LCF and TMF crack growth in cast nickel-base superalloys KME-702

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Background

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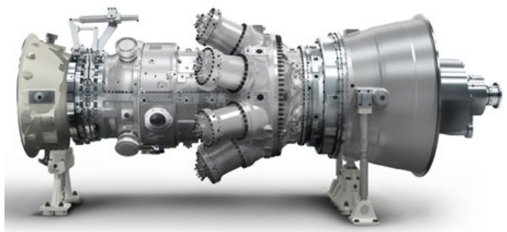


- Traditional gas turbines are originally designed primarily for base load operation
- Due to new market conditions and the introduction of more intermittent energy sources (e.g. wind and solar power) the **operational flexibility** of gas turbines must increase.

➔ More start and stop cycles
➔ Fatigue problems

Relation to previous projects

KME-502:

- Focus on
  - Crack initiation during ThermoMechanical Fatigue (TMF)
  - Constitutive properties of a single crystal superalloys

KME-702:

- Focus on
  - Crack propagation during LCF and TMF
  - Corrosion resistant cast superalloys for blades and vanes

Key objectives

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.

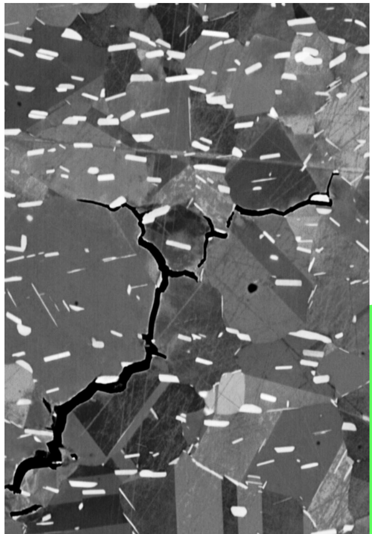
Contribution to KME-programme goals

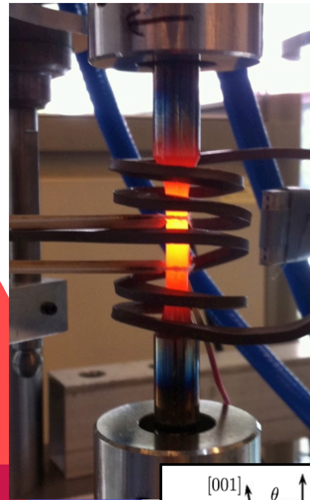
The proposed project mainly address the following two goals of the KME-programme:

- “To test and validate new materials and surface coatings for future industrial gas turbines in order to permit high fuel flexibility, availability and efficiency, as well as cyclic operation.”

- “To evaluate the mechanical properties and service life of various materials in relation to new material requirements for more efficient electricity production”

