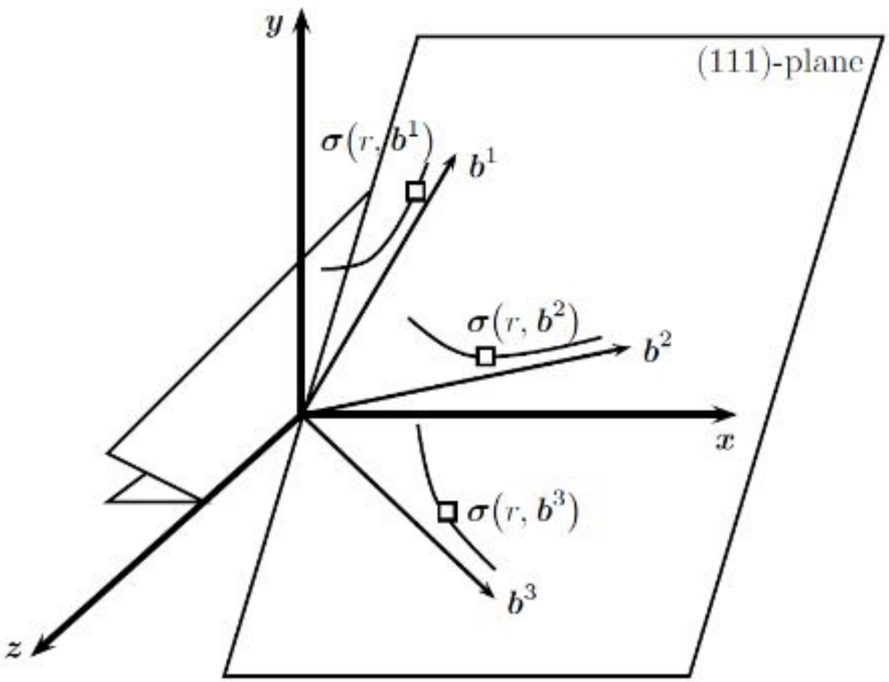
FRANC 3D

- Supports automated crack growth in an FE mesh
- Uses power of external FE codes (eg Abaqus or Ansys)
- Possibility to extract su-model





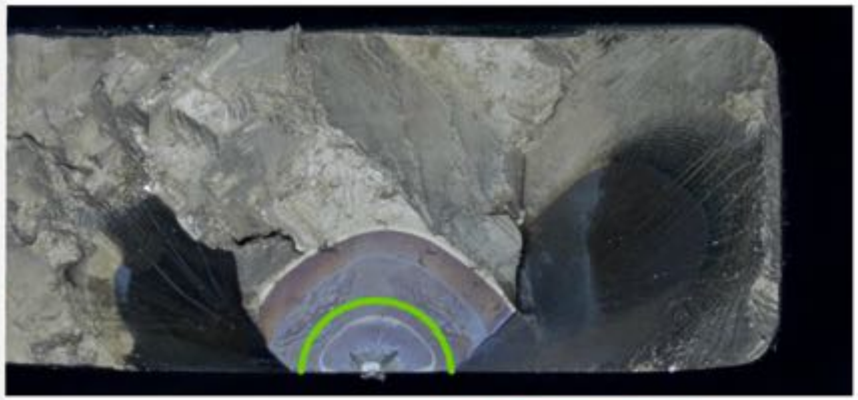
How to evaluate crystallographic crack growth

