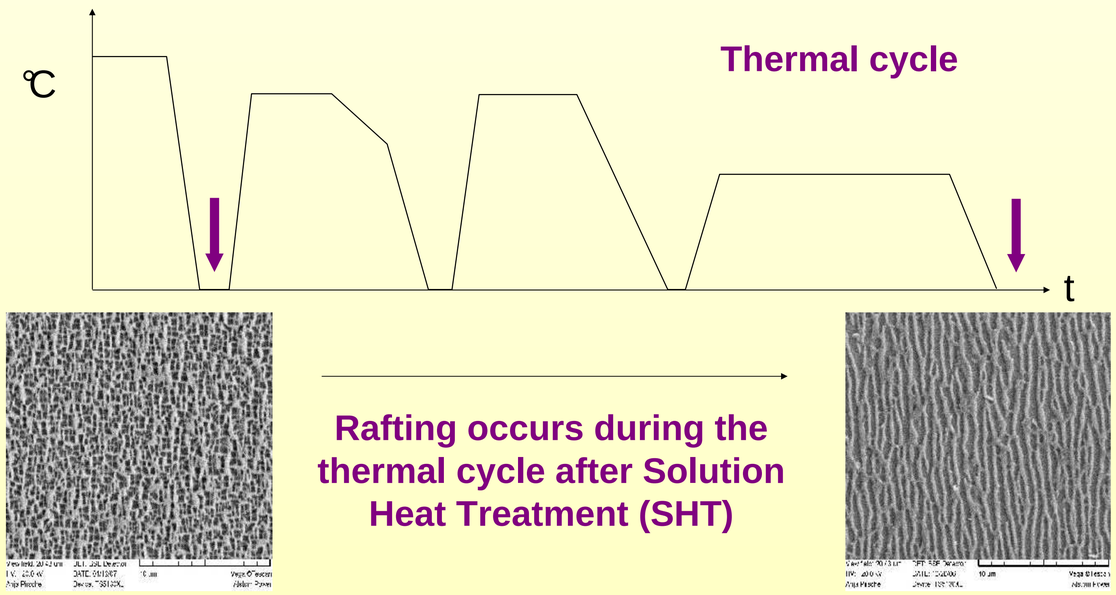
Residual strain measurements in a monocrystalline Ni-based superalloy turbine blade using neutron diffraction

S. Pierret[1] , A. Evans[1] , A. Paradowska[2], T. Etter[3] , H. Van Swygenhoven[1]

1 ASQ/NUM – Materials Science and Simulation, Paul Scherrer Institut, CH-5322 Villigen, Switzerland
2 ISIS, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, UK
3 ALSTOM (Switzerland) Ltd – TTTM.M Department, Brown Boveri Str. 7, CH-5401 Baden

Motivation

A rafted microstructure often can be observed in different areas of monocrystalline (SX) Ni-based superalloy blades after operation. Here, rafting has been investigated in a blade before operation. Since a rafted microstructure will decrease the mechanical properties of the superalloy, it is of a crucial importance to understand the cause of rafting in that case.

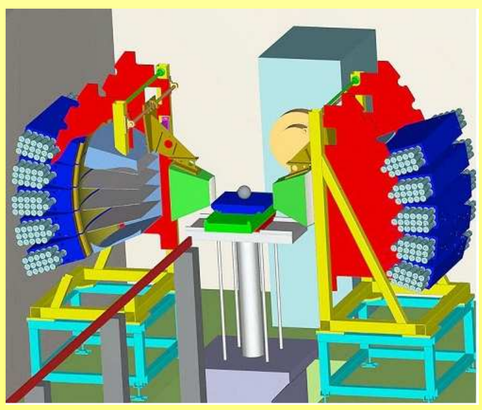


Objectives

It is thought that residual stresses are built up during the cooling from the solution heat treatment, which could have induced rafting on the fully heat-treated blade. The blade investigated here has followed the solution heat treatment and has then been cooled. The objectives are:

- measurement of residual strain using neutron diffraction (high penetration in engineering materials) in the areas where rafted microstructures are observed in the fully heat-treated condition,
- repeat the same measurements where the microstructure has not changed to compare both strain states.