Our approach



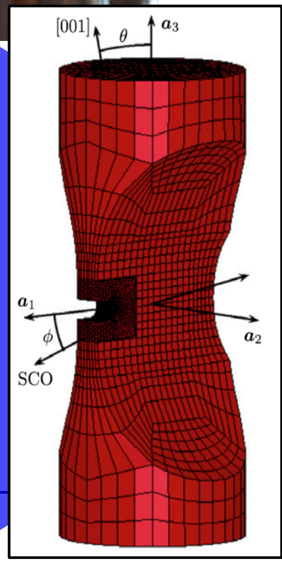


Mechanical testing

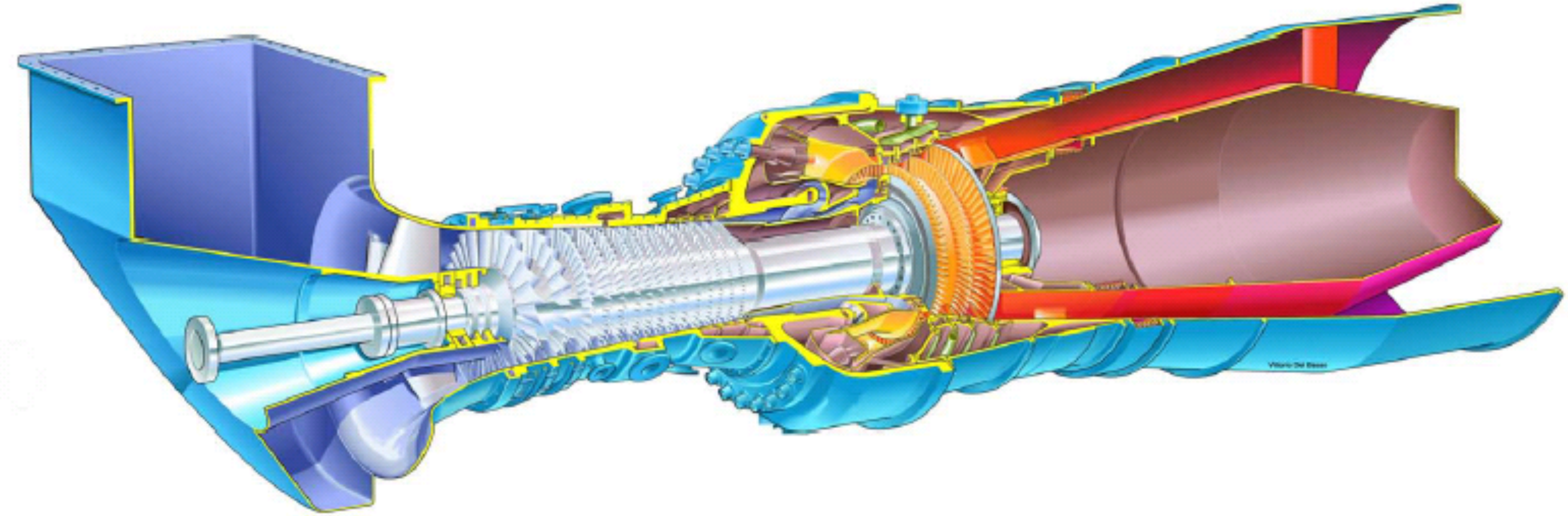
KME-702

Microstructure

Modelling

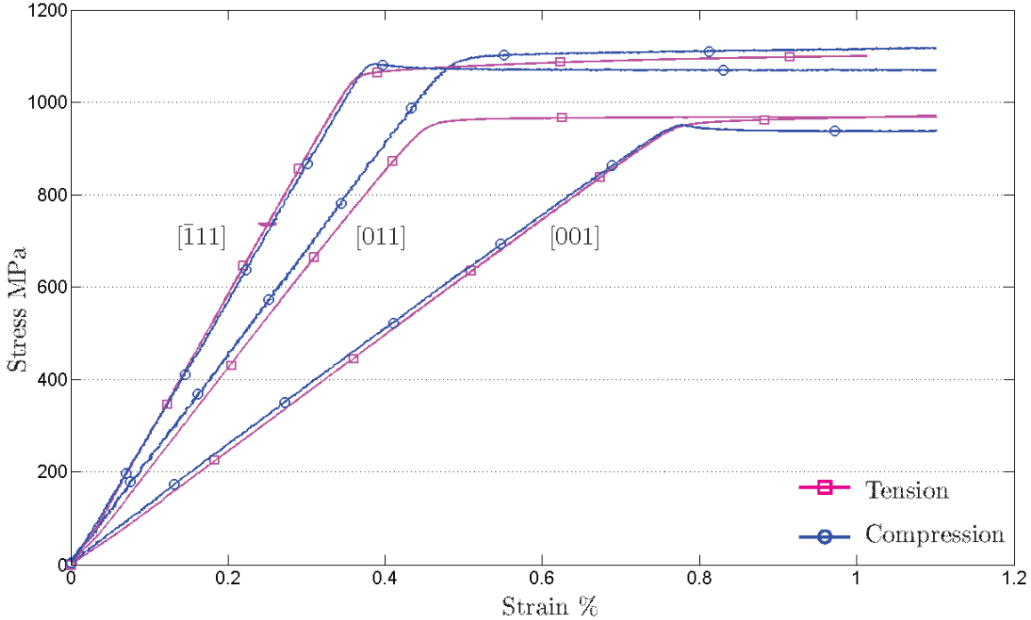


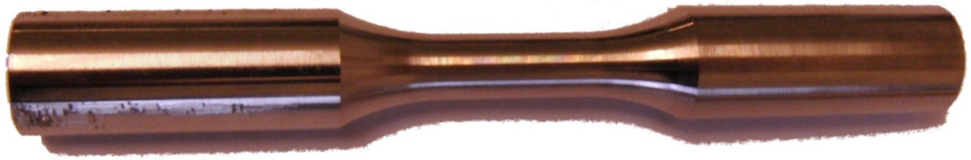
Gas turbines



Single-crystal material

Experiment

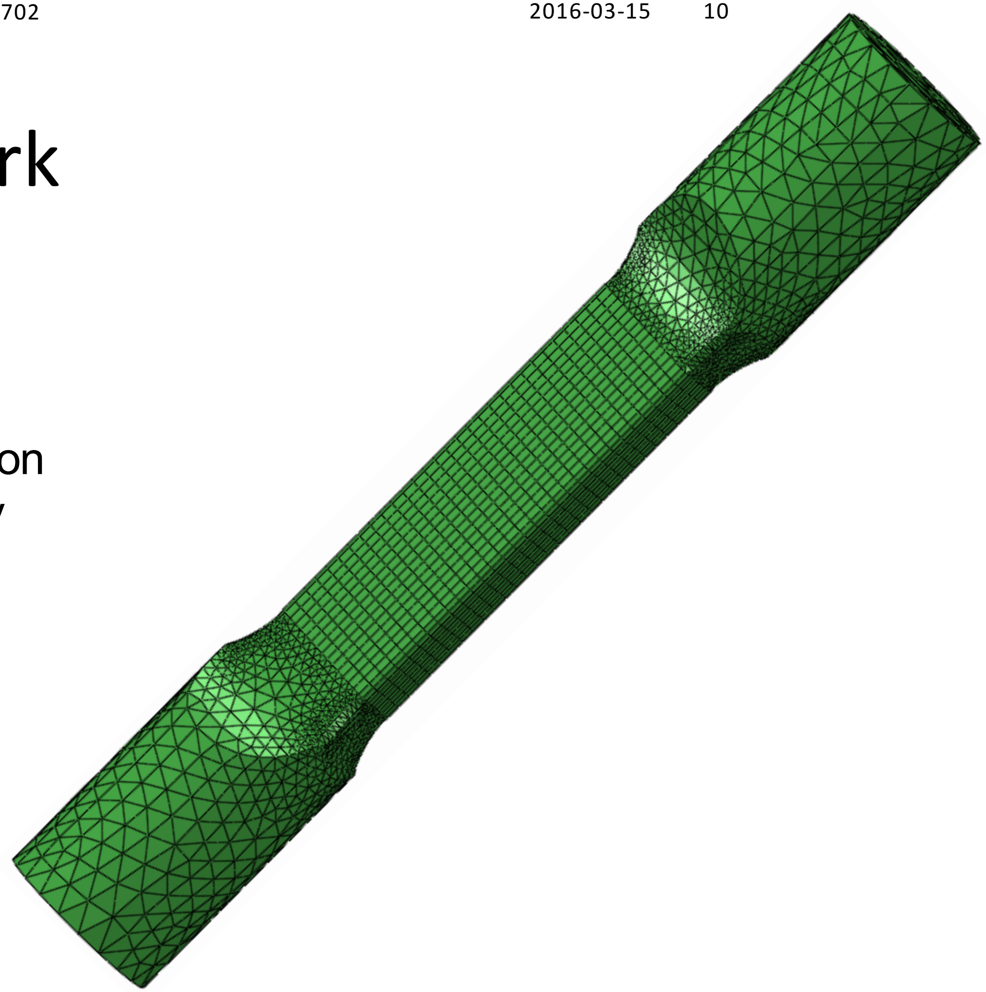




- Elastic anisotropy
- Plastic anisotropy
- Tension/compression-asymmetry
