Physics and Chemistry of the Earth 36 (2011) 1891–1897

Contents lists available at SciVerse ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Strengthening and stress relaxation of Opalinus Clay

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ARTICLE INFO

Article history:
Available online 19 August 2011

Keywords:
Long-term ductility
Opalinus Clay
Stress relaxation
Far-field behaviour

ABSTRACT

In the near-field of underground openings the rock will undergo damage. Closure and re-establishment of the initial rock integrity may be assisted by long-term creep of the un-disturbed clay stone in the far-field, thus promoting self sealing processes in the dilated clay-portions by convergence. Therefore, the understanding of creep is essential for the assessment of the long-term post-closure behaviour in a waste repository.

Stress relaxation testing on pre-strained Opalinus Clay specimens from the Mont Terri Rock Laboratory was performed to check if a time dependent, though non-dilatant deformation is present.

The stress relaxation behaviour of the four tested specimens was investigated during triaxial loading using different sample orientations, i.e. referring to the bedding, and under drained or und-drained conditions, respectively. To suppress artefacts as far as possible, e.g. due to sampling and rock preparation, several loading cycles were performed. After these repeated turns of loading, the stress relaxation was found to be independent from loading geometry or draining anymore. In general, the normalized stress relaxation curves plot in a narrow band.

The experimental results are discussed on the basis of common equations for the stress–strain-behaviour which may be appropriate to model the recorded time dependent stress relaxation.

1. Introduction

During mining of a repository, the rock in the near-field of the underground openings will undergo damage, resulting in an excavation damaged zone (EDZ). In course of the performance assessment with respect to the required long-term isolation of radioactive waste, the re-consolidation of the EDZ has to be proven. This work is concentrated on the question, whether convergence and reduction of open space by long-term creep will take place in a host rock of indurated clay stone, where laboratory investigation on Opalinus Clay from the Mont Terri Rock Laboratory was performed for this purpose.

Several results from investigations on the long-term deformation behaviour of clay stone exist already (e.g. Blümling et al., 2007; NAGRA, 2002). Nevertheless, to the author's knowledge the sound proof of a time-dependent, but non-dilatant viscous deformation in the undisturbed far-field of indurated clay stone is still missing. On the contrary, results from the rock laboratory at the Mt. Terri site yield hints for an anisotropic state of in situ stresses. Bossart and Thury (2008) reported that the maximum of the horizontal stress is found to be 4–5 MPa and the minimum 2–3 MPa (cf. page 14 of that report). This anisotropy may continuously exist in the undisturbed far-field for the long lasting periods of geological times. Consequently, demands on concepts for backfilling and closure of a repository in a clay stone formation as well as model calculations for safety analyses generally do not make use of convergence by creep, which otherwise would result from a viscous stress re-distribution at underground openings. The processes which cause an obvious time dependent rock deformation in clay formations are complex, but they are mainly coupled to processes in the near-field of underground openings, e.g. pore pressure dissipation, dilatation, desaturation/resaturation (e.g. NAGRA, 2002).

Since there is some doubt, whether the un-disturbed indurated Opalinus Clay is creeping at all, the technique of stress-relaxation was applied for a deeper insight. For this, strengthening by a strain rate controlled deformation is stopped at a certain level of stress, i.e. the strain is kept constant for a few days, and the relaxation of the stress is measured. In course of this technique, the deformability, which may result from artefacts, i.e. rock alteration and damage, is ruled out as far as possible by compaction and induration. Then, the stress relaxation – if any – will be maintained by true long-term deformation processes, which should be active and responsible for any convergence in an at least only partly backfilled mine.

2. Material

In total, four specimens of Opalinus Clay from the Mont Terri Rock Laboratory were used for the stress relaxation testing. The two specimens 09002 (BLT-14/11/02) and 09003 (BLT-14/11/03) originate from a core at the gallery 98, NW-exit. They were loaded parallel to the bedding (p-geometry). The two specimens 09024

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doi:10.1016/j.pce.2011.07.090

(BLT-19/10/01) and 09025 (BLT-19/10/02) originate from a core at the MI niche. These specimens were loaded perpendicular to the bedding (s-geometry). The two different cores were drilled from the shaly facies with dry air rinsing. The material from gallery 98 contains some pyrite and carbonates, the material from the MI niche contains no pyrite and a minor amount of carbonates. A more detailed analysis of the mineral composition of the specimens is not carried out up to now.

After drilling, the cores were immediately sealed with a vapour resistant metallic foil and stored in N_2-gas pressure controlled tubes (liners). Thus, no further alteration by oxidation or loss of water could take place during the interim storage of the core material. A representative measure for the content of water is 5–10 wt.%. Nevertheless, in some cases micro-cracking occurs inevitably during drilling and the further preparation of a specimen, thus lowering the overall rock saturation. Determination of ultrasonic wave velocities was not successful in any case.

