

# Experimental detection and quantification of crack networks in heterogeneous materials using techniques based on 3D digital images

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# Introduction

- Micro-macro (structure-property) relationship

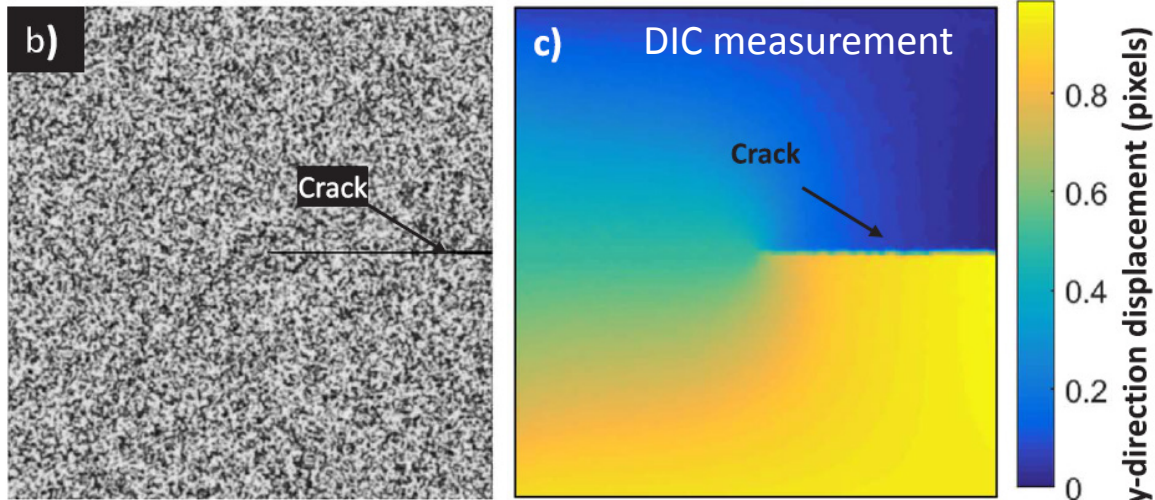
Composite materials

Microstructure

Fracture behaviour

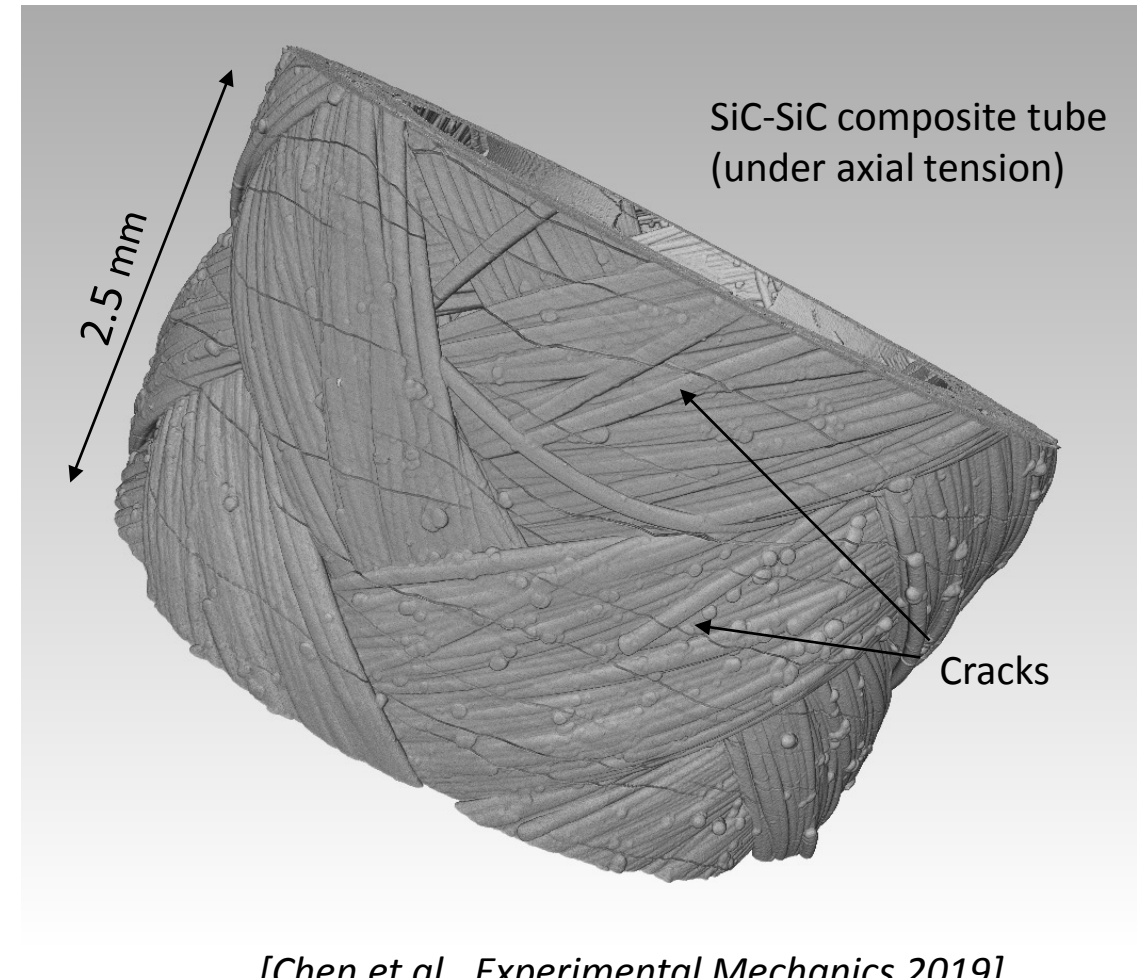
Microcracks

- If only a few cracks, ...



[Cinar et al., Optics and Lasers in Eng. 2017]

