

# Full 3D Strain Field analysis with in-situ $\mu$ CT based Digital Volume Correlation

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## Introduction

Strain analysis in mechanical loading experiments is typically carried out via Digital Image Correlation (DIC) as well as post mortem acquired cross-sectional micrographs. Therefore knowledge of initial failure and damage development relies either on surface- or unloaded-state data which both do not necessarily represent bulk material behavior.

By using high resolution in situ X-Ray tomography together with Digital Volume Correlation (DVC), full 3D strain fields in the investigated sample volume are determined. Local 3D knowledge of strain development provides extended insight in the initiation of damage leading up to material failure and thus supports understanding and predicting material failure.

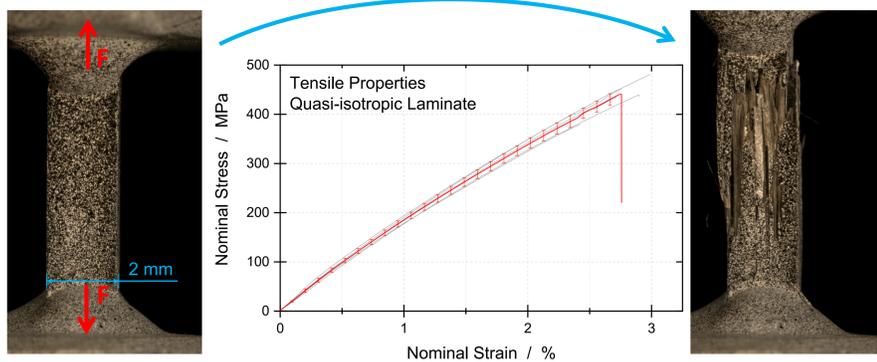


Figure 1: Investigation of the stress-strain behavior is typically based on analysis of the specimens surface. A DIC-algorithm captures the deformation while load increases until it ultimately fails (right). The mechanical characterization considers no preliminary effects inside the material.

Exemplary for modern composites, BFRP was chosen. The difference in attenuation of fiber and polymer gives rise to an excellent X-ray contrast. Making use of non-destructive in-situ  $\mu$ CT imaging in combination with the state of the art DVC toolbox elastix [1] enables locating the full 3D strain field within the sample volume.

## BFRP In-Situ Testing

A BFRP specimen, fixed in a loading rig, is placed in a laboratory  $\mu$ CT (Figure 2). A series of CT measurements is carried out, starting with an unloaded state, followed by successively increased loading states. The CT data is then investigated by DVC to determine the strain and to detect defects such as cracks inside the structure volume, see Figure 3.

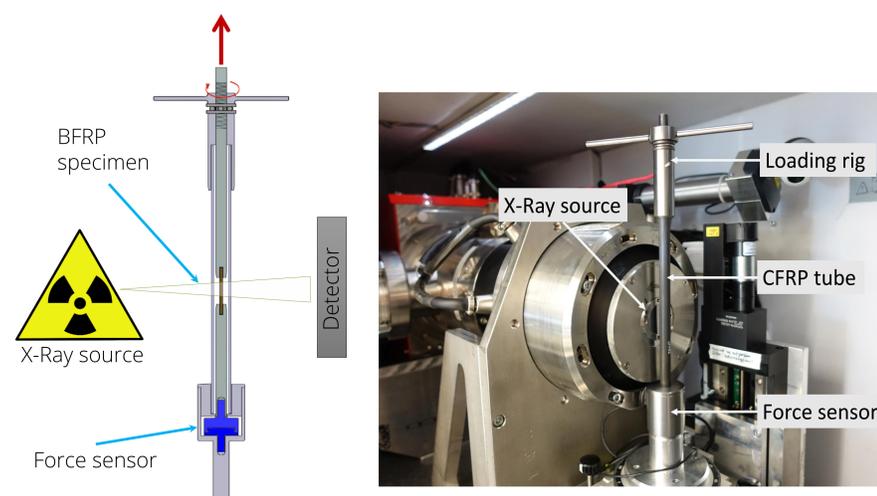


Figure 2: Sketch of the loading rig for in-situ testing (left). By turning the wing nut at the top, the inner rod is pulled upwards and initiates tensile stress in the specimen. Right: Picture of the measurement chamber inside the CT. To achieve the required magnification, the distance between X-Ray source and the loading rig is only 2 mm.

