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STRESS-STRAIN MODELLING OF HEATED CONCRETE

V.A.Salomoni[1], C.E.Majorana[2] and G.A.Khoury[3]

[1] Department of Construction and Transportation Engineering, Faculty of Engineering, University of Padua, via F. Marzolo, 9 – 35131 Padua, Italy
salomoni@dic.unipd.it
www.dic.unipd.it

[2] Department of Construction and Transportation Engineering, Faculty of Engineering, University of Padua, via F. Marzolo, 9 – 35131 Padua, Italy
majorana@dic.unipd.it
www.dic.unipd.it

[3] Department of Civil & Environmental Engineering, Faculty of Engineering, Imperial College London, Skempton Building, London SW7 2AZ
gabriel@clara.net
www3.imperial.ac.uk

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ABSTRACT

This paper presents a stress-strain model of heated concrete [1,2] based on extensive testing carried out by the third author on the strain behaviour of concrete during two heat cycles to temperatures up to 600^{o}C [3-7]. Strain measurements of three concretes during two cycles of heating with and without compressive load over a period of 14 days allow the identification, and separation, of strain components for the transient and steady state temperature conditions as functions of temperature. Contractive strain components during first heating are dominated by the Load Induced Thermal Strain (LITS) with shrinkage being the second strain component. The contractive strains during the subsequent period at constant temperature comprises both creep and shrinkage. The former would contain delayed Transient creep (relevant to the temperature in question) as well as constant temperature creep. While LITS is absent during cooling and subsequent thermal cycle, another important strain component appears which is expansive and which is related to the cracks that develop during cooling and subsequent thermal cycle. These crack strains depend on the type of concrete, the temperature level and the load level. The residual strain is measured directly and modelled indirectly as the sum of the irrecoverable contractive and expansive components. The comprehensive strain model obtained from the tests is then directly integrated in the mechanical part of a 3D fully coupled thermo-hydro-mechanical numerical model of heated concrete, developed by the first two authors, described in this paper along with the test results [8-14]. The generated F.E. code is called NEWCON. Concrete is treated as a multiphase system where the voids of the skeleton are partly filled with liquid and partly with a gas phase [15-17]. As regards the mechanical field, NEWCON couples creep and shrinkage [18-25], chemo-thermo-mechanical damage [26-30] and plasticity effects under medium and high temperature levels.

REFERENCES

[1] Majorana C.E., Salomoni V., Schrefler B.A. - "Hygrothermal and mechanical model of concrete at high temperature", *Materials and Structures*, vol. 31, no. 210, 1998, pp. 378-386.

[2] Khoury G.A., Majorana, C.E., Pesavento, F., Schrefler, B.A. - "Modeling of heated concrete", *Magazine of Concrete Research*, vol. 54, no. 2, 2002, pp. 77-101.

[3] Khoury, G.A. - "Strain of heated concrete during two thermal cycles. Part 1: strain over two cycles, during first heating and at subsequent constant temperature", *Magazine of Concrete Research*, vol. 58, no. 6, 2006, pp. 367-385.

[4] Khoury, G.A. - "Strain of heated concrete during two thermal cycles. Part 2: strain during first cooling and subsequent thermal cycle", *Magazine of Concrete Research*, vol. 58, no. 6, 2006, pp. 387-400.

[5] Khoury, G.A. - "Strain of heated concrete during two thermal cycles. Part 3: isolation of strain components and strain model development", *Magazine of Concrete Research*, vol. 58, no. 7, 2006, pp. 421-435.

[6] Khoury, G.A., Grainger, B.N., Sullivan, P.J.E. - "Strain of concrete during first heating to 600°C under load", *Magazine of Concrete Research*, vol. 37, no. 133, 1985, pp. 195-215.

[7] Khoury, G.A. - *Transient thermal creep of nuclear reactor pressure vessel type concretes*, PhD thesis, Imperial College, London University, vol. 1 pp. 1126, vol. 2 pp. 418, vol. 3 pp. 895, 1983.

[8] Schrefler B.A., Simoni L., Majorana C.E. - "A general model for the mechanics of saturated-unsaturated porous materials", *Materials and Structures*, vol. 22, 1989, pp. 323-334.

[9] Lewis, R.W., Schrefler, B.A. - *The Finite Element Method in the Static and Dynamic Deformation and Consolidation of Porous Media*, John Wiley & Sons, Chichester, 1998.

[10] Majorana C.E., Salomoni V., Secchi S. - "Effects of mass growing on mechanical and hygrothermic response of three-dimensional bodies", *Journal of Materials Processing Technology*, vol. PROO64/1-3, 1997, pp. 277-286.