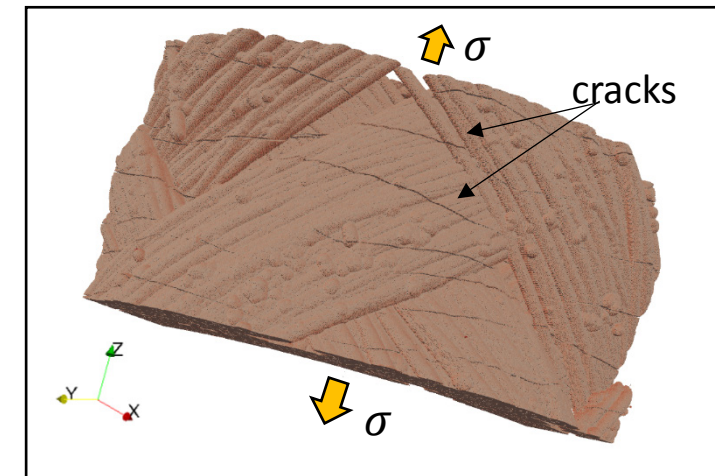
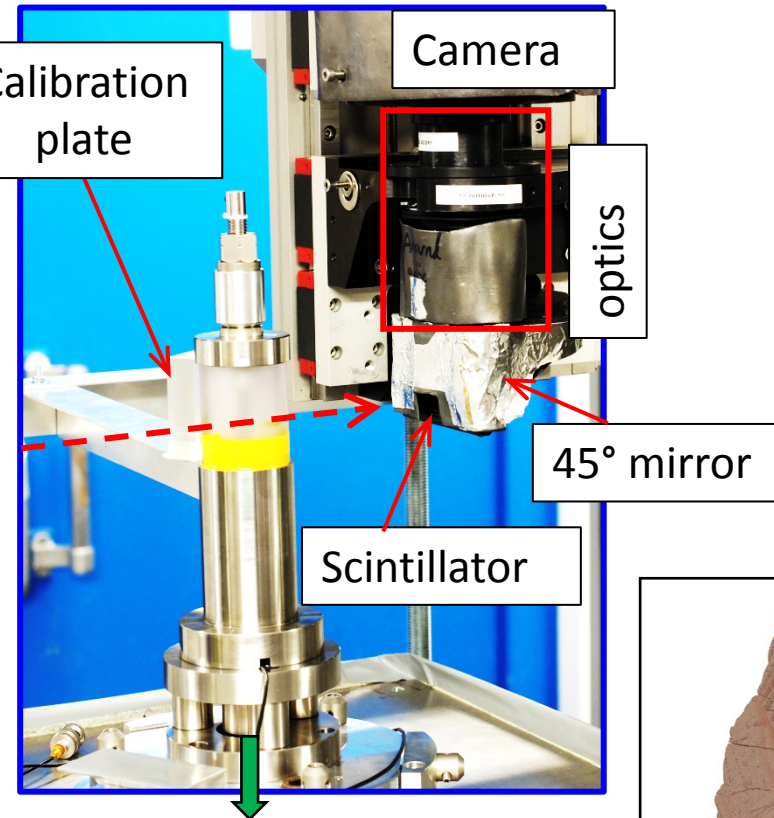
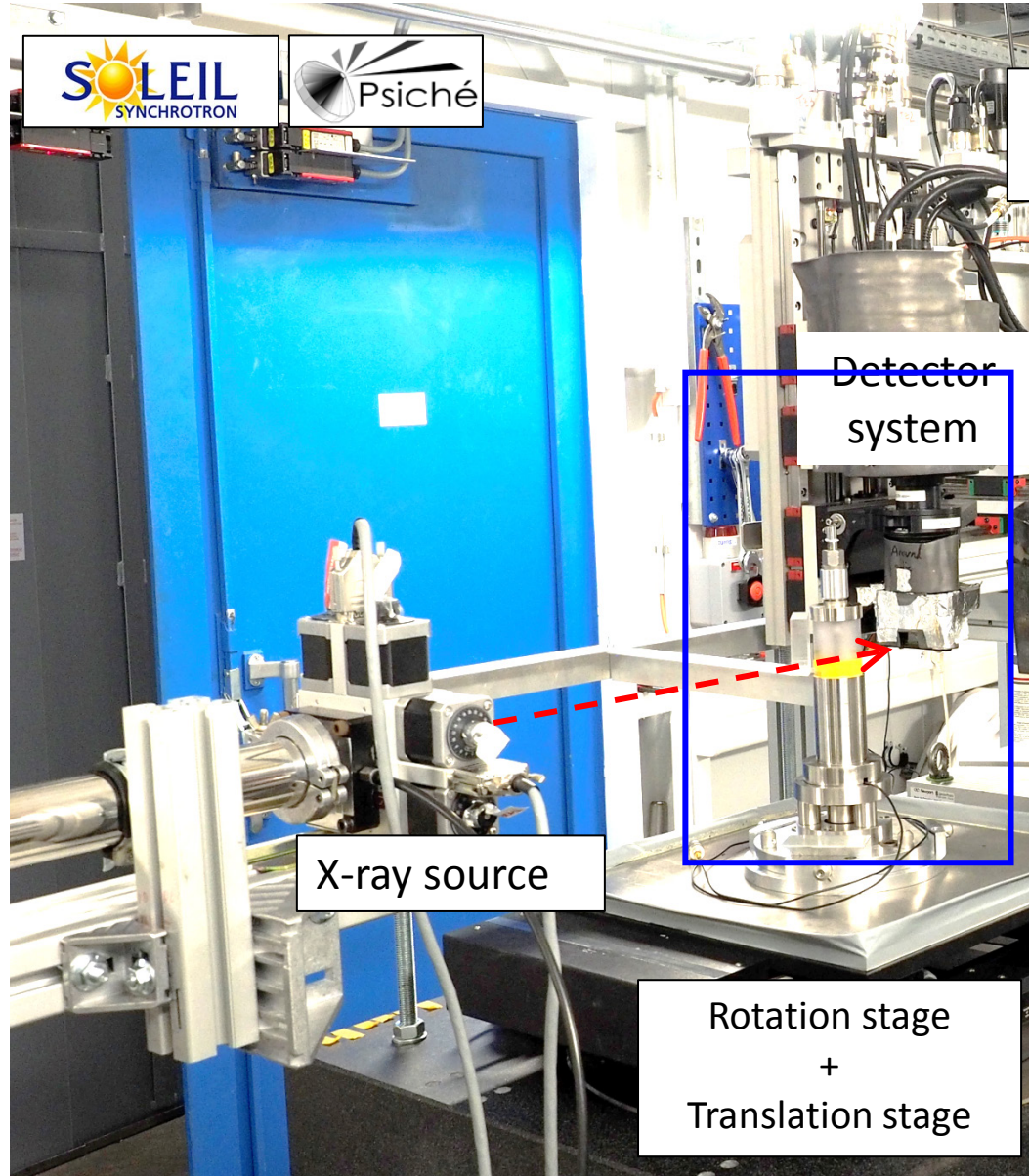
- However, in real composite materials, ...



