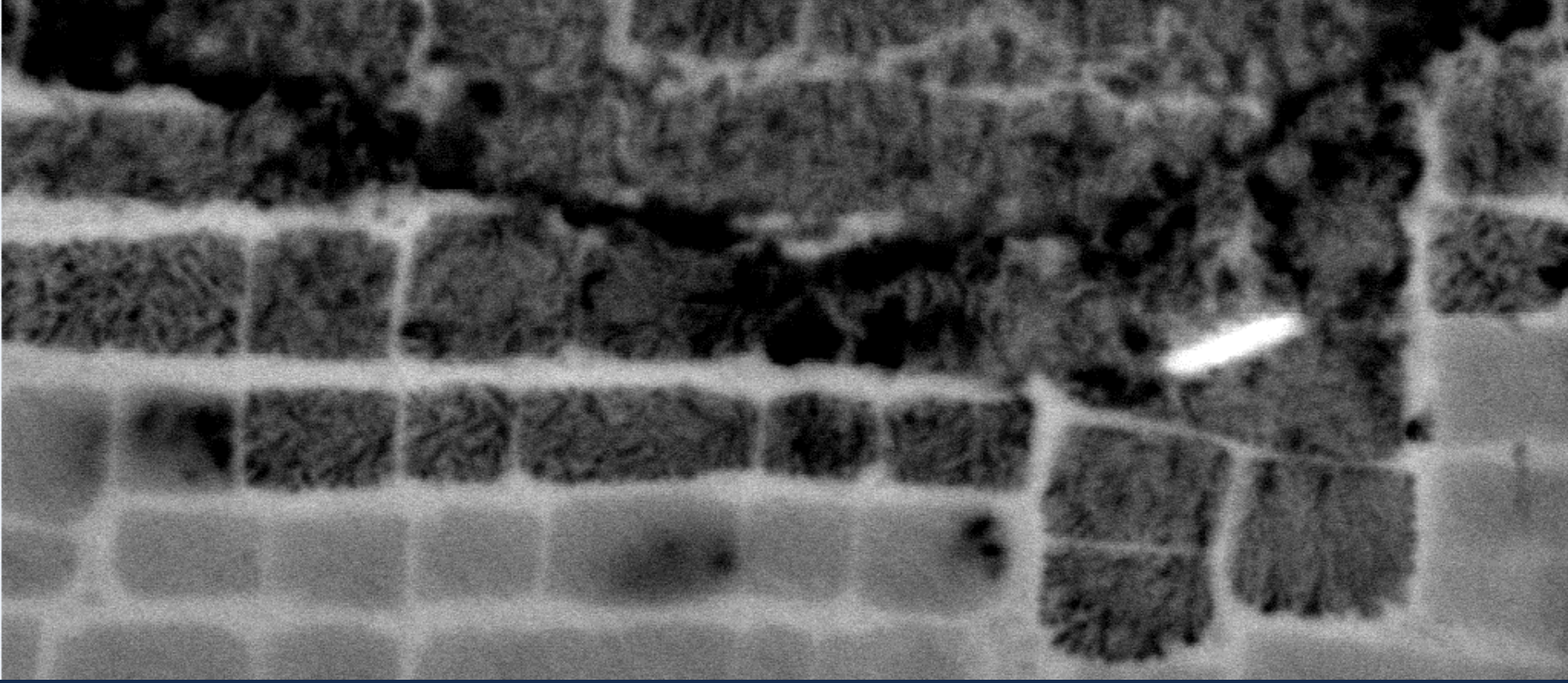


GT Life Time Extension, Risks & Reliability
(A New Working Group at ETN)

