Strain and Damage Interactions During Ductile Tearing: 3D in situ Measurements and Simulations

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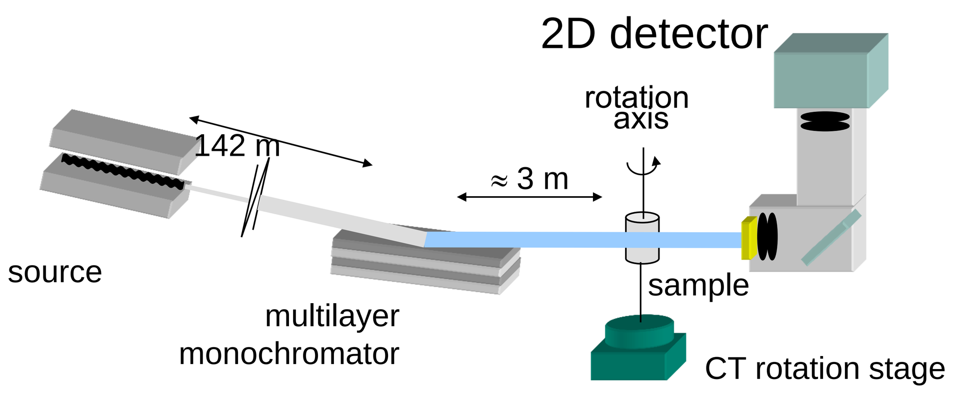
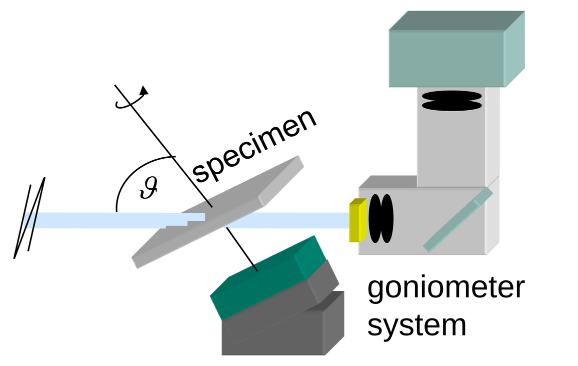
Tomo - Laminography

Principle of synchrotron tomography:



Principle of synchrotron laminography:

Change in rotation axis orientation!



Helfen *et al. Appl. Phys. Lett.* **86** (2005), 071915
Helfen *et al. Appl. Phys. Lett.* **94** (2009), 104103

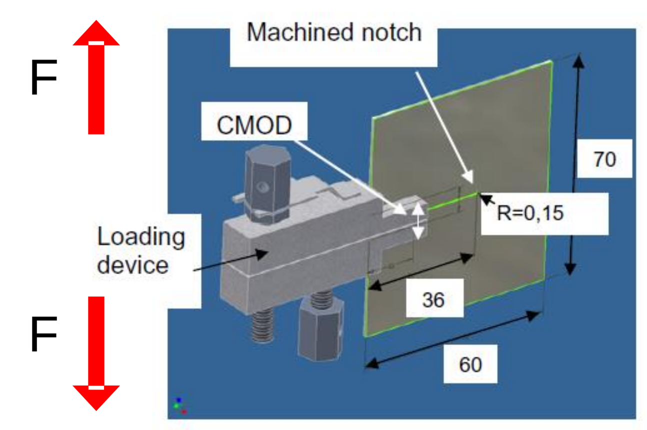
Advantage of laminography:

- Specimen can be much larger than lateral field of view of detector!
- Laterally extended objects may be imaged in 3D
- → opportunity arises to perform *in-situ* tests on sheet material with boundary conditions similar to standard tests

In-situ testing

Material:
2139 Al-alloy in T3 condition

Test rig:
a loading device that opens the notch



Morgeneyer *et al., Scripta Materialia*, **65** (2011) 1010-1013

Specimen dimension 60 mm x 70 mm x 1 mm
Anti-buckling frame not shown here
~20 loading steps performed