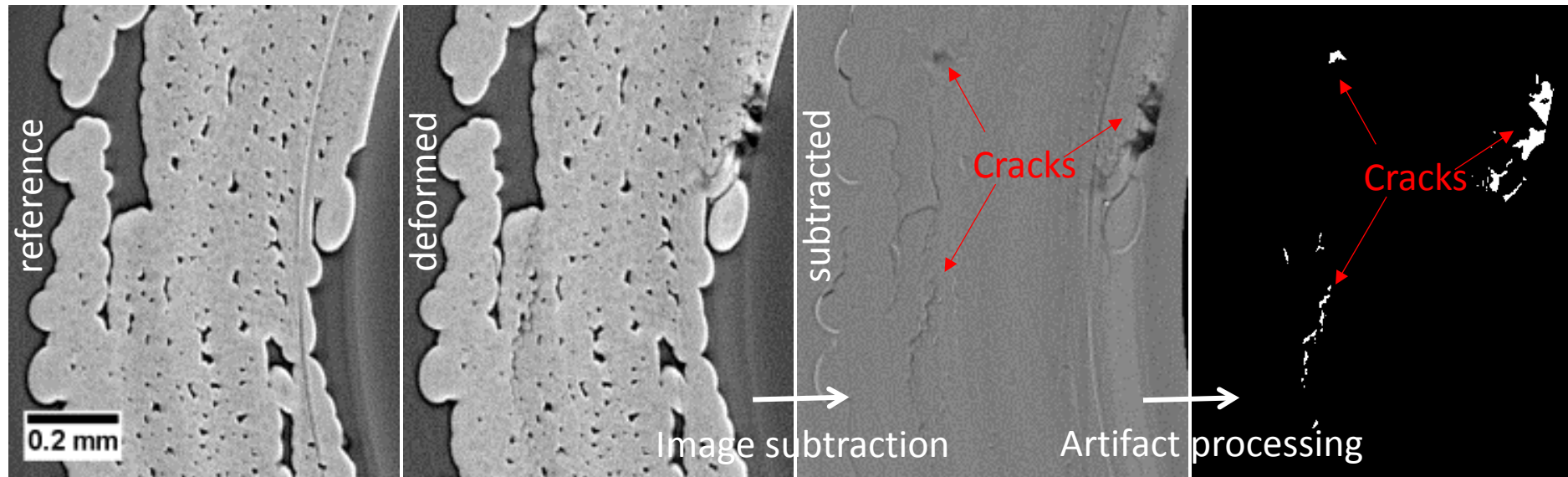
[Chen et al., Experimental Mechanics 2019]



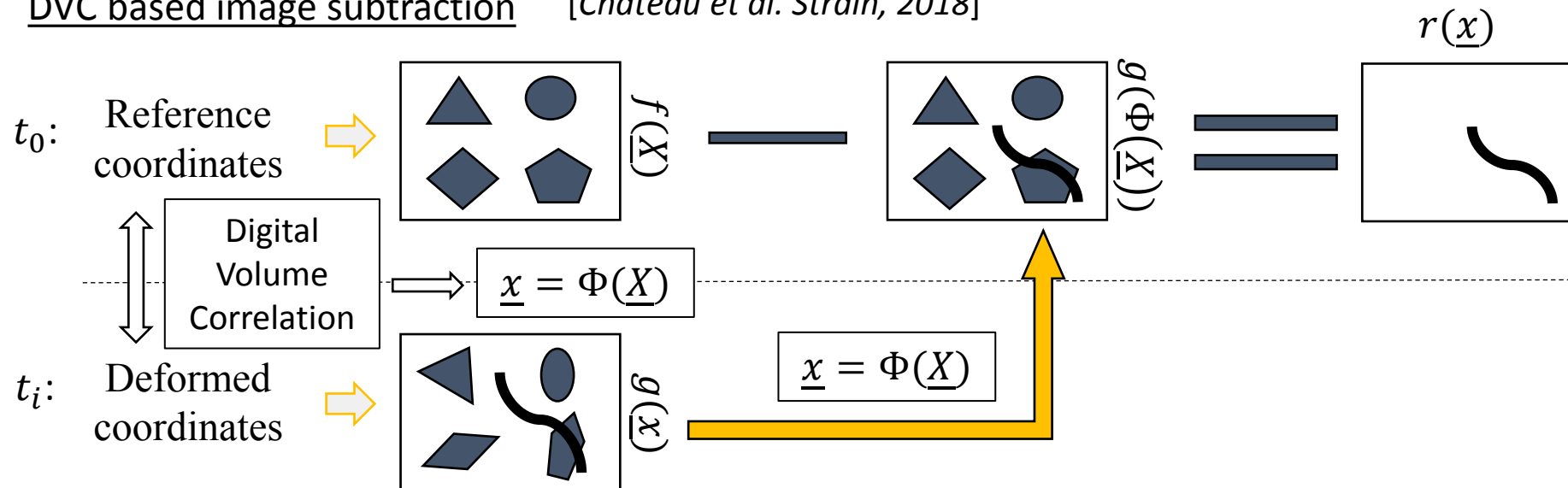
# In situ test with X-ray CT



# Crack detection: DVC based image subtraction



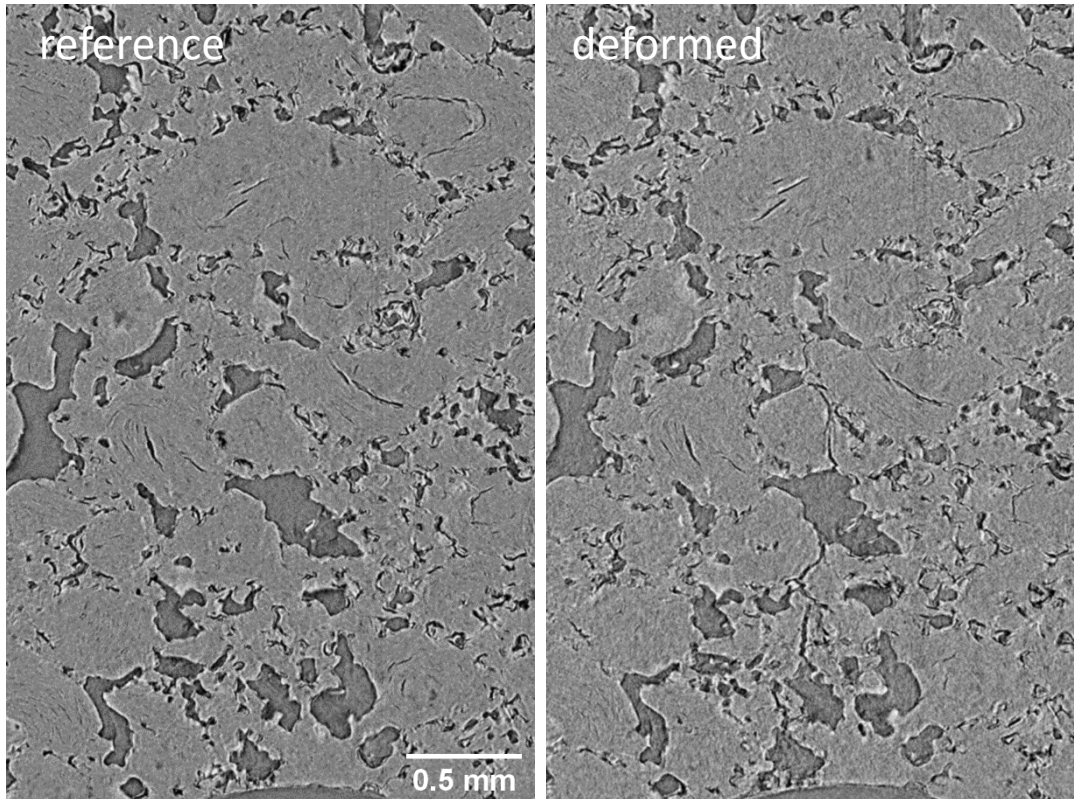
DVC based image subtraction [Chateau et al. Strain, 2018]