Siavash Pahlavanyali

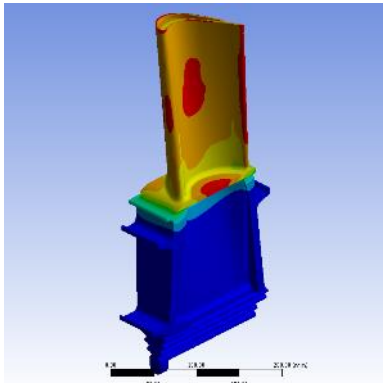
Contents

- Background to RINA's GT experience
- Integrity assessment - reliability improvement? Cases for:
    - Compressor
    - Turbine
    - Rotor
- Room for improvement

Background to RINA's GT Experience

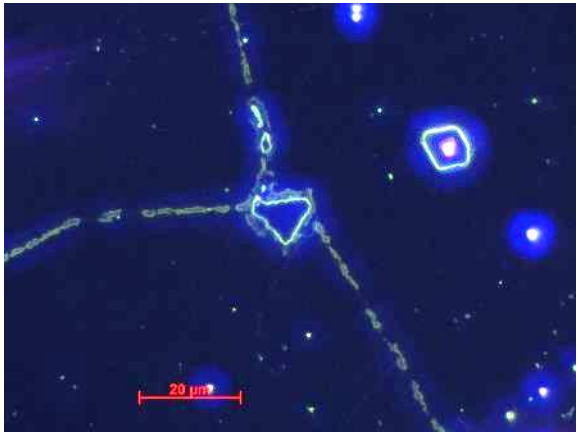
Engine Types:

- Gas turbines of different makes and models
- 3MW to 400MW units (PowerGen, Oil&Gas, CHP)
- Some very old turbines (1960) to modern units (H class engines)



Turbine Life Assessments:

- Hot section parts:
  - More than 400 sets of turbine blades assessed after their nominal design life)
  - A wide range of superalloys and castings (CC, DS, SC)
  - ~80% of the parts were approved for additional service intervals
- Turbine rotor:
  - A number of turbine rotors/discs assessed for further safe operation



Background to RINA's GT Experience

Turbine failures:

- Around 230 gas turbine failure cases investigated at RINA UK
    - Mostly catastrophic failures
    - >50% of the failures were compressor related (in recent years),
        - Several failures happened a short while after an outage/inspection

Other related engineering support:

- Developing superalloy lifing, considering long-term aging, or refurbishment cycles
- Blade coating development (alloy selection, powder manufacturing, spraying, and testing)
- Turbine vibration and performance analysis

Background to RINA's GT Experience

Third party verifications:

- Repair/refurbishment, vendor inspection
- Re-engineering, reverse engineering & manufacturing

Laboratory (superalloy and coating assessments):

- Advanced metallurgical laboratories (Rina UK and Italy)
- Range of mechanical testing facilities (Rina Italy, CSM)
- Alloy and coating manufacturing capabilities (Rina Italy, CSM)

Turbine Integrity and Reliability (ETN inititive)

Integrity-reliability - points to be considered:

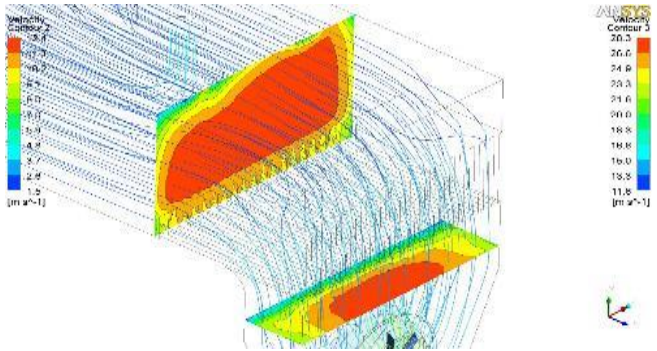
- Engine makes & models
- Maintenance; Standards, procedures, and practices
    - Rejuvenation: inspection, repair, and quality checks
- Upgrade (mechanical, control system)
- Operation & operating regime
    - Past operation
    - Expected future operation
- Compressor, combustion, or turbine issues
- Personnel training and competency
- ...

