In situ experiments using X-Ray tomography

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Outline

- Introduction
  - Motivation
  - X-ray imaging Setups
- 1. In situ capabilities of X-Ray tomography
  - Deformation
    - Tension
    - Double torsion, Hydrostatic pressure, Fatigue
- Temperature
  - Heating
  - Cooling
  - Mixed:
    - Hot tension
- 2. Case studies:
  - Ductile damage
- 3. FE and DVC
- 4. Prospects (high resolution, high speed)
Motivation for in situ experiments

- **Experimental mechanics**: identification of the mechanisms at play *mostly by imaging*
  - What is happening to the microstructure under load?
  - Thermal, Mechanical...

- Allows to:
  - Understand
  - Optimize
  - Model

- Standard ways used so far to achieve this: OM, SEM, TEM, AFM

- Ideal imaging method: non-destructive + bulk
All you need to know about XRCT (to understand this talk...)

- Radiography = bulk information but projected in 2D:
  \[ I = I_0 \cdot \sum(\exp(-\mu x)) \]

- Tomography (medical scanner) = 1000 radiographs of a same sample at different angles

- X-ray source + absorption detector + rotation stage

- Computed reconstructed step

- Final image = 3D map of \( \mu \)
SETUPS: Parallel/divergent beam

- Two different systems:
  - Synchrotron (parallel, monochromatic, intense)
  - Laboratory tomographs (divergent, polyλ, weak)

Different constraints on the in situ devices
Different ways of studying microstructural evolution

Whatever the observation method

- Post mortem
  - Several samples
  - Tomography at RT

- Ex situ
  - One sample
  - Treatment out of the tomograph

- Interrupted in situ
  - One sample
  - Treatment carried out on the tomograph

- Continuous in situ
  - One sample
  - Treatment carried out on the tomograph
  - No interruption
1. Deformation

A standard tensile frame (pillars) induces missing views ...reconstruction?
In situ testing

- Tension, compression

- Stepping motor
- Reductor
- F and disp recorded
- $10^{-5} - 1$ mm/s
- Several Force sensors: 50 – 5000 N
- Grips adapted for different geometries

Buffiere et al Exp Mech 2009
A lot achieved so far in the interrupted mode (15 years at the ESRF)

- Al/SiC
- TiSiC
- Al alloys
- Polymers, Composites
- Steels
  - DP, Trip, TWIP
- Co, Cu, Ti

Model materials

- Cu sheets
- Mc Master University

Industrial

- Al alloy 5xxx
From this initial machine: derivations
For a lab tomograph:
Faster (fatigue device)

- 50 Hz
- Tension mostly, Buffiere et al.
- Ex situ compression of metal hollow spheres, Caty et al.
- JY Buffière, W Ludwig
- Cracks initiate at the pore/surface intersection
2. Temperature
Furnances

- The problem of missing views vanishes
- Different technologies for heating
  - Lamps
  - Induction
  - Standard resistors
- The sample rotates in the furnance which is fix and equipped with windows for the X rays
Cooling
3. Both Temperature+Deformation
Tension test in the semi solid state
Two images of the specimen in reference state and in deformed state obey the following relation:

\[ f(x) = g(x - u) \]

Optical flow conservation.

From the knowledge of \( f \) and \( g \), the problem consists in estimating \( u \) as accurately as possible.
3D displacement fields

- Mainly mode I opening ($U_x$)
PHD T Zhang co supervized with Luc Salvo
Not broken

Highly stressed, no intermets
Prospects
Improve spatial resolution using KB mirrors

Use a conical beam on synchrotron to magnify

Spot size down to 20 nm
Temporal resolution

Using ID15 beamline (pink beam = high flux)
Resolution 1.5 µm
See previous movies
Conclusion

- In situ + X-Ray imaging brings a lot of new information in the field of materials science
- Radiography: no requirements
- Tomography: adapted devices
- + Digital volume correlation
- + FE simulation

= a complete set of new tools for experimental mechanics