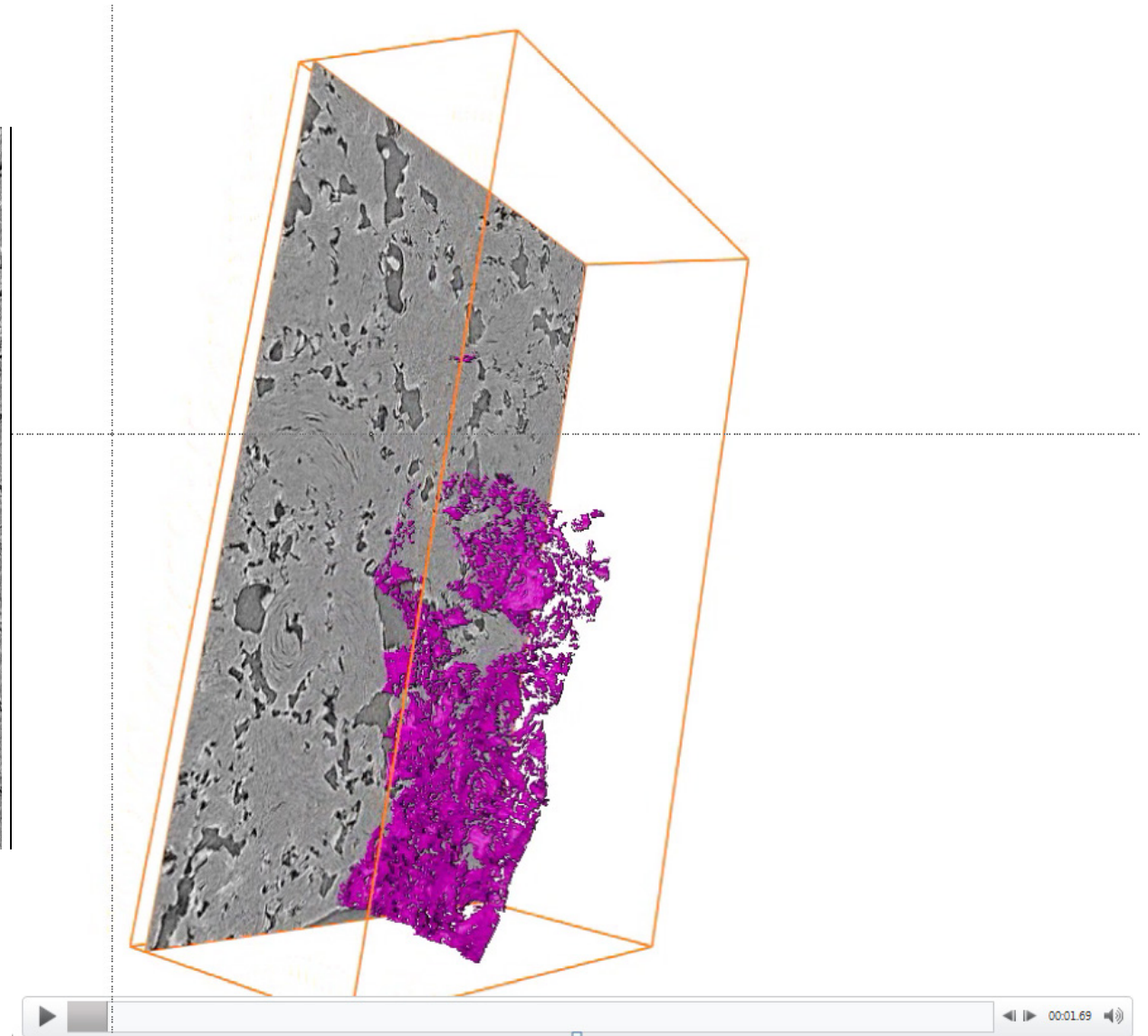


# Applications: Nuclear graphite

Quasi-brittle materials with fine image texture

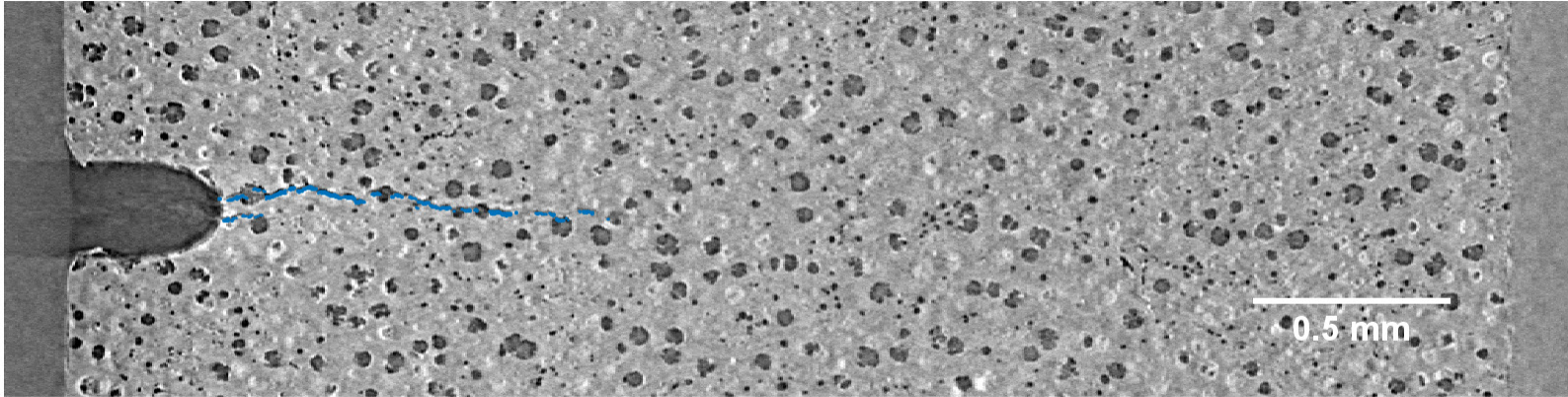


(under quasi-static loading)