ETN Global; To consider a wide range of units, operations (and skill gap)

Integrity and Risk Assessment of Compressor

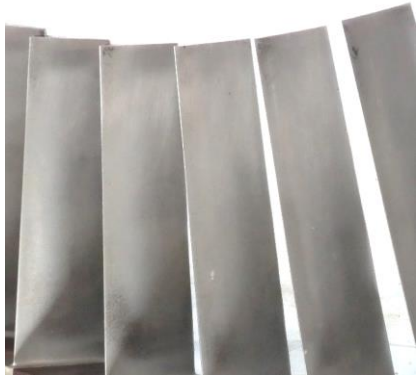
Damage mechanism, inspection, and integrity assessment:

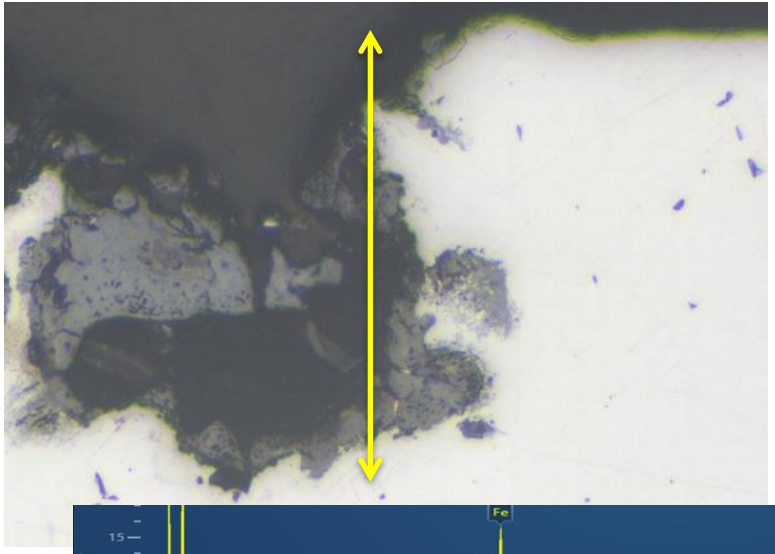
- Cracking and failure:
    - Most compressor failures start by high cycle fatigue (HCF) cracking of the rotating blades or the stator vanes
    - Crack starts from defect (pitting, impact etc) of: ~0.2-0.6mm!
- Cause(s) of HCF crack initiation:
    - Impact (FOD / DOD)
    - Pitting, or IGA
    - Erosion
    - Tip rubbing
    - Fretting damage (root)
    - Blade/vane damping, and aerodynamic disturbance
- IGV/VGV assemblies; wear and function

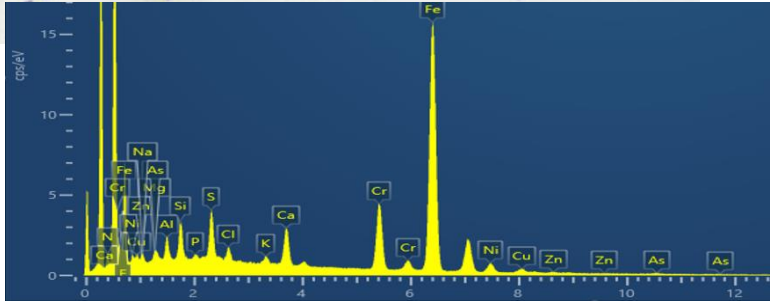


Integrity and Risk Assessment of Compressor (cont.)