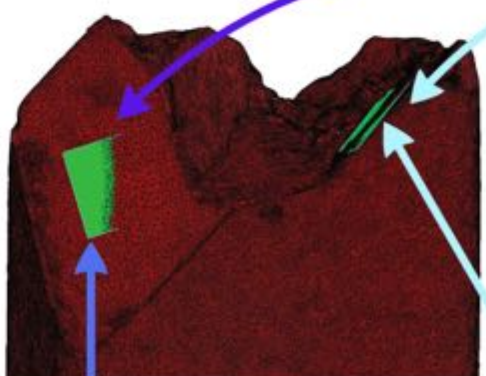


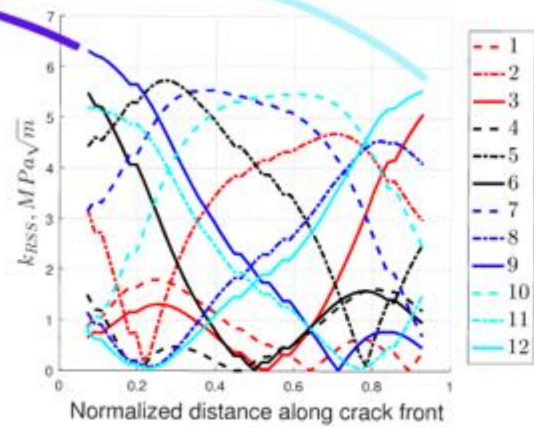
α	τ_{pb}^{α}
1	$(1\,1\,1)[0\,1\,\bar{1}]$
2	$(1\,1\,1)[\bar{1}\,0\,1]$
3	$(1\,1\,1)[1\,\bar{1}\,0]$
4	$(1\,\bar{1}\,\bar{1})[0\,\bar{1}\,1]$
5	$(1\,\bar{1}\,\bar{1})[\bar{1}\,0\,\bar{1}]$
6	$(1\,\bar{1}\,\bar{1})[1\,1\,0]$
7	$(\bar{1}\,1\,\bar{1})[0\,1\,1]$
8	$(\bar{1}\,1\,\bar{1})[1\,0\,\bar{1}]$
9	$(\bar{1}\,1\,\bar{1})[\bar{1}\,\bar{1}\,0]$
10	$(\bar{1}\,\bar{1}\,1)[0\,\bar{1}\,\bar{1}]$
11	$(\bar{1}\,\bar{1}\,1)[1\,0\,1]$
12	$(\bar{1}\,\bar{1}\,1)[\bar{1}\,1\,0]$

Resolved stress intensity factors on crystal planes along the different burgers vectors

α	τ^{α}_{pb}
1	$(1\,1\,1)[0\,1\,\bar{1}]$
2	$(1\,1\,1)[\bar{1}\,0\,1]$
3	$(1\,1\,1)[1\,\bar{1}\,0]$
4	$(1\,\bar{1}\,\bar{1})[0\,\bar{1}\,1]$
5	$(1\,\bar{1}\,\bar{1})[\bar{1}\,0\,\bar{1}]$
6	$(1\,\bar{1}\,\bar{1})[1\,1\,0]$
7	$(\bar{1}\,1\,\bar{1})[0\,1\,1]$
8	$(\bar{1}\,1\,\bar{1})[1\,0\,\bar{1}]$
9	$(\bar{1}\,1\,\bar{1})[\bar{1}\,\bar{1}\,0]$
10	$(\bar{1}\,\bar{1}\,1)[0\,\bar{1}\,\bar{1}]$
11	$(\bar{1}\,\bar{1}\,1)[1\,0\,1]$
12	$(\bar{1}\,\bar{1}\,1)[\bar{1}\,1\,0]$