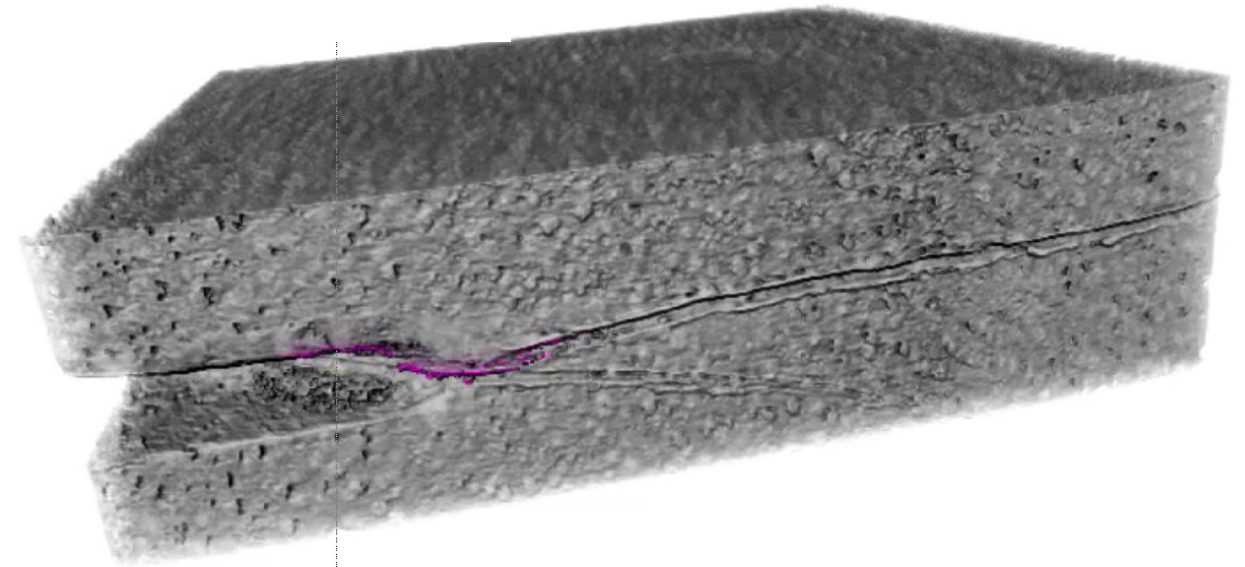


# Applications: Nodular cast iron

Ductile materials



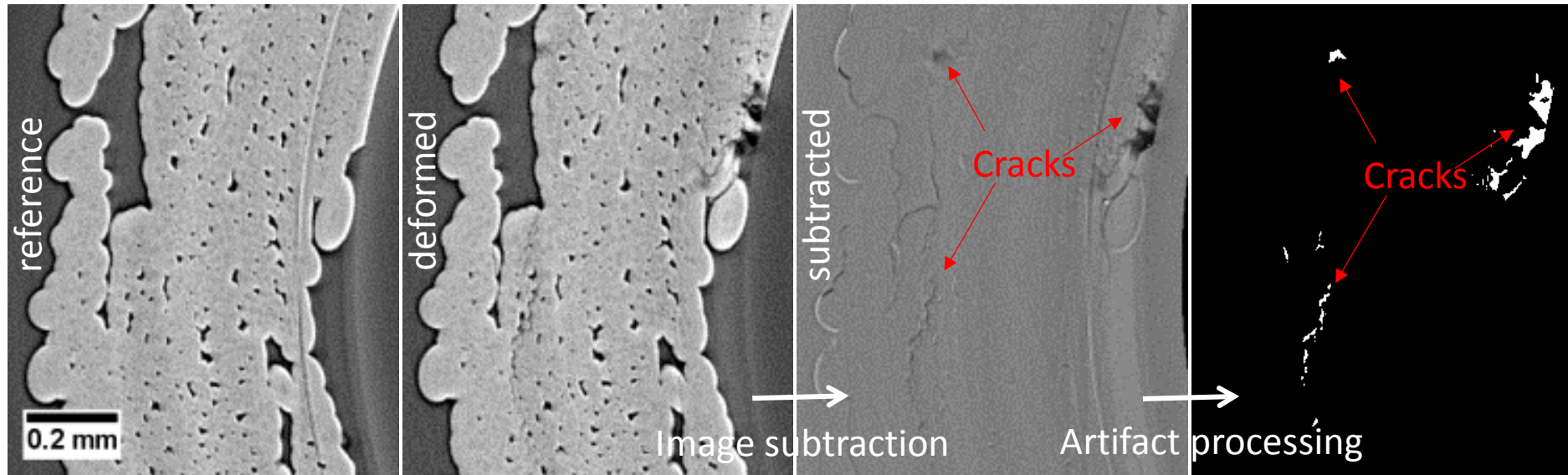
(under fatigue loading)





# Applications: SiC-SiC composites

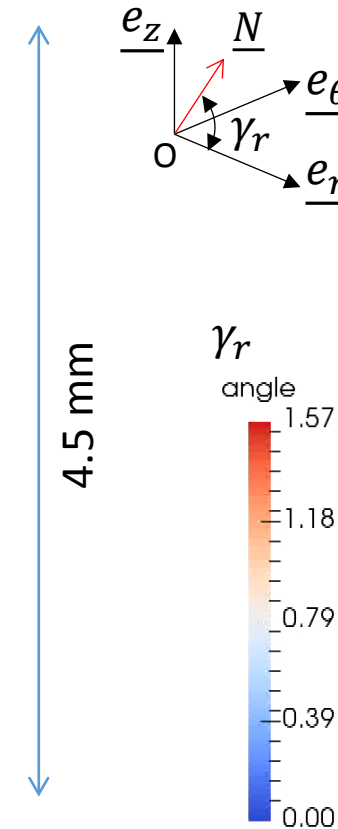
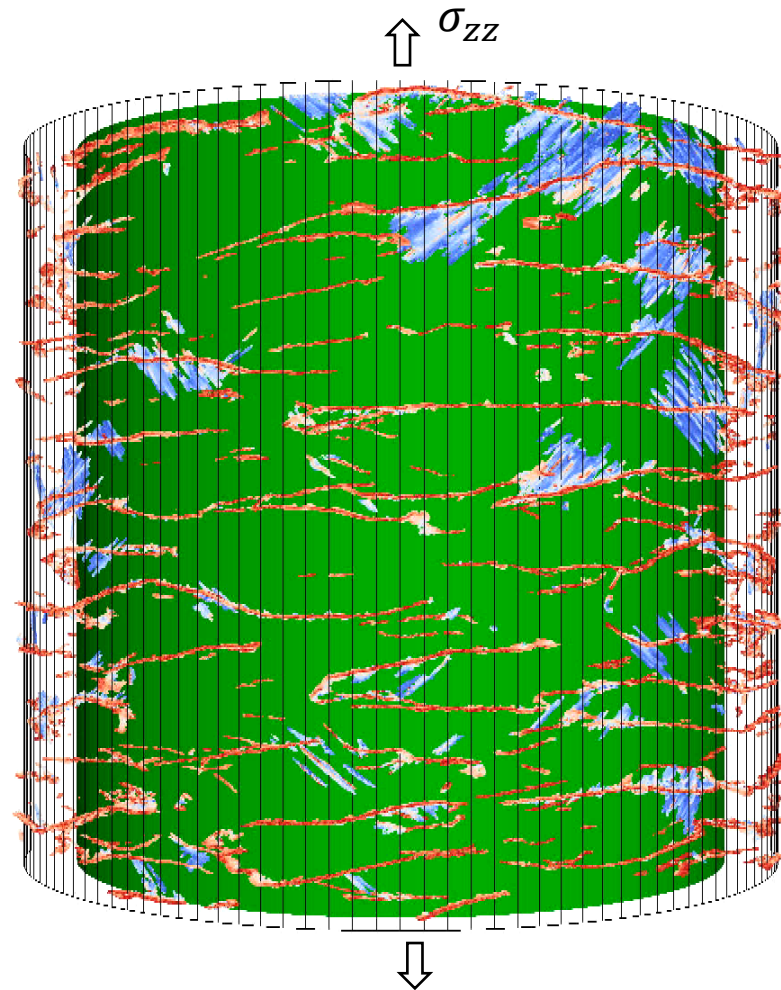
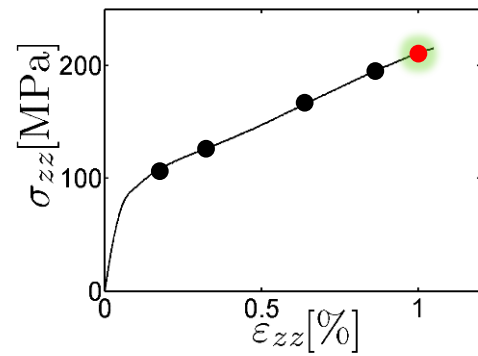
Quasi-brittle materials with moderate image texture