- Perfectly-plastic behaviour

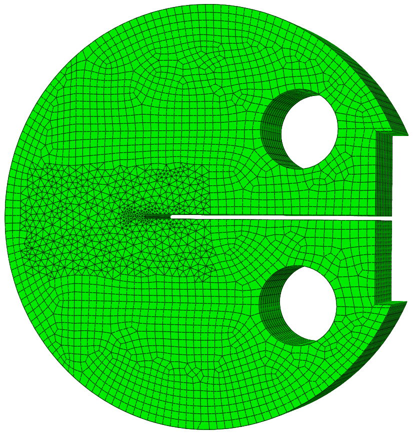
Overview – performed work

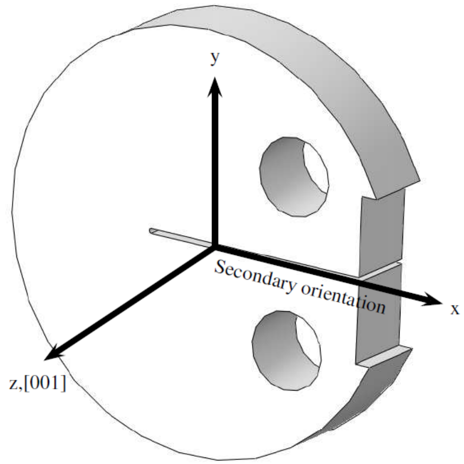
- Background studies on LCF crack propagation simulations on IN718 using FRANC3D
- FE-study of the effect of crystal orientation and misalignment on the stress intensity factor in a single-crystal
- Isothermal crack growth testing on two different specimen types at ambient and elevated temperature