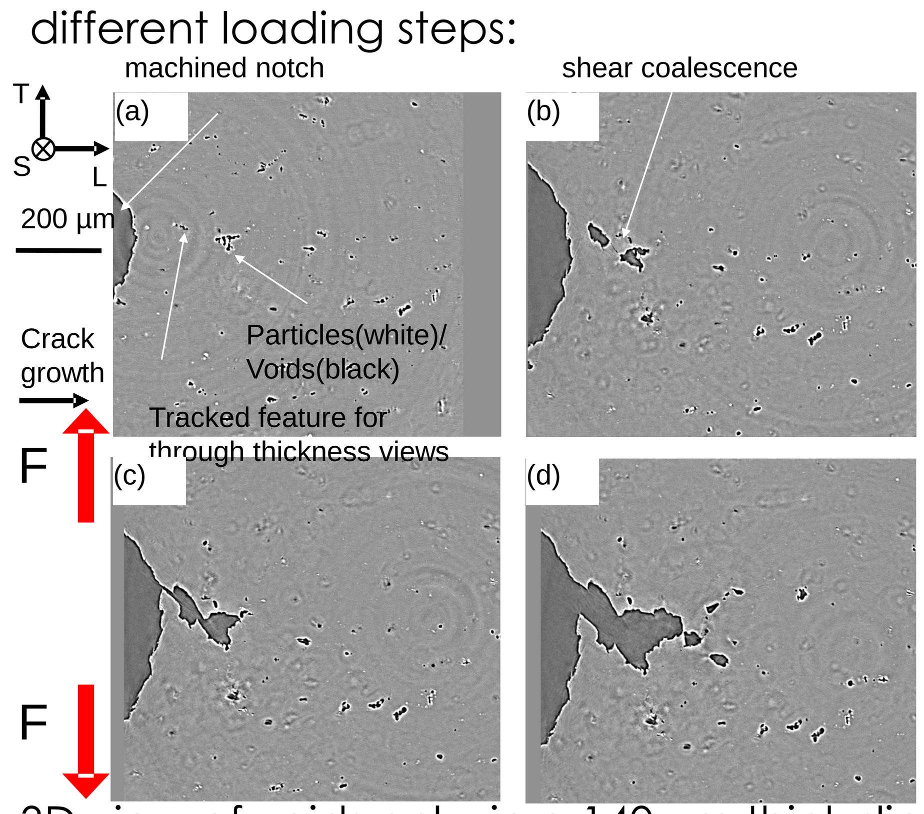
Laminography scanning conditions:

- at the European Synchrotron Radiation Facility (ESRF), ID19
- Voxel size 0.7 µm
- Tilt angle 25 degree
- Scanned volume ~(1 mm)^3
- 1500 views
- ~70 mm detector distance
- Scan size 8GB
- Scan time ~12 mins

Shen *et al., Acta Materialia*, **61** (2013) 2571-2582

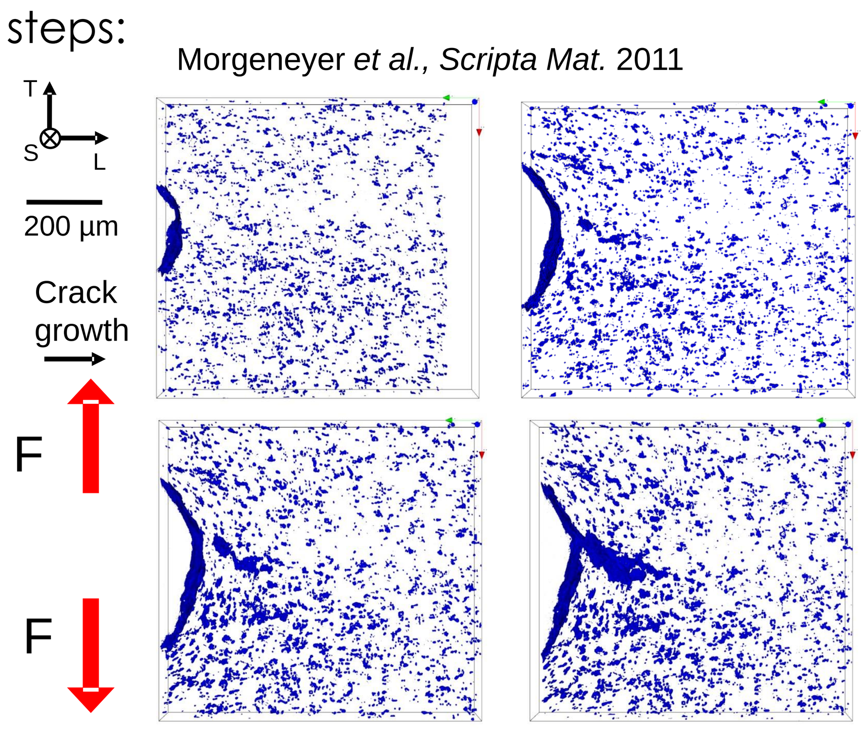
Laminography data

2D sections at sample mid-thickness for different loading steps:



3D view of voids only in a 140 µm thick slice around mid-thickness for different loading steps:

Morgeneyer *et al., Scripta Mat.* 2011



Digital volume correlation (DVC)

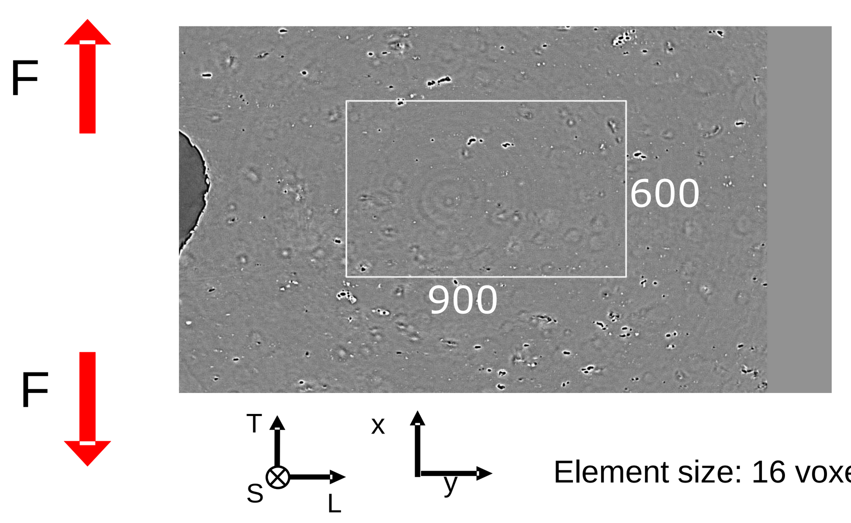
Principle :
Gray level 3D images with natural contrast
Image 1: $f(\underline{x})$ (deformed) image 2: $g(\underline{x})$
Conservation of grey values:

$$g(\underline{x}) \cong f(\underline{x} + \underline{u}(\underline{x}))$$

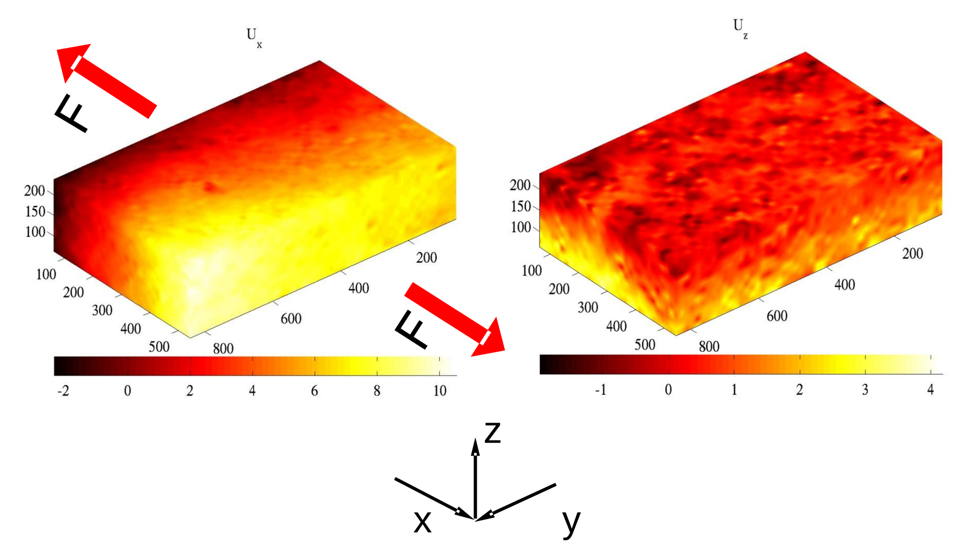
Measure $\underline{u}(\underline{x})$?