Example of stator failure







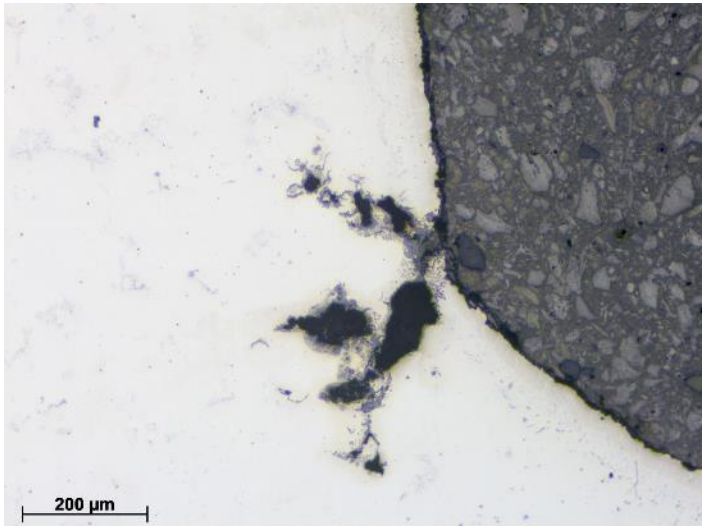
- Corrosive species such as Cl, S, and Na found in the pitting area
- Corrosion-related HCF initiation (root cause of the problem)!

Implications?

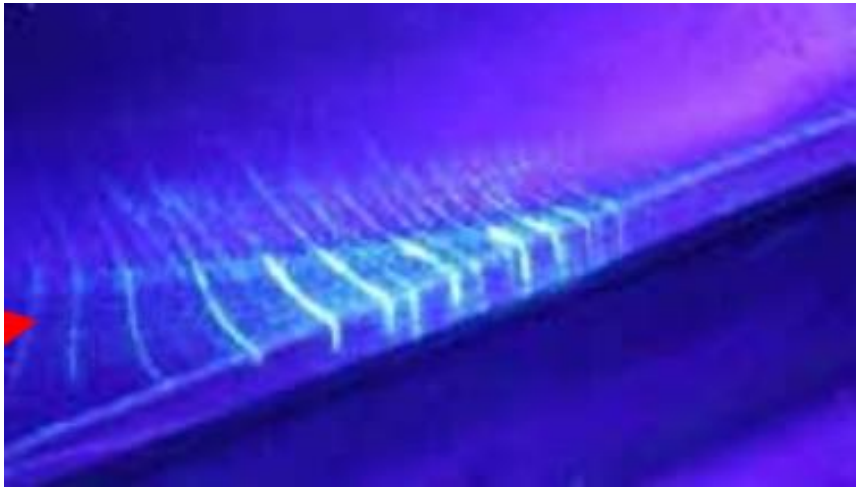
Integrity Assessment - Reliability Improvements (Turbine)

Damage mechanism, inspection, and assessment:

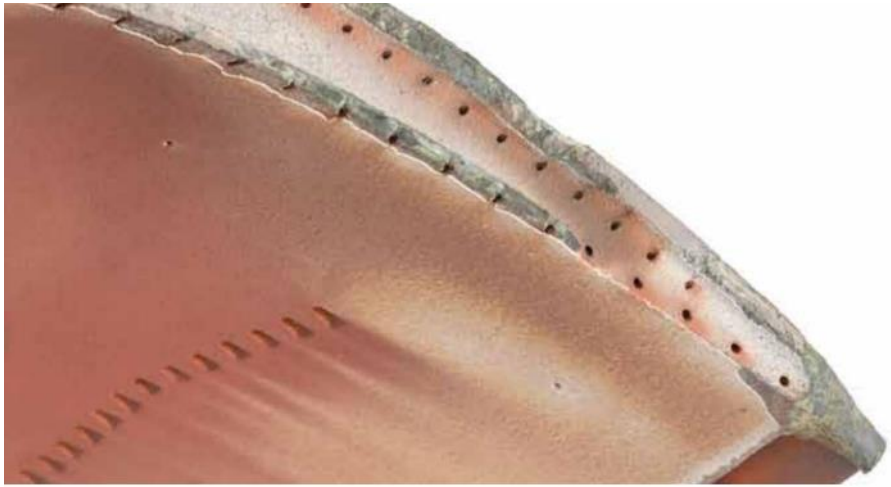
- Turbine:
    - Oxidation/corrosion, creep, fatigue, and a few others, (the progression of damage depends on the design, alloy, component and location in the engine, and the operational duty of the plant)
        - Early stages or later stages (blade and vanes)
        - Single crystal (SC), directionally solidified (DS) & conventional casting (CC)
        - Shrouded/shroudless
        - Early rows to later rows
        - Inspection and quality:
            - Visual/borescope during an outage
            - Maintenance/inspection methods/practices
            - Refurbishment cycle of the part
- Rotor: Thermal cracking, creep, fatigue, embrittlement