Overview – performed work

FE-study of the effect of crystal orientation and misalignment on the stress intensity factor in a single-crystal





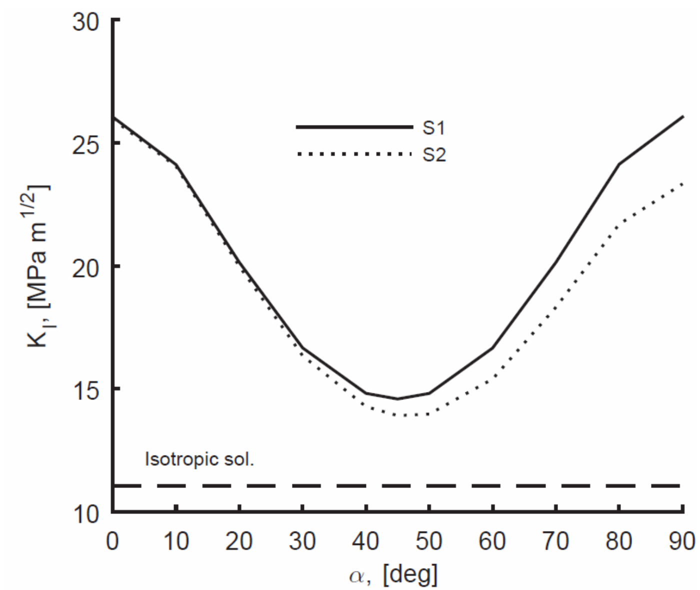


FIGURE 9: SIFs AS A FUNCTION OF α.

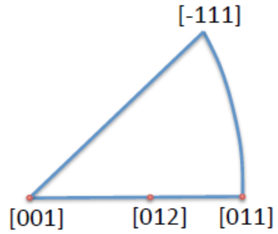
Overview – performed work

Conclusions

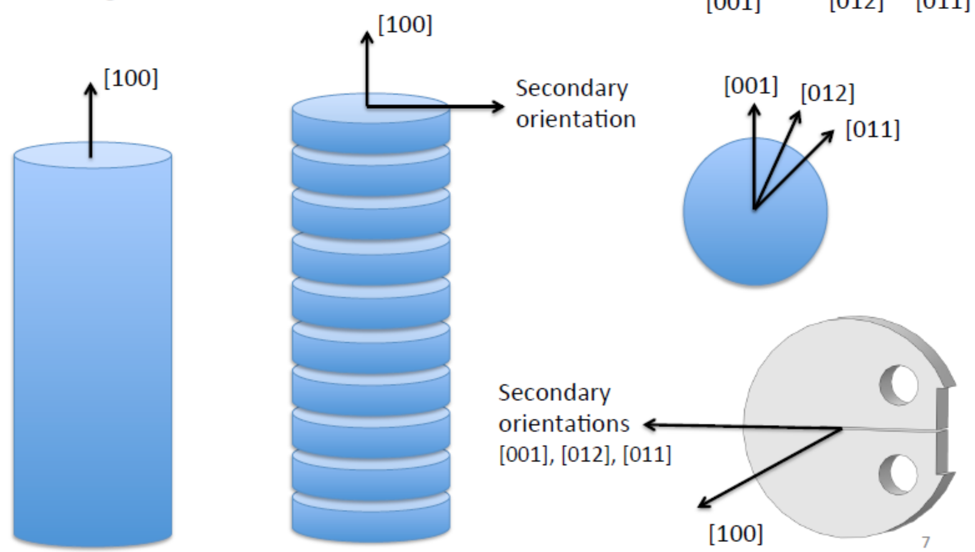
- The crystal orientation is important when the SIFs are evaluated, since they deviate by rotating the crystal in the component.
- It is important to account for the misalignments in a cast component, since they have a major influence on the crack propagation behavior.
- The complex stress state in the notch vicinity has to be accounted for by an appropriate material model.
- Further research is needed to evaluate the full impact of the misalignment also for longer cracks.