The preservation against oxidation of minerals and of the water content is one of the most important challenges during preparation and operation. Fig. 1 shows, how the weight of a compact piece of clay stone is reducing by water evaporation in dependence on the relative air humidity (%rh) and the temperature. In the initial section of testing, the relative humidity in the air conditioned box was reduced in steps from time to time. The temperature was kept constant at $T = 24$ °C. The measureable reduction of weight starts already at 92%rh. During a period of 4 days at that value of relative air humidity, the weight is decreasing continuously by about 0.05 wt.%. During the progressing reduction to about 83%rh, the reduction of weight reaches in total 0.7 wt.% after 40 days. In comparison with the conditions during the rinsing with dry air during drilling, this loss of weight, i.e. this loss of water, seems to be negligible. However, in a laboratory the air humidity can be much lower than just 83%rh. Therefore, the testing was continued after a drop down to about 33%rh. Now the weight is reducing to about 4.5 wt.% in total within 10 days. Although the rate of weight decay is slowing down, the new equilibrium between suction of water in the clay stone and evaporation of water at that value of air humidity is not fully reached. This happens quite rapidly after heating up to about $T = 100$ °C, where the relative air humidity in the open system is nearly zero. Finally, the total loss of weight is about 7 wt.% in this experiment – that is an amount in the order of the natural water content of Opalinus Clay stone.

The results of this experiment prove that this core material, which was stored as described after drilling in a liner, has not lost its original content of water – and the loss of water during proper preparation of a specimen and handling will remain rather limited as long as the material is not exposed to a dry air environment for longer times. Taking care for these points the alteration of the mineral inventory (as may happen also by oxidation) will be avoided as far as possible. However, the initial pore pressure inside the rock is unavoidably lowered.

3. Experimental

The four specimens were tested in a triaxial testing device. The cylindrical specimens have a diameter of $D_o = 100$ mm and a length of $L_o = 220$ mm. A specimen is protected with a thin convex surface of Teflon. Thin end-sheets of Teflon were used to avoid friction between specimen and pistons. Finally, a rubber jacket is mounted to prevent loss of confinement.

The confining oil pressure was kept constant all the time at $p_c = 10$ MPa in each of the four experiments. Also temperature was always kept constant at $T = 30$ °C. The strengthening was performed in compression by strain controlled deformation, $\Delta\varepsilon/\Delta t = 1.0\text{E}{-}07$ 1/s. Stress relaxation was recorded as soon as the straining was stopped at several subsequent and pre-selected values of the deviatoric stress. The general course of the testing program is shown in Fig. 2. The progress of strain and deviatoric stress is plotted for the two experiments on the specimens which were loaded in p-geometry, where experiment 09002 is tested without sinter-metallic end-platens, i.e. un-drained, and experiment 09003 with sinter-metallic end-platens to achieve a drained condition. The pore volume of these sinter-metallic end-platens is sufficient to store the pore water which may be pressed out by a deforming specimen. The plots make obvious the nearly identical relaxation behaviour, where the strain to reach a pre-selected deviatoric stress is greater in case of the drained condition. However, on basis of just two experiments it does not become obvious if the material behaves softer in the drained condition.

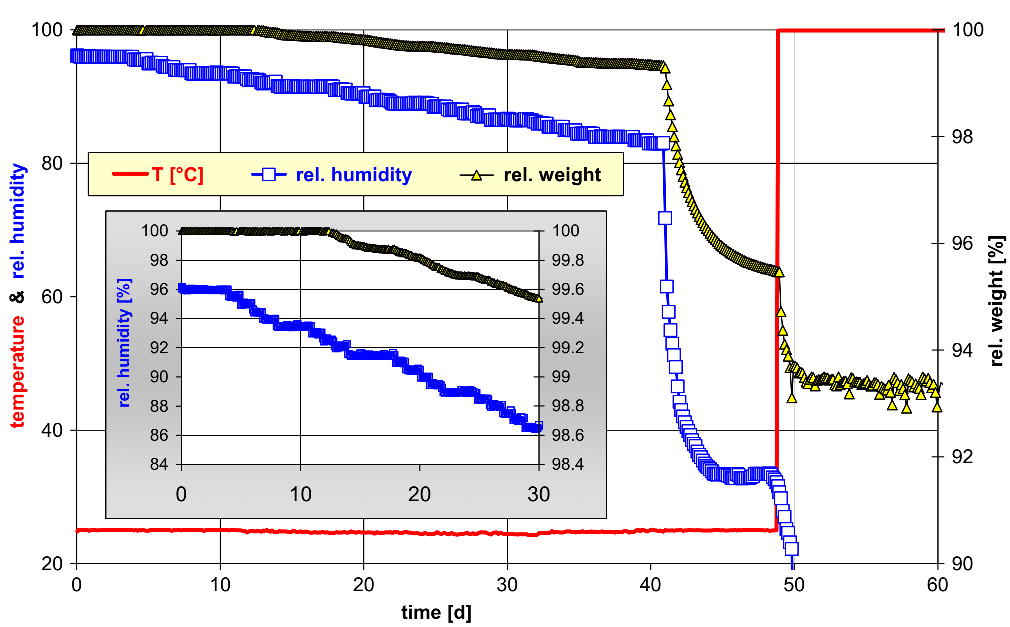

Fig. 1. Relative weight reduction (wt.%), i.e. loss of water, in dependence on relative air humidity (%rh) and temperature (°C).