Roux *et al.* 2008 *Comp Part A* **39**:1253–1265

Investigated area:



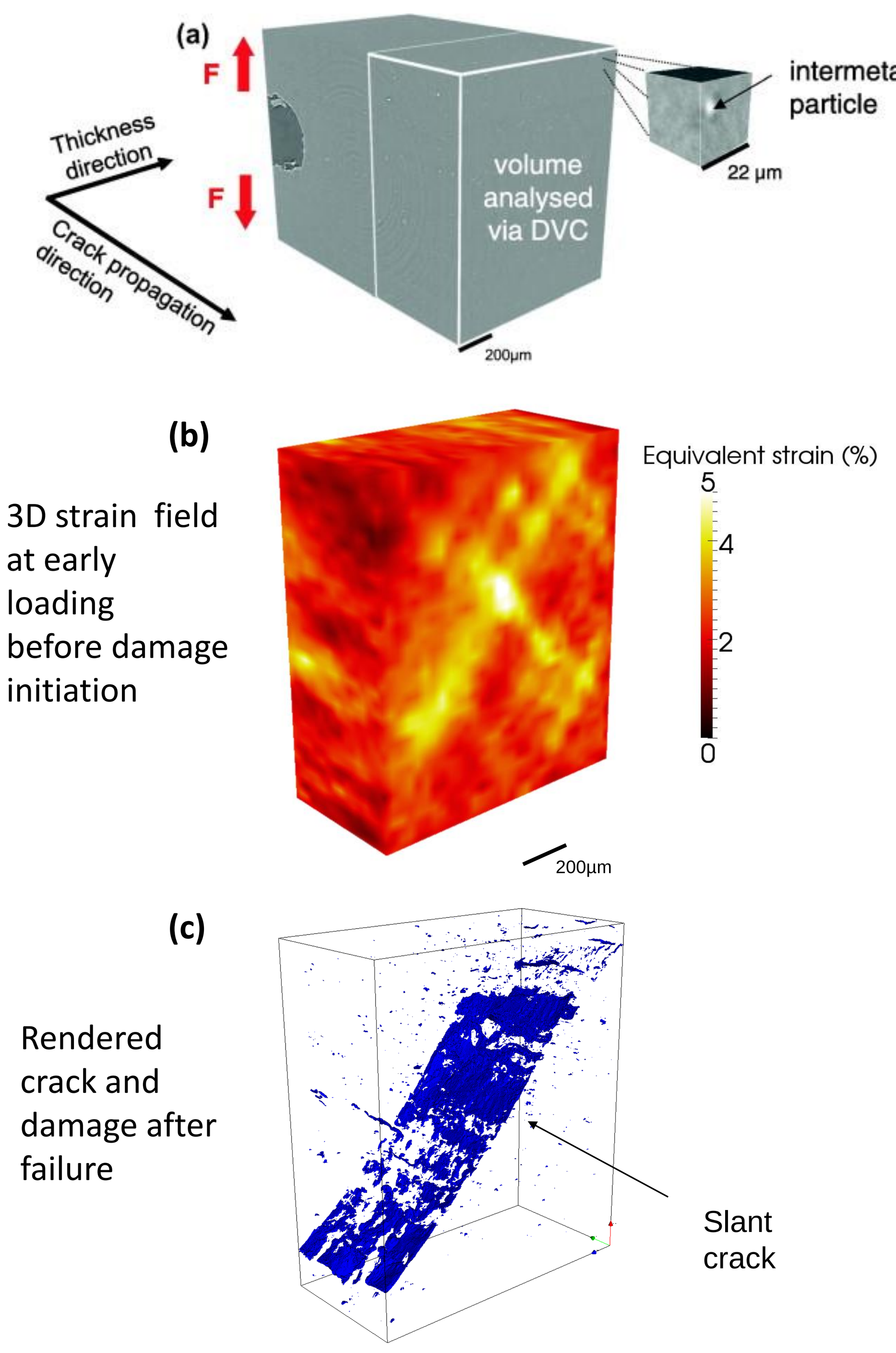
DVC (Correli C8) displacement field results:
X-displacement Z-displacement



Morgeneyer *et al. Experimental Mechanics*, **53**(4), 543-556, 2013

Early strain localization

In-situ 3D observation of early strain localization during failure of thin Al alloy (2198-T8) sheet: Early strain localization precedes crack path



Morgeneyer *et al., Acta Materialia*, **69**, 78-91, May 2014

CONCLUSIONS

1. Laminography provides unprecedented opportunities for observing damage mechanisms in **sheet material *in-situ*** as volumes of interest in laterally extended objects may be imaged. **Various mechanical boundary conditions** are possible.
2. The feasibility of the observation of **damage mechanisms** is shown.
3. Digital **volume correlation** using natural contrast such as intermetallic particles and voids allows to measure displacement fields in 3D.
4. The possibility may arise to derive **strain fields** and make the **link between strain and damage mechanisms** that is still poorly understood for the forming and tearing of thin sheet material.
5. It is found that **strain localizes first** in **slant strained bands** before damage onset.

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