Single crystal blades (ex-service)



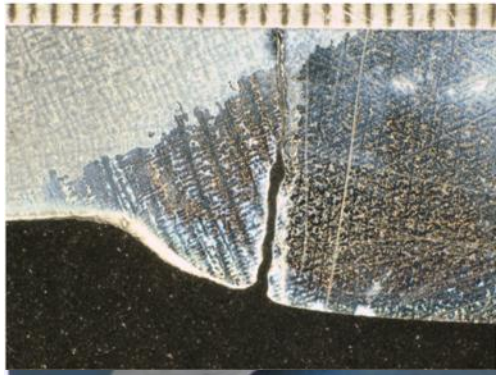
Blade Platform oxidation & cracking

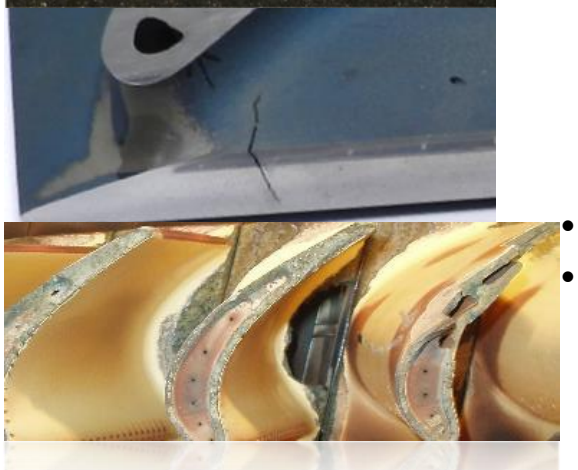


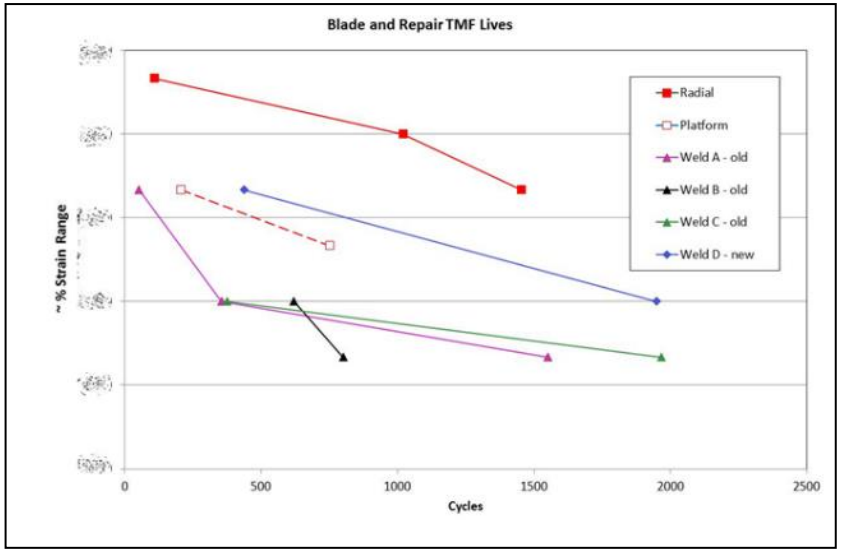
Blade tip oxidation & cracking

Any report of single crystal blade cracking (or failure) from the aerofoil?

