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MULTISCALE MECHANICAL MODELLING OF CHALK

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Summary: Tomography data for chalk, a highly complex rock, was taken from both synchrotron based nanoCT and laboratory µCT. Elastic mechanical properties of the rock were derived via multiscale finite element simulations combining the high resolution of nanoCT with the larger volume imaged in µCT.

1. INTRODUCTION

Chalk is a highly porous rock comprising a large part of subsurface in countries bordering the North Sea. A large volume of groundwater and hydrocarbon reserves are hosted in chalk, thus, studying its complex pore morphology and deriving petrophysical parameters is of importance for a range of applications relevant to society and industry. Chalk is formed from the remains of ancient algae, i.e. coccoliths. Depending on the rock forming conditions, a large part of these coccoliths (a few µm in size) do not recrystallized. This leads to a pore system in chalk that is on the nanometer and submicrometer scale. To image the microstructure of this rock using X-ray tomography and based on these images derive its physical properties, ultra-high resolution is needed [1]. However, higher resolution comes at the cost of a smaller field of view. To overcome this limitation, we present a method to combine synchrotron based nanoCT with laboratory based µCT and demonstrate how to derive elastic mechanical properties using this multiscale modelling approach.

2. EXPERIMENTAL METHOD

Millimeter sized pieces of chalk, taken from core plugs from off-shore drilling sites, were examined using microscale tomography (µCT) (Fig. 1a) collected using an Xradia 420 instrument at the Technical University of Denmark with a voxel size of ~1 µm. NanoCT data were recorded at the BL47XU beamline at SPring-8, Japan (Fig. 1a, inset) with a voxel size of ~40 nm. We took $(6\ \mu m)^3$ sized subvolumes of the nanoCT data and segmented and meshed the data in the finite element software package FEBio. Using a tensile testing setup, we were able to derive a porosity-elasticity relationship on the nanoscale [2]. This relationship is used to determine the Young's modulus for each voxel in the µCT data based on porosity derived from the greyscale value of the individual voxels. We used a similar tensile testing setup for subvolumes of µCT data (Fig. 1b), where we employed a uniform hexahedral mesh to have each voxel correspond to one hexahedral element. With this setup, we were able to derive elastic properties for larger subvolumes of µCT data $(80\ \mu m)^3$ while making use of the high resolution of nanoCT data.

3. RESULTS

The multiscale model shows that it is possible to combine synchrotron based high resolution nanoCT with laboratory µCT. This has two advantages. Firstly, a larger field of view, and thus more a representative data set, from µCT can be employed to derive mechanical properties while implicitly using the high resolution from nanoCT. Secondly, properties for a large number of samples can be estimated more reliably using only a laboratory source. Our preliminary results show that the porosity-elasticity relationship derived from the nanoCT data is reproduced quite accurately on the microscale for some samples but not for all. The origin of this difference is subject to further studies.

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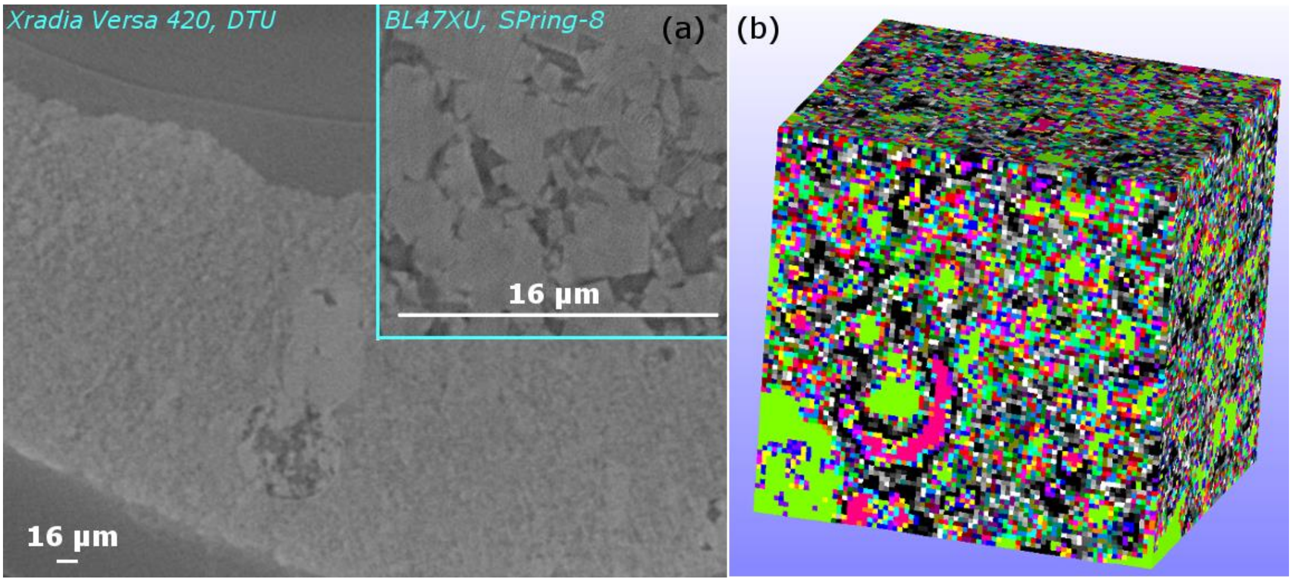

Figure 1: (a) Slices of tomography data on chalk recorded on a laboratory µCT instrument at DTU and at beamline BL47XU, SPring-8, Japan (inset). (b) Subvolume of the µCT data (the cube has side length of 80 voxels) imported and meshed in finite element software. The color code corresponds to local effective Young's modulus determined by the porosity-elasticity relationship derived from the nanoCT data.