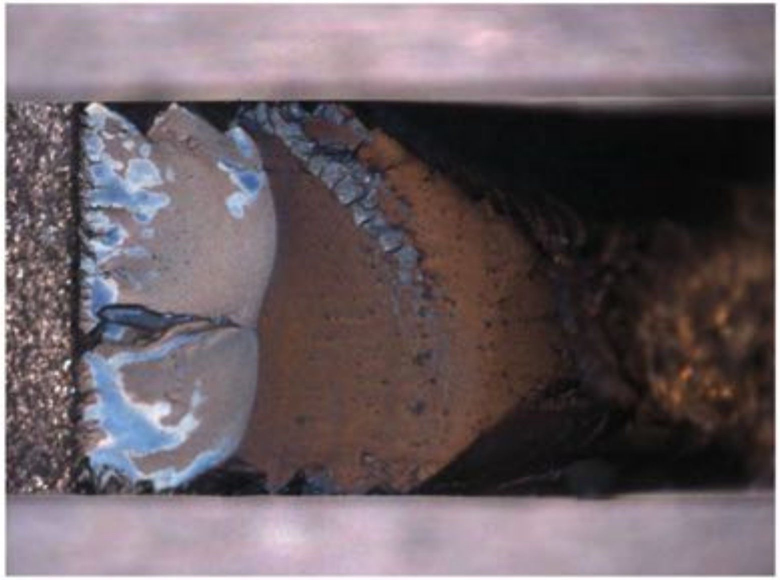




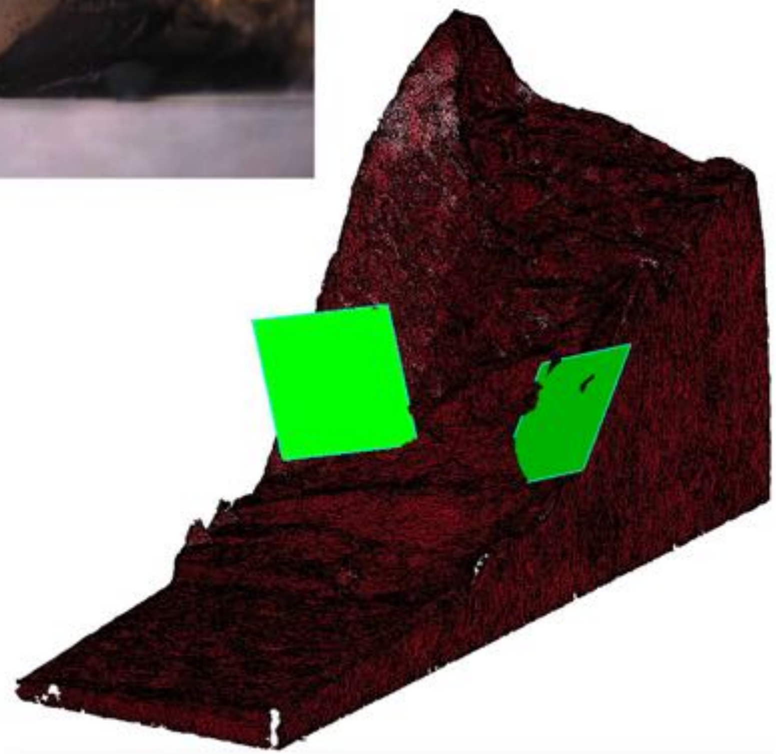


-11-1-plane

-1-11-plane



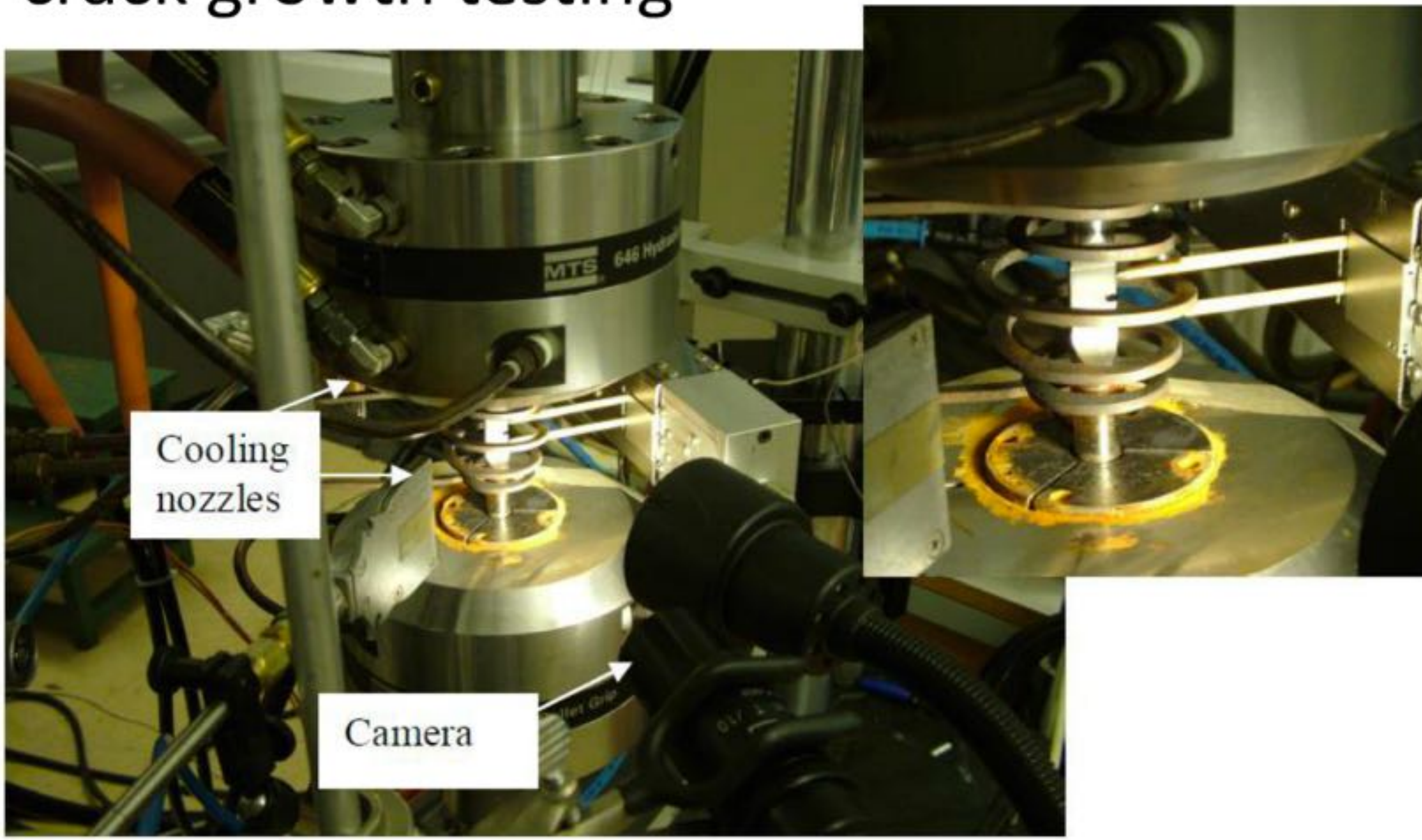
Same procedure
for DCT specimens



Other performed or ongoing activities

- TMF crack propagation testing
  - IN792
    - Validation of methods for TMF crack propagation predictions
    - Influence of dwell times
  - STAL15
    - Influence of cycle type IP/OP
    - Influence of dwell times
- Component near testing