Case I: DS & SC blade TMF cracking & repair



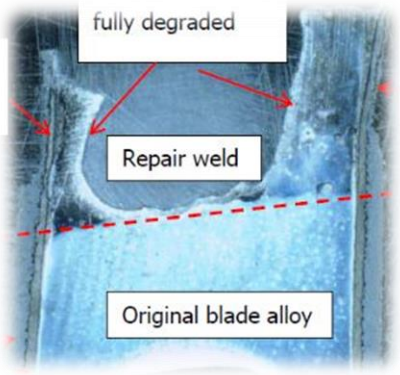


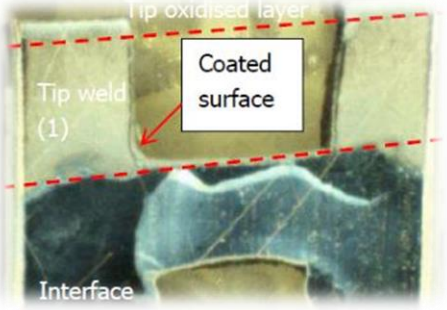


- A significant reduction of the transverse samples' TMF life
- Improvement of the weld repair TMF life with the newer weld metal
  - The new weld metal is now frequently used for repairing advanced turbine blades (platform and tip repair), see next

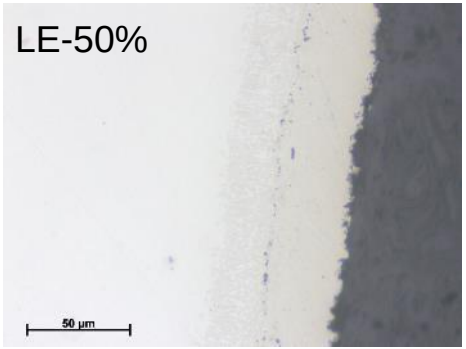
Case II: Blade repair and reliability improvement

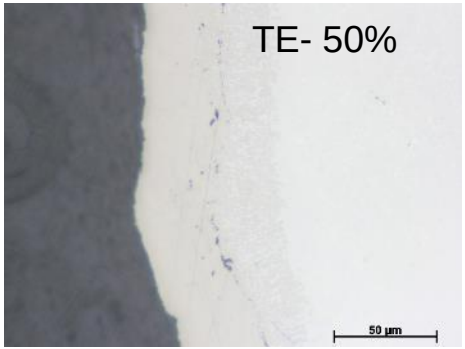
Blade tip repair; using new weld alloy, (after a service interval)

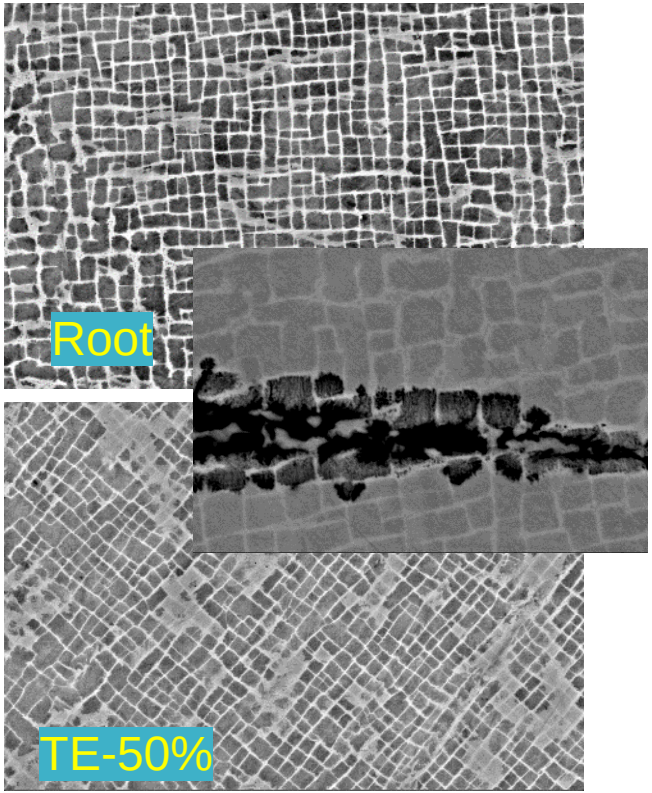




Case III: Advanced blade assessments and risks?