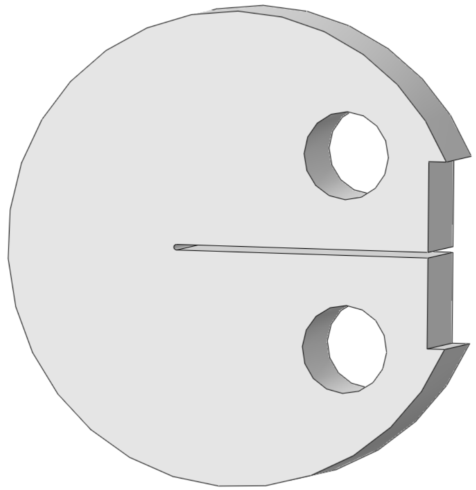
Isothermal crack growth testing on STAL15 DCT specimen

DCT-Specimen

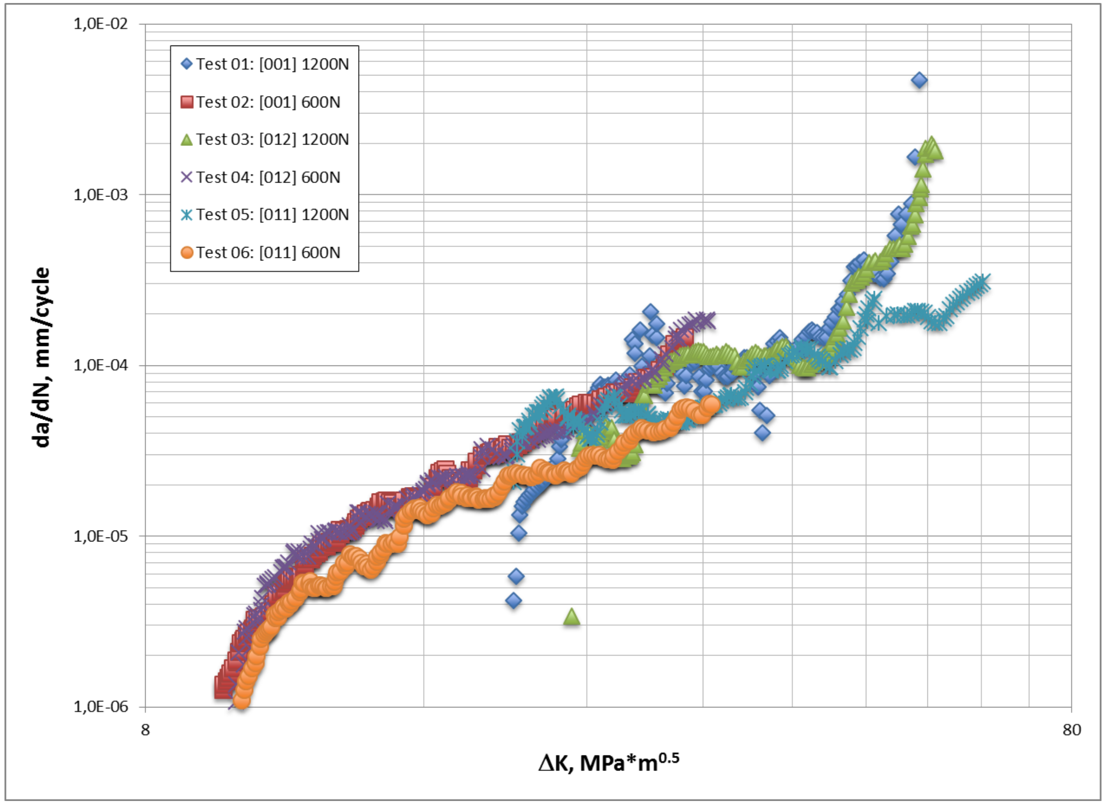


Single crystal bar in STAL15
Cast along the [100] direction