TMF crack growth testing



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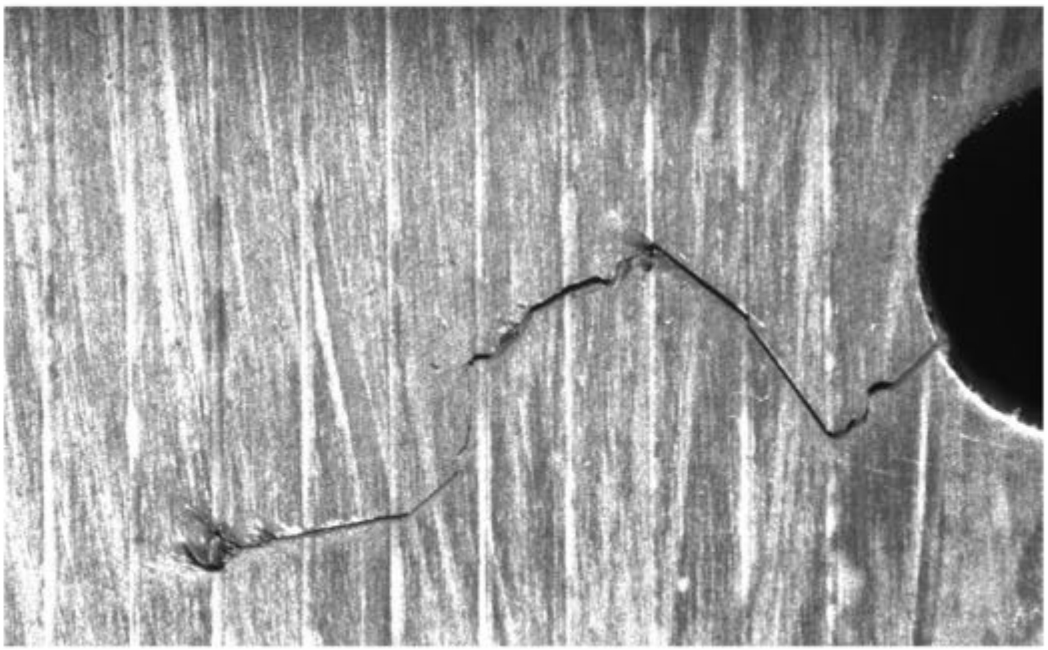
