Cement and Concrete Research 41 (2011) 520–532

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: http://ees.elsevier.com/CEMCON/default.asp

Micromechanics analysis of thermal expansion and thermal pressurization of a hardened cement paste

Siavash Ghabezloo *

Université Paris-Est, Laboratoire Navier, CERMES, Ecole des Ponts ParisTech, Marne la Vallée, France

ARTICLE INFO

Article history:
Received 16 August 2010
Accepted 26 January 2011

Keywords:
Physical properties (C)
Oil well cement (E)
Cement paste (D)
Micromechanics (C)

ABSTRACT

The results of a macro-scale experimental study of the effect of heating on a fluid-saturated hardened cement paste are analysed using a multi-scale homogenization model. The analysis of the experimental results revealed that the thermal expansion coefficient of the cement paste pore fluid is anomalously higher than the one of pure bulk water. The micromechanics model is calibrated using the results of drained and undrained heating tests and permits the extrapolation of the experimentally evaluated thermal expansion and thermal pressurization parameters to cement pastes with different water-to-cement ratios. It permits also to calculate the pore volume thermal expansion coefficient α_ϕ which is difficult to evaluate experimentally. The anomalous pore fluid thermal expansion is also analysed using the micromechanics model.

1. Introduction

A better understanding of the effects of undrained heating and induced thermal pressurization phenomenon is an important point to properly understand the behaviour and evaluate the integrity of an oil well cement sheath submitted to rapid temperature changes. Temperature increase in saturated porous materials under undrained conditions leads to volume change and pore fluid pressure increase. This thermal pressurization is due to discrepancy between thermal expansion coefficients of the pore fluid and of the pore volume. This pore pressure increase induces a reduction of effective mean stress and can lead to shear failure or hydraulic fracturing. Indeed the geomaterials are pressure sensitive and the maximum shear stress depends on the effective mean stress. On the other hand, when pore pressure is higher than maximum principal stress (positive in compression) the material may undergo tensile failure. The thermal pressurization phenomenon is important in petroleum engineering where the reservoir rock and the well cement lining undergo sudden temperature changes, as for example when extracting heavy oils by steam injection methods. This rapid temperature increase could damage cement sheath integrity of wells and lead to loss of zonal isolation. Within this context, a macro-scale experimental program of drained and undrained heating tests is performed on a fluid-saturated hardened oil-well cement paste. The results of this study are presented in [1] and show some important aspects of behaviour of this material when submitted to rapid temperature changes. The thermal pressurization coefficient, defined as the pore pressure increase due to a unit temperature increase in undrained conditions, is evaluated to about 0.6 MPa/°C which is a relatively high value comparing to other geomaterials (see [2] for a review). In accordance with results of Valenza and Scherer [3], the analysis of the undrained heating test revealed that the thermal expansion coefficient of cement paste pore fluid is anomalously higher than the one of pure bulk water. This experimental study was a part of a larger study on the thermo-poro-mechanical behaviour of a hardened cement paste [1,4–6]. The experimental program consisted by drained, undrained and unjacketed compression tests, as well as drained and undrained heating tests and permeability evaluation tests. This experimental program is performed on a particular cement paste, prepared with class G cement at a water-to-cement ratio equal to 0.44. The poroelastic parameters are then extrapolated to cement pastes with different water-to-cement ratios by means of micromechanics modelling and homogenization technique [7]. This is done using a multi-scale micromechanics model, originally proposed by Ulm et al. [8], which is calibrated on the experimental results [7]. The predictive capacity of the micromechanics model is verified by comparing the parameters with some experimental results from literature. In the continuity of the approach used in [7], the micromechanics model is used here in association with the results of drained and undrained heating tests presented in [1]. The model has been already calibrated in [7] for the poroelastic parameters, but a second calibration step should be performed for the thermal behaviour. This permits also to study the thermal expansion of the pore fluid in different parts of the microstructure. The calibrated model will then be used to calculate thermal expansion and thermal pressurization parameters for cement pastes with different water-to-cement ratios.

* CERMES, Ecole des Ponts ParisTech, 6–8 avenue Blaise Pascal, Cité Descartes, 77455 Champs-sur-Marne, Marne la Vallée cedex 2, France.
E-mail address: siavash.ghabezloo@enpc.fr.

0008-8846/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2011.01.023