TIME-RESOLVED X-RAY MICRO TOMOGRAPHIC STUDIES OF SHEAR FAILURE IN A NON-POROUS ROCK

Neelima Kandula*[1], François Renard †[1], Jérôme Weiss [3], Dag Kristian Dysthe [2], Benoît Cordonnier[1,4] & Maya Kobchenko [1]

[1] Departments of Geosciences, University of Oslo, Norway
[2] Departments of Physics, University of Oslo, Norway
[3] ISTerre, Universite´ Grenoble Alpes and CNRS, CS40700, Grenoble 38058, France
[4] The European Synchrotron, ESRF, beamline ID19, Grenoble, France

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Summary: X-ray micro tomographic imaging of the evolving microstructure of rock samples under triaxial deformation was performed using the rig, HADES installed on the beamline ID19 at ESRF. This rig at laboratory scale can simulate conditions of pressure and temperature similar to that of Earth`s crust. Three core samples of Carrara marble under confining pressure between 20 and 30 MPa were deformed until failure. The microstructural origins of localised damage, precursors to rupture is quantified and correlated with macroscopic failure.

1. INTRODUCTION

Characterising microscopic mechanisms that control mechanical failure in crustal rocks is necessary to better understand geological processes in the Earth's crust such as earthquakes. Owing to their material characteristics, rocks of Earth`s crust tend to yield when subjected to external stresses. Brittle compressive failure in quasi-static limit is one such complex yielding phenomenon exhibited by low/non-porous rocks like marble and in recent years much attention has been given to understand it [1]. Damage is preceded by precursory phenomena originating from local heterogeneities at microscopic scale. Numerous micro cracks are observed to grow and accumulate into a shear fault at final rupture directing the problem towards statistical consideration. Non-destructive time-resolved X-ray micro tomography along with HADES deformation apparatus is a novel experimental technique for four dimensional imaging of microstructure of rock samples that can provide information on micro crack population. Understanding precursors to failure can further help in unraveling the physics of precursors to rock rupture at large scales.

2. EXPERIMENTAL METHOD

The experiments were performed at the European Synchrotron Radiation Facility (ESRF) using an in-house triaxial deformation apparatus built by Sanchez Technologies, called HADES (Figure 1a). This rig is installed on the beamline ID19 and open to the user program. It is transparent to X-rays and can reproduce the temperature and pressure conditions similar to that in the mid-crust. This rig can be used for time-lapse micro tomographic studies of the deformation of porous and compact solids (rocks, ceramics, metallic foams) with a resolution of 0.7-6.5 µm, at conditions of confining pressure up to 100 MPa, axial stress to 200 MPa, temperature up to 250 ^{o}C and controlled aqueous fluid flow [2]. Using this apparatus we have deformed three Carrara marble samples of 10 mm height and 5 mm width/diameter at confining pressure of 20 to 30 MPa and at room temperature. The results here concern one of these samples deformed at 25 MPa confining pressure and where axial stress was increased in steps until failure.

* e-mail: neelima.kandula@geo.uio.no
† e-mail: francois.renard@geo.uio.no

3. RESULTS

The deformation of a Carrara marble core sample was imaged in-situ until complete failure and more than 60 microtomography acquisitions were performed to observe the accumulation of damage. The stress versus strain curve is shown in Figure 1b and is characteristic of a brittle fracture in the quasi-static limit. Three dimensional data (volumes) obtained for every step increase in axial stress were segmented to extract the micro-fractures. Damage is observed to evolve towards the rupture point, quantified by the increase in total volume of micro crack population. Micro crack volume saturates to a value much near to zero and increases non-linearly from yield point towards rupture. Figures 1c-e show the micro crack volumes respectively with increasing stress, figure 1e showing the micro crack population at 196 MPa, at the onset of failure. The statistical properties of the population of growing cracks is characterized to search for spatial correlations and further the density of cracks towards failure is shown to increase as a power law.

References

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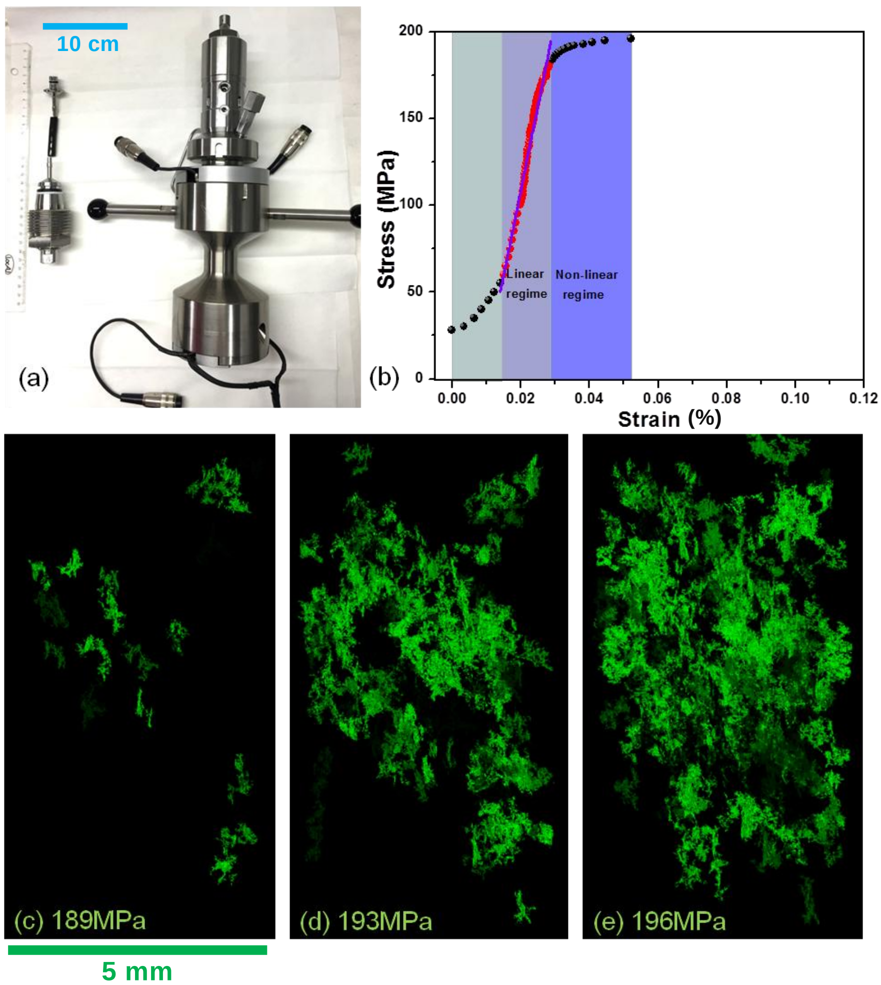

Figure 1: (a) Photograph of the deformation apparatus HADES (body of the rig) used for time-resolved X-ray

tomography of failure in rocks. (b) Stress-strain curve for marble sample under triaxial compression at confining pressure of 25 MPa and at room temperature (failure at 197 MPa). Development of micro cracks prior to failure in the sample at (c) 189 MPa, (d) 193 MPa, (e) 196 MPa.