(under quasi-static loading)

# Applications: SiC-SiC composites

## ☐ Detected crack networks in SiC-SiC composites

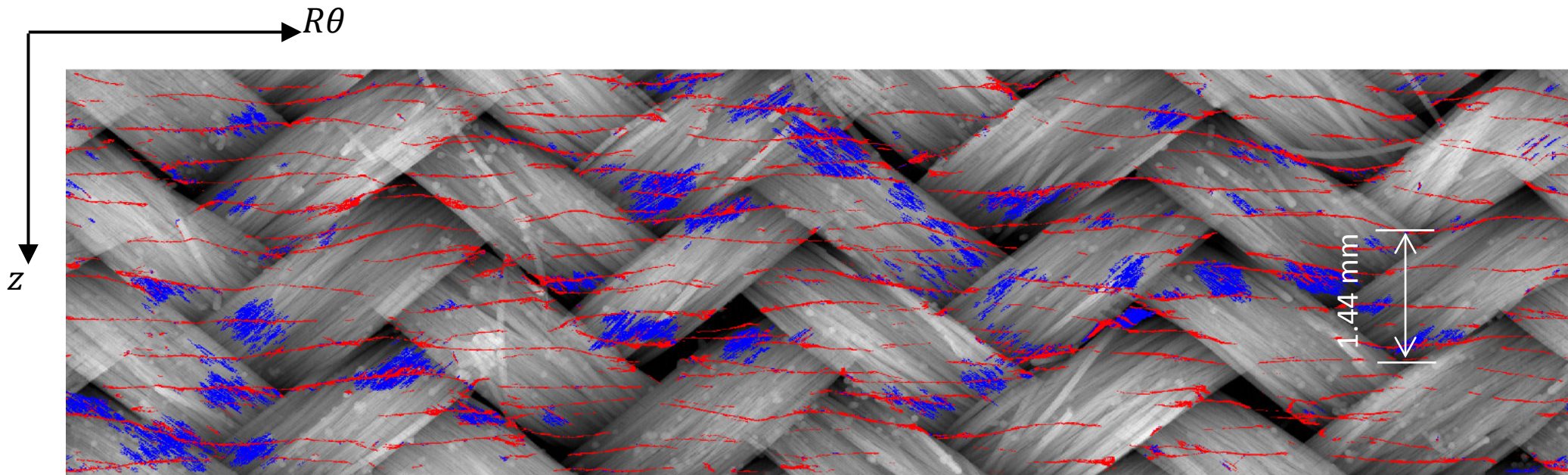
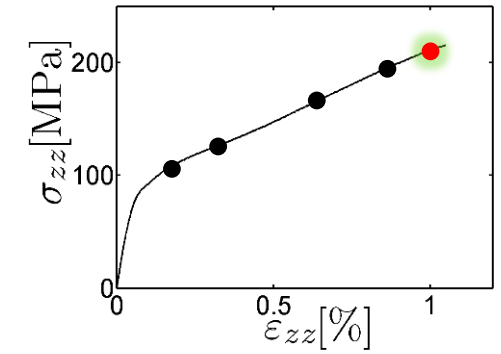
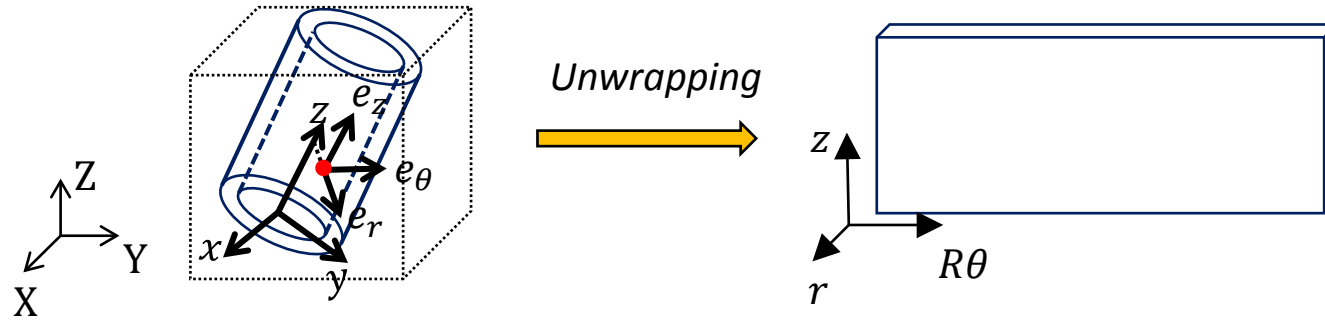


[Y.Chen et al., *Experimental Mechanics*, 2019]



# Applications: SiC-SiC composites

## Cracks and braiding structure



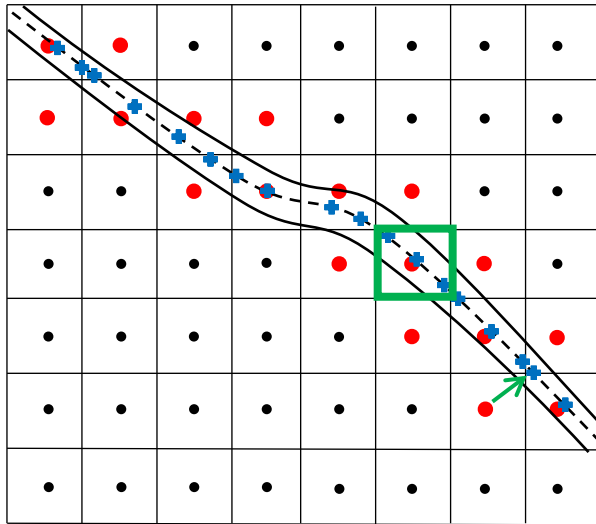
**Can we do more ?**

**Quantitative measurements ?**

...