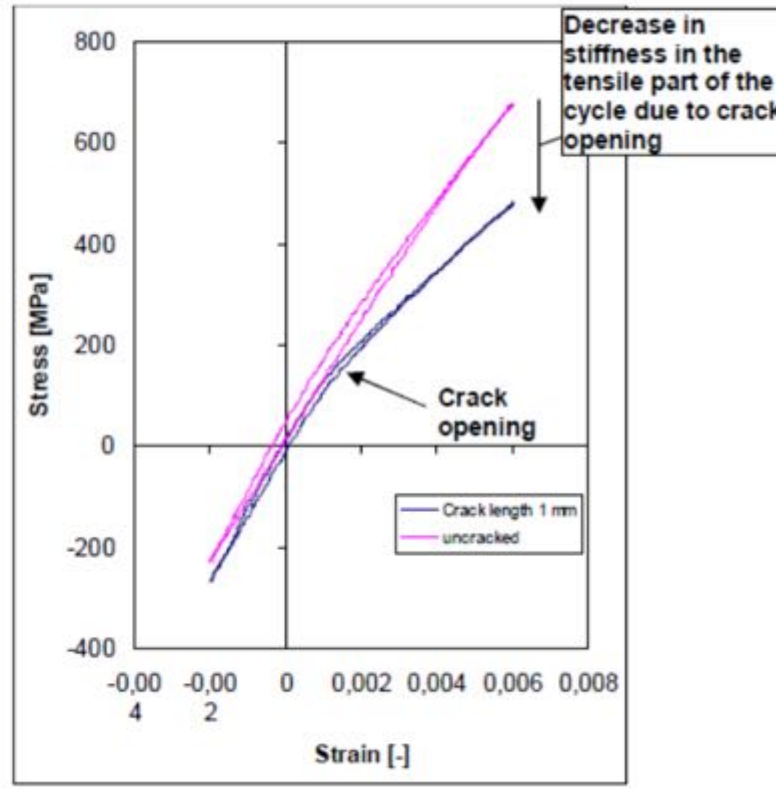
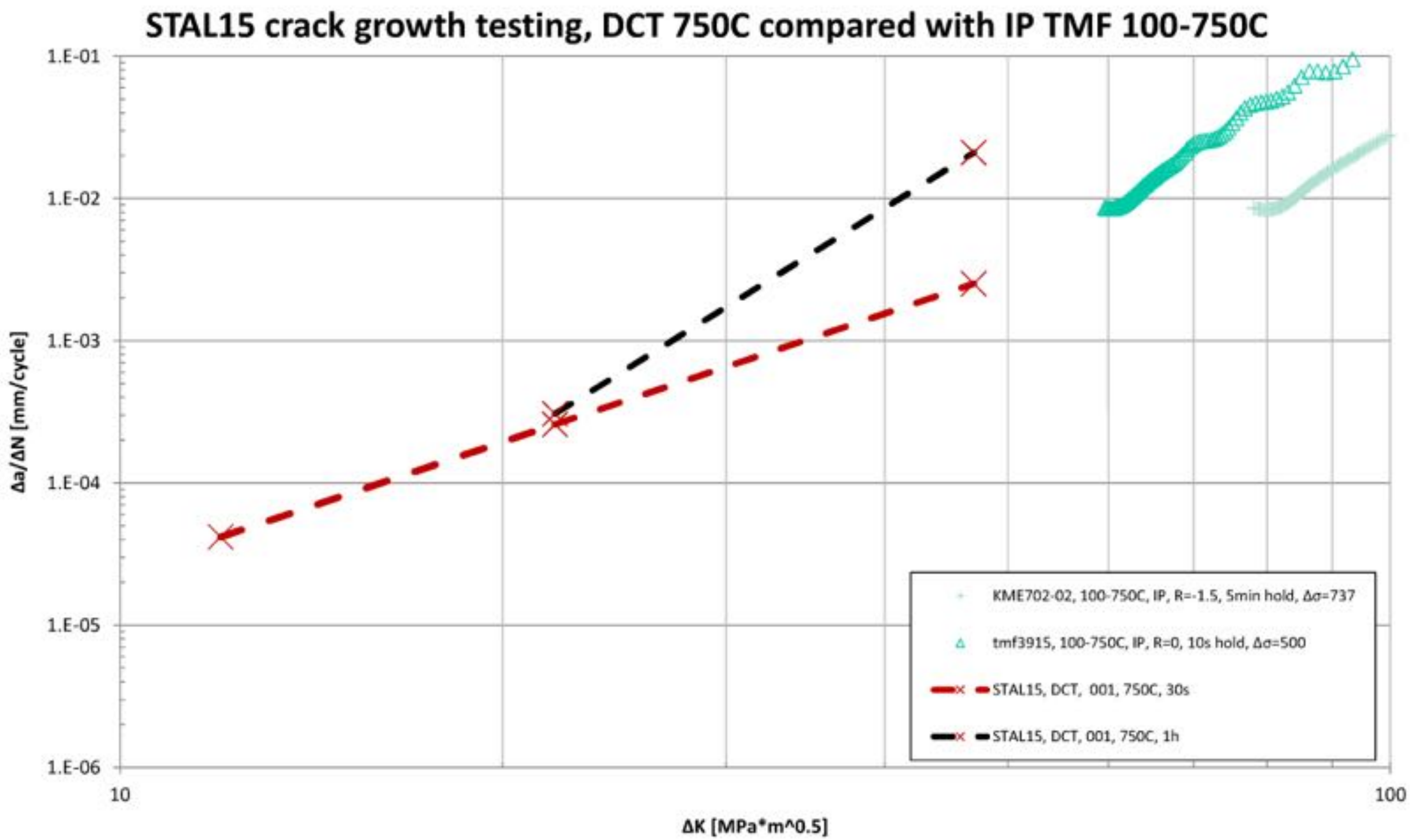
Crack growth measurements