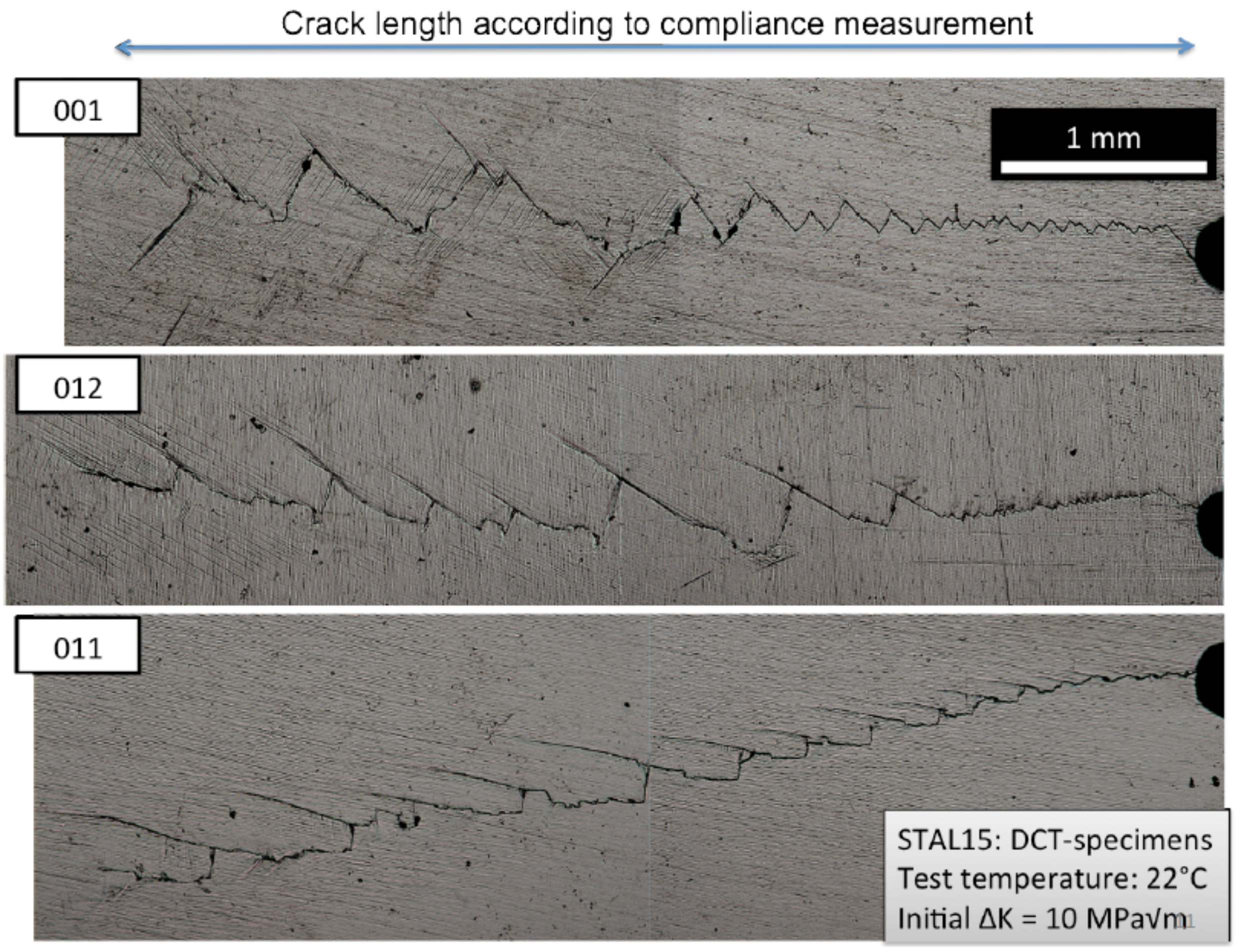




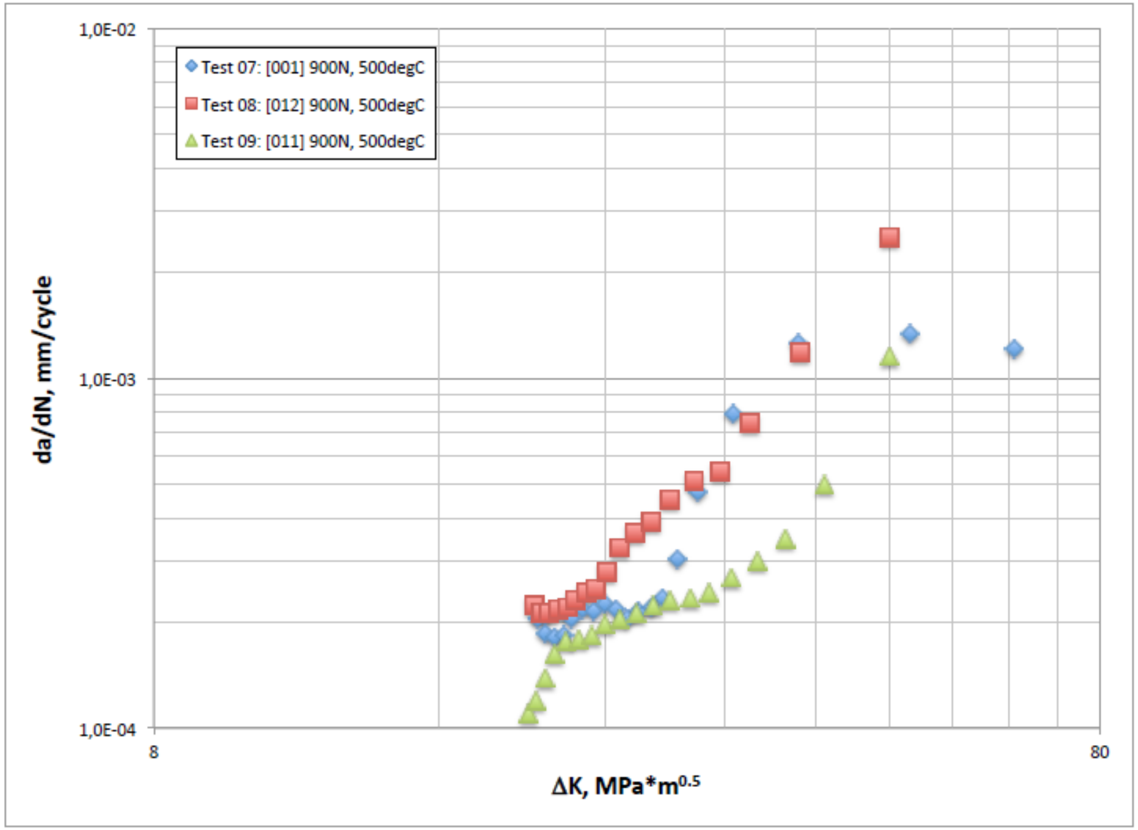
Test results



- Isothermal, RT
- Stress controlled
- $R_\sigma = 0.1$
- Air environment
- No pre-crack