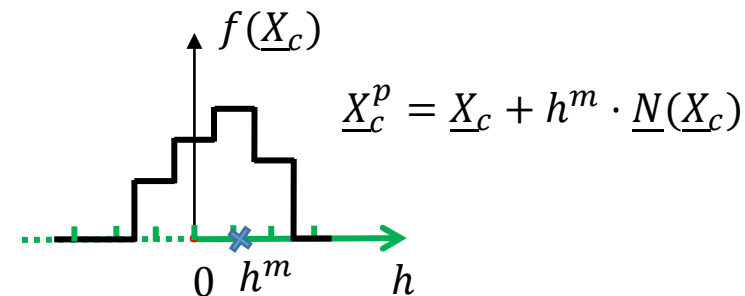
# Crack quantification: Grey-level based method

□ Crack in digital image: a set of points, each having a grey level

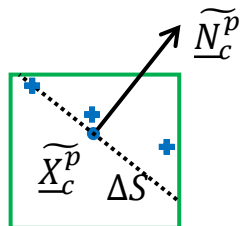


● Crack voxel    + Projected position

- Local normal direction ?  
→ Inertia tensor calculated around the considered voxel
- Projected position ?  
→ Grey level profile along the normal direction



- Local crack surface area  
→ plane-voxel intersection area



⇒ Crack surface area

- Local opening level → integration along  $\underline{N}$

$$f(\underline{X}_c) \xrightarrow{[0, 255]} d(\underline{X}_c) \xrightarrow{[0, 1]} \frac{f(\underline{X}_c) - f_{solid}}{f_{void} - f_{solid}}$$

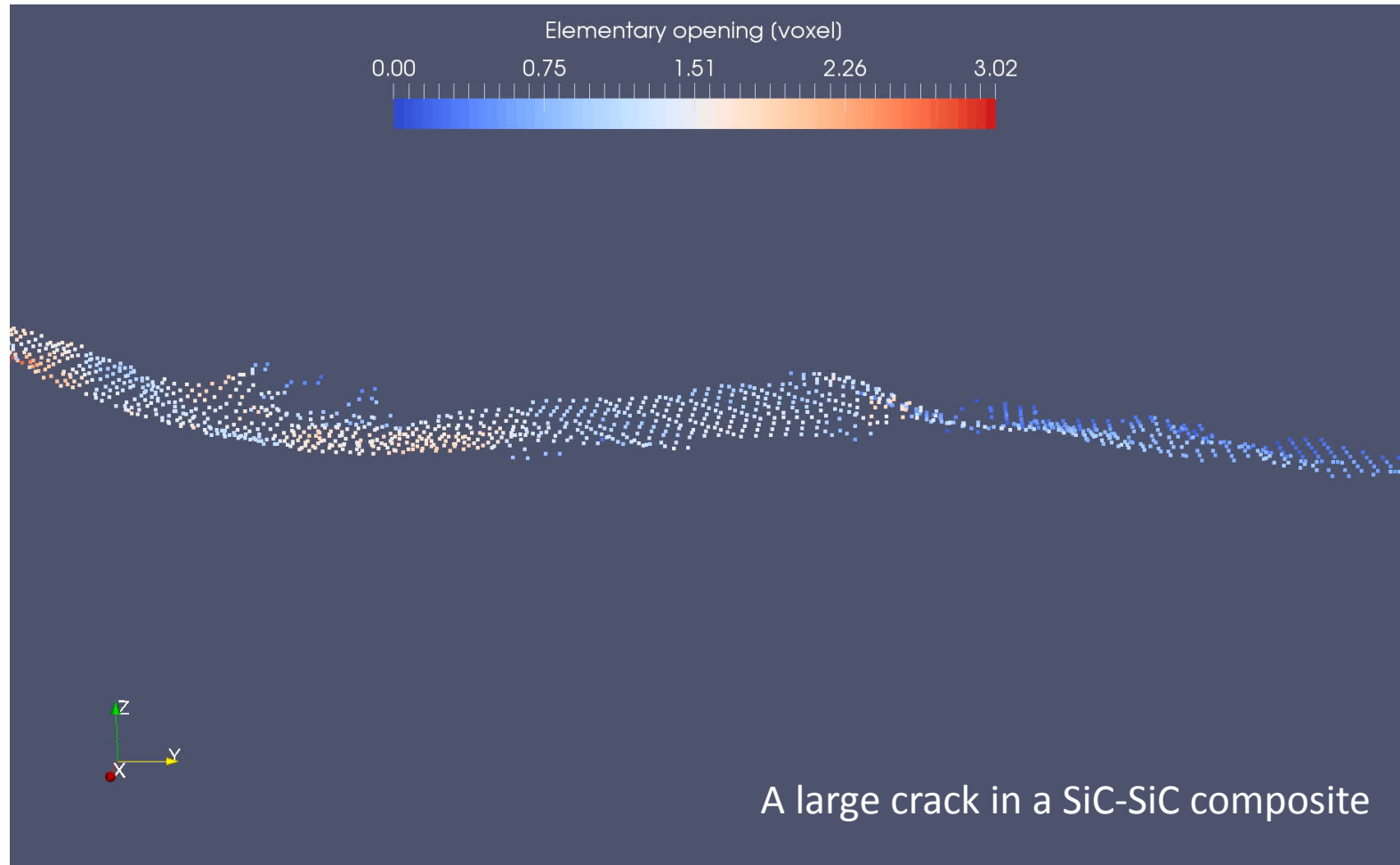
Physical meaning of grey level for XCT image: Beer-Lambert law

⇒ Crack opening



# Crack quantification: Grey-level based method

- 3D visualisation of the projected positions with local opening levels described by different colours