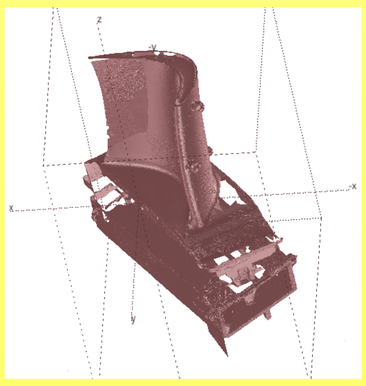
Technique

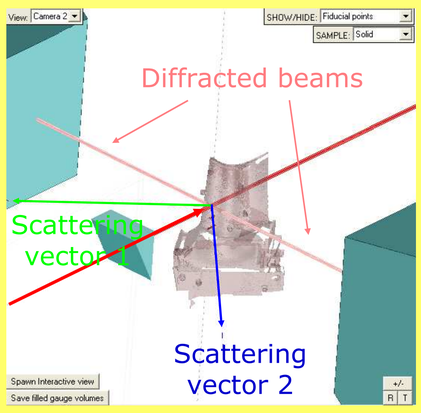


ENGIN-X (ISIS): Time-Of-Flight neutron diffractometer

- Wavelength range: 0.5-6 A
- 2 banks detectors at +/- 90°
- Goniometer (Cybaman Manipulator)

The blade was positioned within the beam with the SScanSS program





- Coordinates Measurement Machine
- **SScanSS* program**

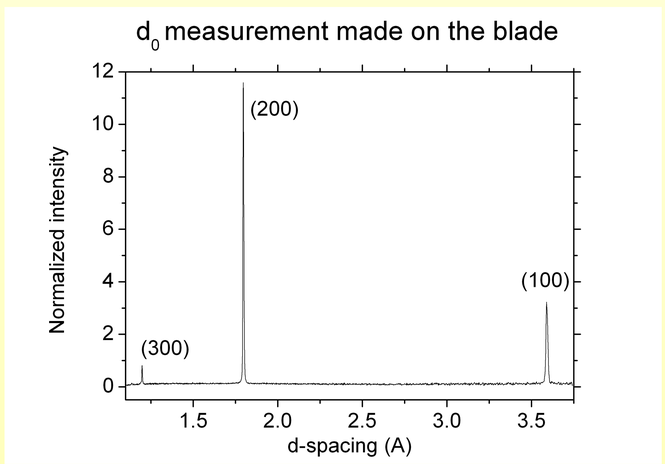
* Developed by Dr. Jon James, Department of Materials Engineering, Open University

Results

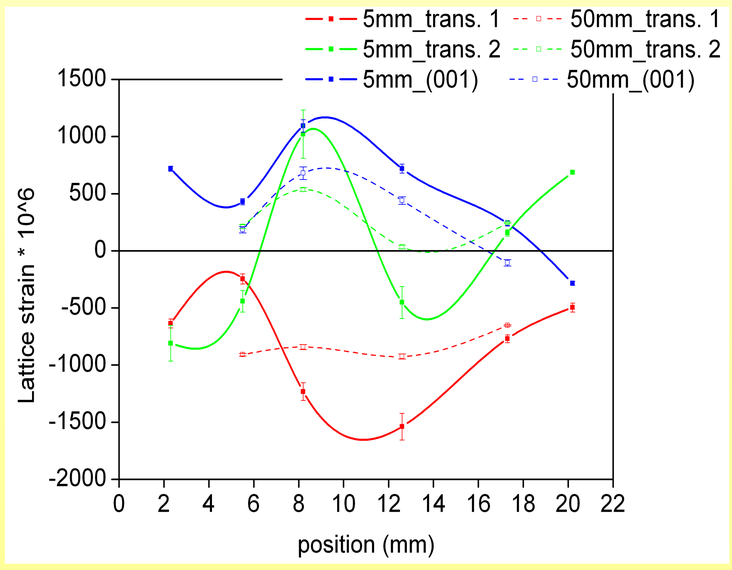
- Residual strain (ε) was measured from the **d-spacing variation across the blade airfoil relative to a stress-free lattice spacing d_0** on the (200) peaks, averaging both γ and γ‘.

$$\varepsilon = \frac{d - d_0}{d_0} \times 10^6$$

- **Two measurement lines** across the blade airfoil: 5mm above platform (rafting) and 50mm above platform (no rafting).
- Strain is measured in the **three crystallographic directions**: (001) along the blade axis and (010)/(100) in the transverse directions.
- A far field **d_0 measurement is made on the blade**, away from the highly stressed region.



Diffraction pattern showing the **(100)/(300) superlattice reflections and the (200) reflection**, where diffraction peaks of both phases are overlapping.



Lattice strain variations are measured where rafting has been observed

Tensile residual strains along the blade axis and compression residual state in one of the transverse direction.

Scattering of the data is significant **(long neutron travelling path)** for the middle point on the measurement lines.

Conclusion

- A complicated experiment has been performed on a real engineering component, showing the **presence of a residual strains variation across the airfoil**, which could be responsible of rafting during the subsequent thermal stage.
- **EDX mapping has to be performed** where the residual strains have been measured in order to investigate possible **heavy elements segregation** across the airfoil which could also have induced macroscopic lattice strain variation.
- **A more spatially resolved d_0 determination** ($\sin^2\psi$ method, stress free sample) is necessary to decouple chemical and strain variations across the airfoil.

Acknowledgements

The authors thank the Competence Center for Materials Science and Technology (CCMX at EPFL) for the financial support of this project.