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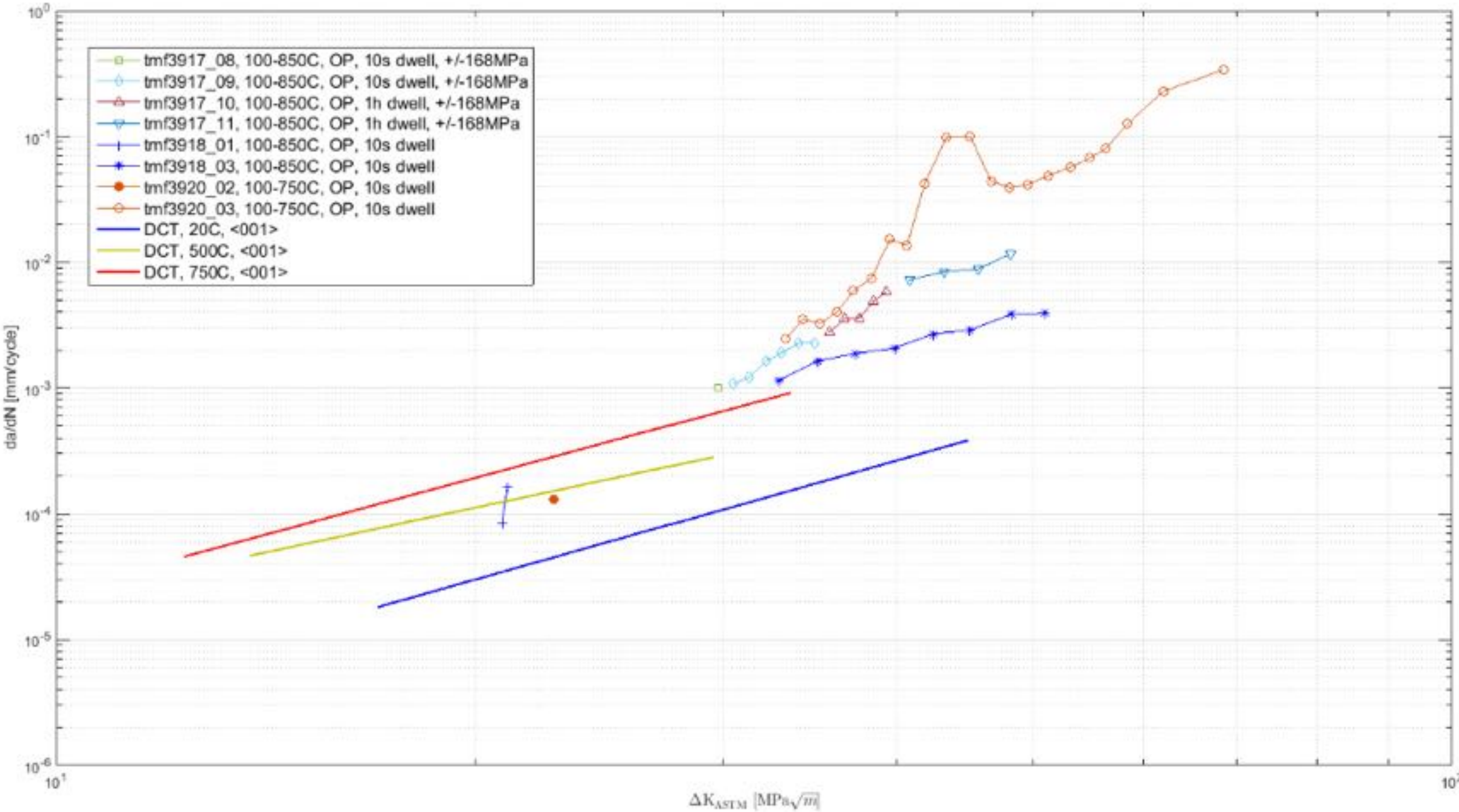
STAL15 crack growth testing, DCT compared with OP TMF



Conclusions

- We know little bit more now
- But more work is needed…

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