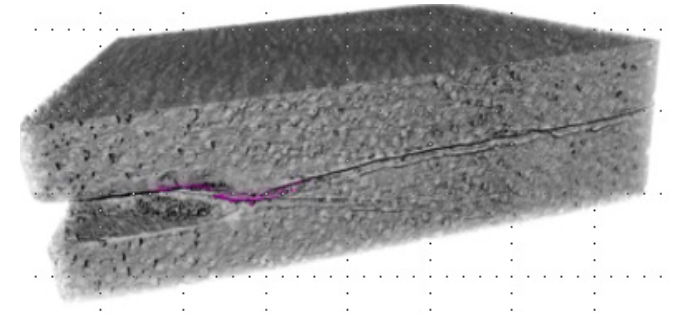
# Crack quantification: Grey-level based method

## Comparison with another quantification method

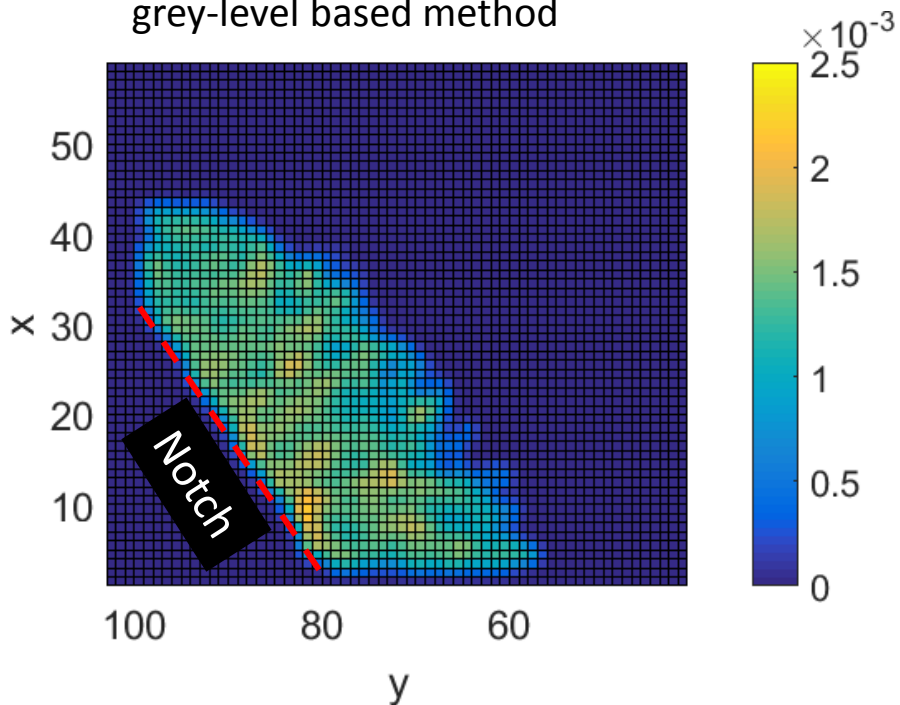
↑ measurement from DVC displacement field  
[Cinar et al., 2017]

- Similar magnitude of crack opening
- Similar crack tip position

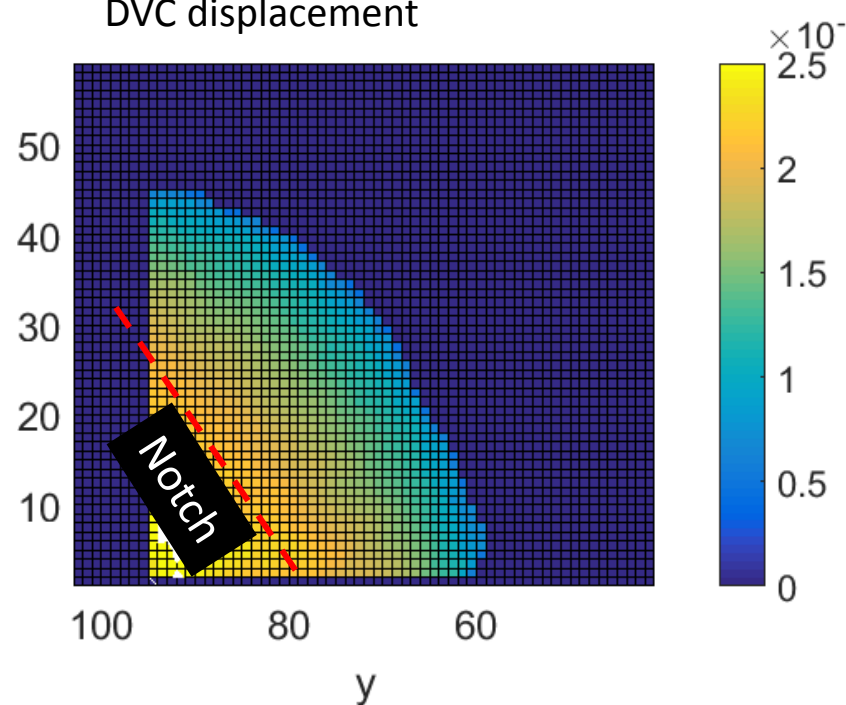
Cast Iron – fatigue test



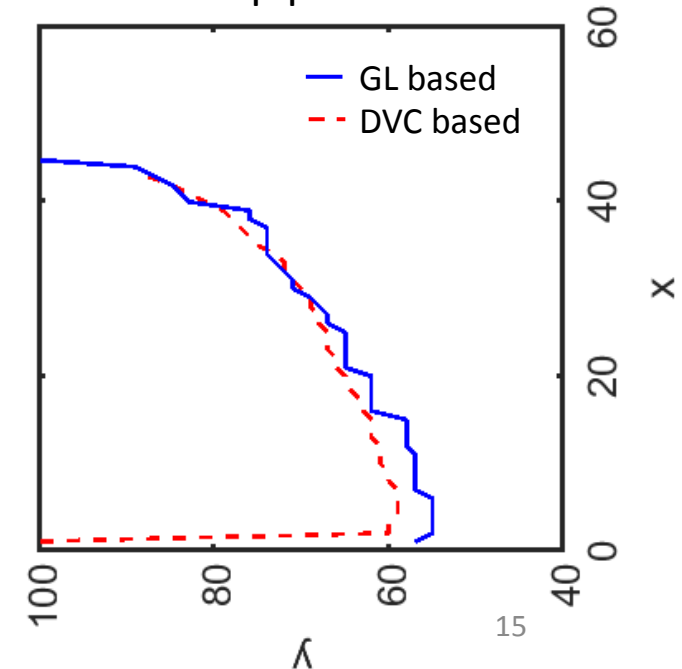
Crack opening measured by grey-level based method



Crack opening measured from DVC displacement



Crack tip position



# Concluding remarks

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Now, we can do:

- Detection of crack networks in complex heterogeneous microstructures
- Measurement of crack opening and surface area

Limitations ?

...

Useful ?

- For understanding the micro-macro (structure-property) relationship
  - 3D information on crack **networks**
  - Quantitative measurement
- For numerical modelling
  - Validation of numerical models
  - Identification/Calibration of numerical models