X-ray Computed Tomography Investigation of Structures in Claystone at Large Scale and High Speed

G. Zacher[1]*, A. Kaufhold[2], M. Halisch[3] , I. Britto[4]
[1] GE Sensing & Inspection Technologies GmbH, phoenix|x-ray, Niels-Bohr-Str. 7, 31515 Wunstorf, Germany
[2] Federal Institute for Geosciences and Natural Resources, Stilleweg 2, D-30655 Hannover, Germany
[3] Leibniz Institute for Applied Geophysics, Stilleweg 2, D-30655 Hannover, Germany
[4] GE Oil & Gas Measurement & Control Solutions, Rua 36 (Praia dos Coqueiros), Ilha do Bom Jesus, Rio de Janeiro, Brazil
* presenting author

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Summary

In the past years X-ray Computed Tomography (CT) became more and more common in geo-scientific applications and is used from the µ-scale (microfossils) up to the dm-scale (cores or soil columns). Hence a variety of different systems was adapted to these applications.

In the present paper we investigate CT results from an Opalinus Clay core (diameter ~100 mm) considering the 3D distribution of cracks. Two CT systems are compared both, with specific ad- and disadvantages:

the large and flexible phoenix v|tome|x L300 high energy CT scanner and the high throughput speed|scan CT 64 helix CT system (both GE Measurement & Control).

The results are compared regarding the contrast resolution, spatial resolution, and scanning speed. The fast medical scanners provided a quick overview whereas the microfocus tube provided a more detailed view on cracks.

Introduction

During the last years, the non-destructive investigations using X-ray Computed Tomography (CT) of geomaterial became more and more important. Especially in the field of geomechanical investigations, it is essential to get information about the mineral composition, spatial distribution of minerals, pores, and fractures – before and after mechanical tests. All these parameters have to be characterized to be able to increase the understanding of deformation processes.

The Opalinus Clay sample was first scanned with the speed|scan CT 64 located at the GE facility in Ahrensburg (Germany). The scan was recorded with 140 KV and 140 mA within 13 seconds at a spatial resolution of approx. 0.3 mm. The reconstruction was performed automatically. The 3D data, therefore, could be evaluated after 30 seconds.

Secondly, a CT scan of the same sample was recorded with the v|tome|x L300 system at the GE facility in Wunstorf (Germany). The scan parameters were 270 KV and 0.3 mA and the scan duration was 145 min. With this system a spatial resolution of approx. 60 µm could be achieved.

Material and Methods

The specimen “file 13001” (drilling BLT-A6) was derived from the Underground Rock Laboratory (URL) Mont Terri (St. Ursanne, Switzerland) and belonged to the sandy facies of the Opalinus Clay (Kaufhold et al. 2013). The investigated core sample had a diameter of 100 mm and a length of 180 mm. The drilling was orientated perpendicular to the bedding. The material of the sandy facies in the URL Mont Terri consists of 20-40 wt.% carbonates, 30-50 wt.% quartz, and 15-25 wt.% clay minerals (< 5 wt.% swellable clay minerals). The natural water content of the specimen was preserved as good as possible,

Mechanical Testing

The claystone was tested by triaxial strength testing until a failure was developed. The test was executed in deformation controlled mode with a deformation rate of dε/dt=10-5 s-1 and carried out under undrained condition. After the mechanical testing the core was embedded in a resin to stabilize the specimen.

Fast Computed Tomography

Based on a medical CT gantry adopted for high throughput and harsh production environments, the new speed|scan CT scanner allows to record CT scans several hundred times faster than with a conventional fan beam CT. The system consists of a dust protected radiation protection cabinet with an integrated, rotating ring-shaped scanning device (gantry) and sample transport system for moving components through the scan ring. The system may accommodate samples of up to 900 mm in length and 500 mm in diameter. The CT datasets are automatically generated in the so-called helix scan mode with a high performance rotating anode X-ray tube and a 64 channel multi-line detector rotating around the sample.