In service:

- A single-cycle unit (i.e. without HRSG)
- ~ 24,000 fired hours (with very few strats)
- Operating at a partial load of ~ 25-30% of the nominal site rating
- Natural gas (good quality), no corrosion issue
- Advanced single crystal alloy (γ' vol>70%)

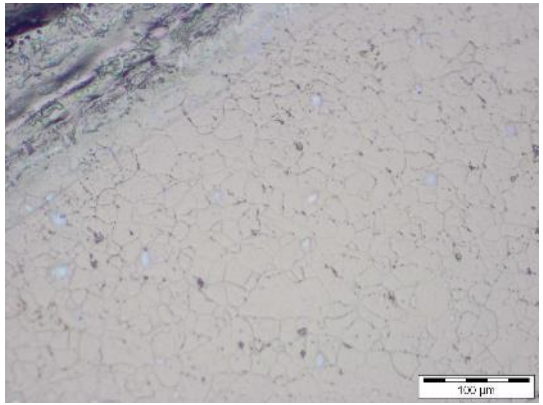
Examinations and Assessment:

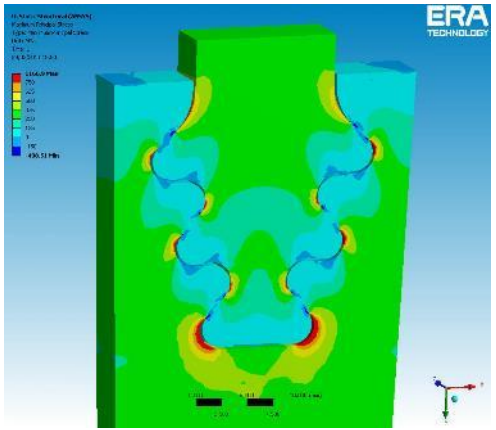
- Little external oxidation/corrosion and little microstructural change to the coating (less than 10% of the orignal coating life consumed)
- Little change to the alloy microstructure
- Creep rupture test → long life

Are there any other risks?

Issues of rotor/disc inspection and assessment

- Rotor/disc lifing: critical and challenging:
  - Thermal analysis ✓
  - Stress analysis ✓
  - Creep/fatigue analysis ✓





- Crack growth
  - Alloy embrittlement and toughness?
- Uncertainty & risk analysis?
- Verification

Areas to which ETN can contribute:

With the objective of improving compressor integrity and reliability:

- Contamination mapping:
    - Methods of assessing contamination in a compressor (and gas turbine)
    - Acceptable level (if any)?
- Compressor inspection:
    - To consider developing a simplified (site practible) compressor inspection protocol (i.e code of practice etc)
- Risk assessments and mitigations:
    - To develop a risk assessment process for the integrity assessment of the compressor

Turbine Integrity and Reliability (ETN Global)
Potential areas for further improvement

Turbine (with a view of the flexible operation):

- Blading:
  - Advanced single-crystal (& DS alloy) blade lifing
  - Turbine blade (later stages) life assessments
- Coating:
  - Post-service TBC coating assessments (nondestructive)
- Repair, rejuvenation, and upgrade
  - Hot section repair verification (advanced alloy)

Turbine Integrity and Reliability (ETN Global)
Potential areas for further improvement

Rotor/disc:

- Inspections:
  - On-site inspection practices
- Disc/Rotor lifing:
  - Creep/Fatigue lifing?
  - Alloy embrittlement

Thank you!