## DVC for Material Science and Biomaterials

DVC is the 3D extension to the well-established DIC. It enables detection of 3D displacement fields within the full volume of a sample, based on CT-images acquired under varying loads.

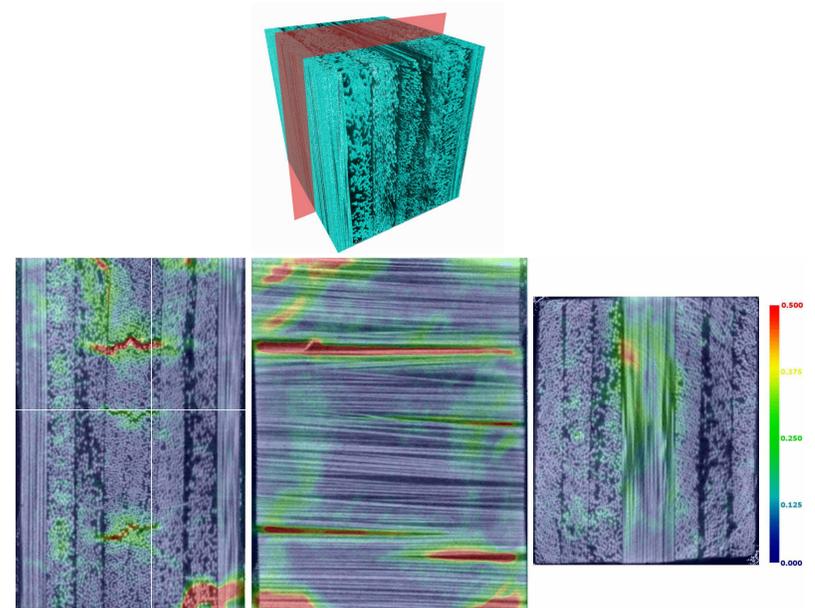


Figure 3: Top: Volume rendering of the 1.7x1.9x2.8 mm<sup>3</sup> BFRP sample with indication of the coronal slice position. Bottom: Ortho CT-slices superimposed with strain field information (strain[-]). Cross-hairs (left) indicate the spatial position of the sagittal (center) and axial (right) slices.

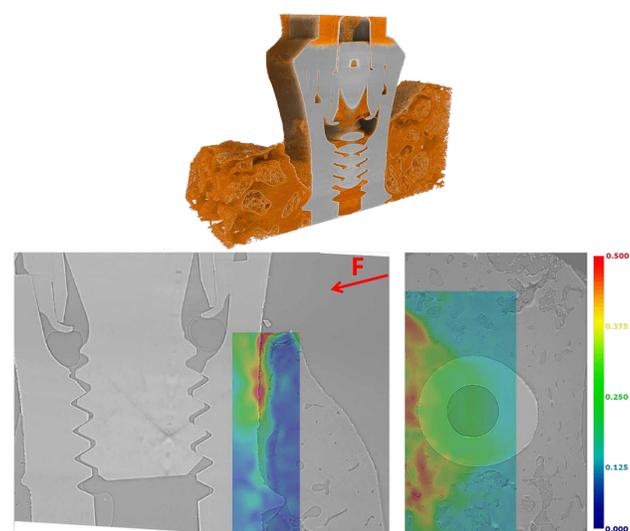


Figure 4: Top: Volume rendering cut through the center of a Titanium screw in a jaw bone [2]. Bottom: CT-slice of a ROI superimposed with strain field information of a sagittal (left) and an axial (right) slice.

## Conclusions

In situ CT measurements in combination with DVC are a great enhancement to regular strain analysis as they provide information about the strain distribution in the whole sample volume. This gives rise to improved failure detection as well as better prediction of material behavior and local damage initiation.

## References

- [1] S. Klein et al., "elastix: a toolbox for intensity based medical image registration", *IEEE Transactions on Medical Imaging*, vol. 29, no. 1, pp. 196 - 205, January 2010.
- [2] CT-Data courtesy of Prof. Dr. Nelson, Department of Oral and Maxillofacial Surgery, Regional Plastic Surgery, Faculty of Medicine, Medical Center - University of Freiburg.