CT scanning, volume reconstruction and evaluation, documentation, archiving, network transfer, and result display happen simultaneously allowing an overall cycle time of typically 1 minute per inspected sample (Ambos et al., 2014).

Results

Large Scale and High Speed X-ray CT results

The CT results of the speed|scan CT 64 show good contrast resolution due to its high power (up to 72 kW). Layering within the core can be easily detected based on slightly changing density (see figure 1). Cracks and pores can be spatially resolved down to 0.5 mm. The 3D data set can be virtually sliced in any direction to emphasize the specific layering or location of the crack system.

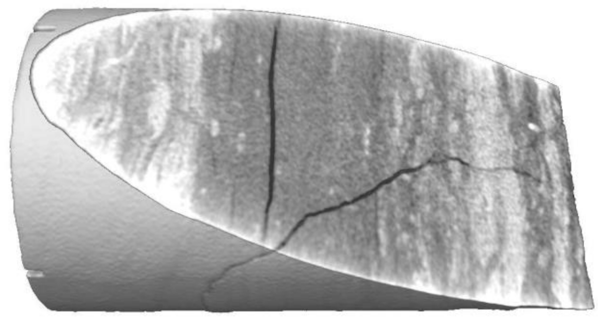

Figure 1. 3D view of the speed|scan CT result. The virtual slice shows the inner structure (layering, cracks).

Large Scale and High Resolution X-ray CT results

Compared to the faster device explained in the preceeding paragraph, the CT results of the v|tome|x L300 show much better spatial resolution (down to ~60 µm for 10 cm sample width). As the highest power of this system is 0.5 kW, the contrast is not as high but still sufficient to detect different densities. On the other hand the fractures are much better resolved (5 times better resolution) and the delicate network can be nicely visualized (see figure 2). The segmentation was performed in the central part of the sample, where one large horizontal crack is intersected by a diagonal oriented crack system. Additionally, many cracks which are located close to the core surface could be observed.

Figure 2. Transparent 3D view of the L300 CT result. Cracks are segmented (red colour).

Conclusions and Outlook

The fast analysis with X-ray CT based on medical scanners (here speed|scan CT 64 in the first example) is suitable to give an overview of large core samples and the high throughput enables a 3D documentation of large core archives.

On the other hand, the use of microfocus tubes (as in the second example on the v|tome|x L300) can provide much more detailed images necessary for special high resolution core analysis.

For the understanding of deformation processes during mechanical testings detailed information before and after the mechanical testing are required. Thus, it is necessary to get micro fabric information of the undisturbed specimen and after the mechanical test an overview of the deformed specimen. Using the overview scan it is possible to select regions of interest (ROI) which then can be analysed in more detail using high resolution CT devices. An example is given in Figure 3. The fast scan 3D data set was analysed and a suitable position for further micro plugging could be identified.

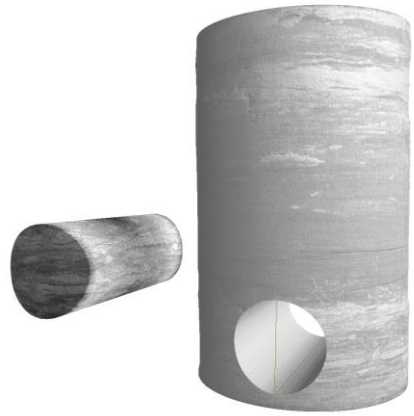

Figure 3. 3D view of the L300 CT result. The virtual plug has a typical diameter (~4 cm) used for additional experiments.

The selected area will be analysed using high-resolution CT techniques, as well as mineralogical and geochemical methods. The overall aim of the investigation of the Opalinus Clay (LT-A Project, Mont Terri) is to understand the rock deformation processes upon mechanical stresses. This behaviour is largely governed by microstructure. CT investigations, therefore, are the key methods.

Additionally, chemical and mineralogical methods are used not only to characterize the stiffness of the matrix but also to identify homogeneous areas which can be considered representative of the entire rock. Hence, the CT information gathered from a small volume can be used to understand the mechanical processes of the entire rock.

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