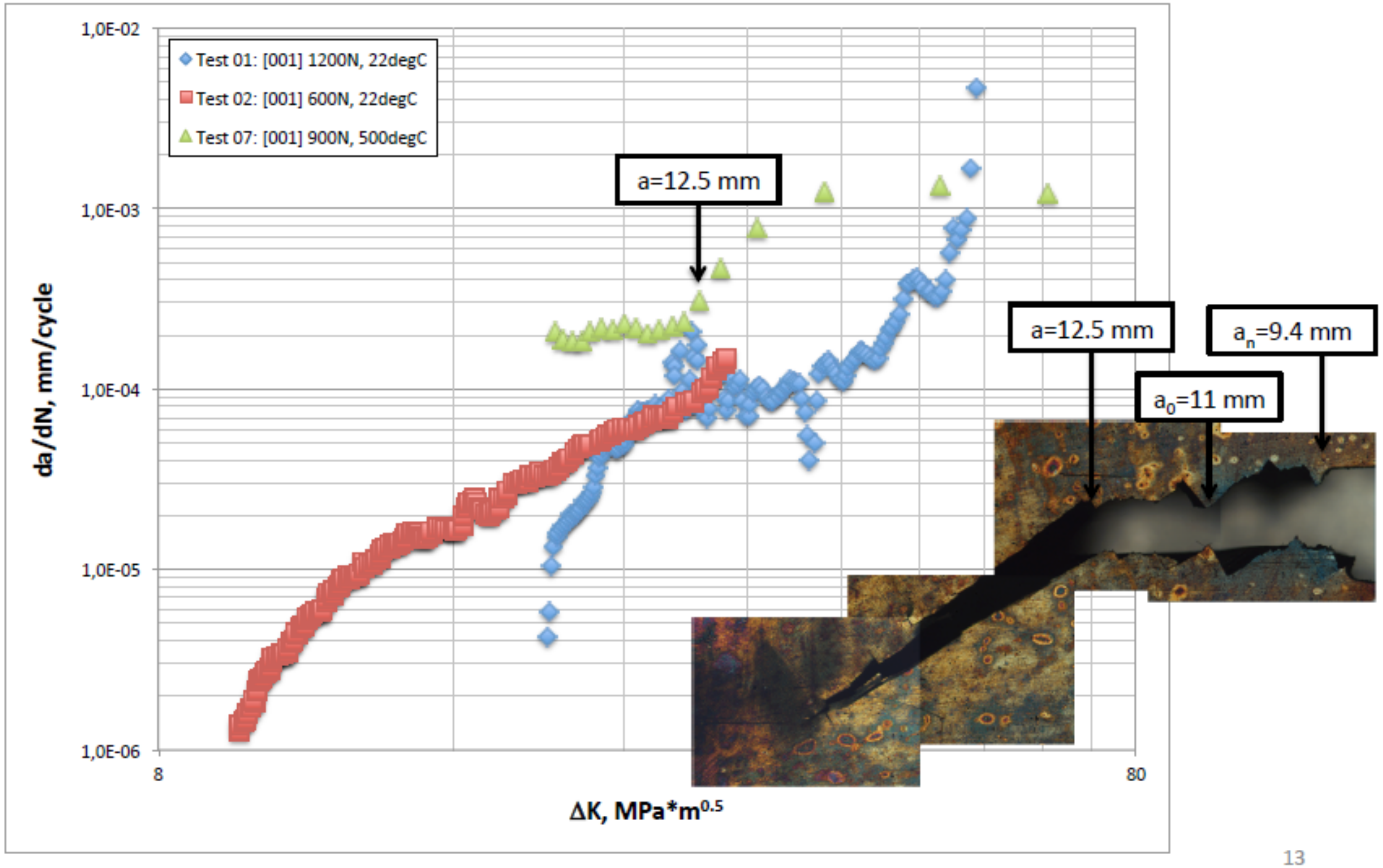

Crack length according to compliance measurement
001
1 mm
012
011
STAL15: DCT-specimens
Test temperature: 22°C
Initial ΔK = 10 MPa√m

Crack growth rates @ 500°C



- Isothermal, 500C
- Stress controlled
- $R_\sigma = 0.1$
- Air environment
- Pre-cracked at RT

Crack growth rates for [001]-specimens at 500°C



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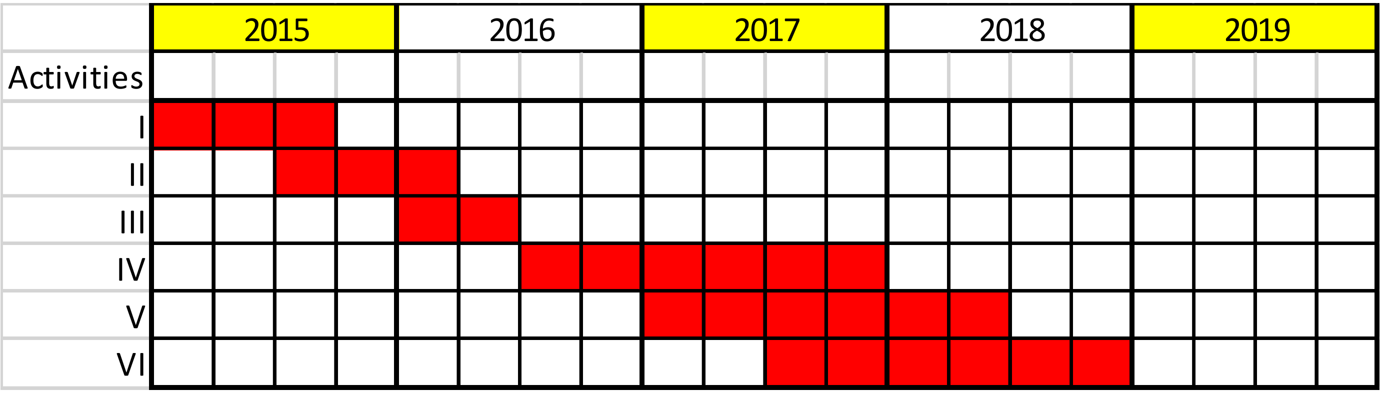
Future work

- Perform isothermal, monotonic tension/compression testings at:
  RT, 500C, 750C and in the respective [001], [011] and [111] direction
- Isothermal crack growth testing at higher temperatures and with hold times
- TMF crack growth testing
- Metallographic examination of tested specimens
- Develop suitable aging procedure to simulate service conditions
- Generate crack growth parameter
- Find a model to predict crystallographic crack growth as well as switching between cracking modes

Future Work - Project Plan



I : Finishing first laboratory tests and evaluate results (Pacman)
II : Study on influnce of crystal orientation
III : Pacman simulations of LCF tests on STAL15 SX
IV : TMF crack propagation behaviour, Hold-time and creep influences
V : Same as IV but aging is considered
VI : More component like geometries are considered

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