[11] Majorana C.E., Salomoni V.A. - "Parametric analyses of diffusion of activated sources in disposal forms", *Journal of Hazardous Materials*, vol. A113, 2004, pp. 45-56.

[12] Salomoni, V.A., Majorana, C.E., Giannuzzi, G.M., Miliozzi, A. - Thermal-fluid flow within innovative heat storage concrete systems for solar power plants", *International Journal for Numerical Methods in Heat and Fluid Flow*, 2008 (in press).

[13] Salomoni, V.A., Majorana, C.E., Khoury, G.A. - "Stress-strain experimental-based modeling of concrete under high temperature conditions", *Proc. 11th International Conf. on Civil, Structural and Environmental Engrg. Computing*, St. Julians, Malta, sept. 18-21, 2007 (Special Invited lecture).

[14] Majorana, C.E., Salomoni, V.A., Khoury, G.A. - "Micro-structural modelling of concrete under fire conditions", keynote paper on "Micro-modelling of structures under fire", Fire design of concrete structures, from material modelling to structural performance, FIB Workshop, Coimbra, Portugal, 8-9 November 2007.

[15] Bažant Z.P., Thonguthai W. - "Pore pressure and drying of concrete at high temperature", *Journal of the Engineering Mechanics Division,* ASME, vol. 104, 1978, pp. 1058-1080.

[16] Bažant Z.P., Thonguthai W. - "Pore pressure in heated concrete walls: theoretical predictions", *Magazine of Concrete Research*, vol. 31, no. 107, 1979, pp. 67-76.

[17] Gawin, D., Majorana, C.E., Schrefler, B.A. - "Numerical analysis of hygro-thermal behaviour and damage of concrete at high temperature", *Mechanics of Cohesive Frictional Materials*, vol. 4, 1999, pp. 37-74.

[18] Bažant, Z.P., Prasannan, S. - "Solidification Theory for Concrete Creep. I: Formulation", *Journal of Engineering Mechanics*, vol. 115, no. 8, 1989, pp. 1691–1703.

[19] Bažant, Z.P., Prasannan, S. - "Solidification Theory for Concrete Creep. II: Verification and Application", *Journal of Engineering Mechanics*, vol. 115, no. 8, 1989, pp. 1704–1725.

[20] Bažant, Z.P., Kim, J.K. - "Improved prediction model for time-dependent deformations of concrete: Part 2: basic creep", *Materials and Structures*, vol. 24, 1991, pp. 409-421.

[21] Bažant, Z.P., Xi, Y. - "Continuous Retardation Spectrum for Solidification Theory of Concrete Creep", *Journal of Engineering Mechanics*, vol. 121, no. 2, 1993, pp. 281-288.

[22] Bažant, Z.P., Zi, G. - "Continuous Relaxation Spectrum for Concrete Creep and its Incorporation into Microplane Model M4", *Journal of Engineering Mechanics*, vol. 128, no. 12, 2002, pp. 1331-1336.

[23] Bažant, Z.P., Hauggaard, A.B., Baweja, S., Ulm, F.J. - "Microprestress-Solidification Theory for Concrete Creep. I: Aging and Drying Effects", *Journal of Engineering Mechanics*, vol. 123, no. 11, 1997, 1188-1194.

[24] Bažant, Z.P. - "Creep of Concrete", *Encyclopedia of Materials: Science and Technology*, K.H.J. Buschow et al. Eds., Elsevier, Amsterdam, vol. 2C, 2001, pp. 1797-1800.

[25] Bažant, Z.P., Cusatis, G., Cedolin, L. - "Temperature Effect on Concrete Creep Modeled by Microprestress-Solidification Theory", *Journal of Engineering Mechanics*, vol. 130, no. 6, 2004, pp. 691-699.

[26] Mazars, J. - *Application de la mecanique de l'endommagement au comportament non lineaire et la rupture du beton de structure*, Thèse de Doctorat d' Etat, L.M.T., Universitè de Paris, France, 1984.

[27] Mazars, J., Pijaudier–Cabot, J. - "Continuum Damage Theory – Application to Concrete", *Journal of Engineering Mechanics*, ASCE, vol. 115, 1989, pp. 345-365.

[28] Majorana, C.E., Saetta, A., Scotta, R., Vitaliani, R. - "Mechanical and durability models for lifespan analysis of bridges", *IABSE Sym.: Extending the lifespan of structures*, San Francisco, CA, USA, aug. 23-25, 1995, pp. 1253-1258.

[29] Gerard, B., Pijaudier-Cabot, J., Laborderie, C. - "Coupled diffusion-damage modelling and the implications on failure due to strain localization", *International Journal of Solids & Structures*, vol. 35, no. 31–32, 1998, pp. 4107–4120.

[30] Nechnech, W., Reynouard, J.M., Meftah, F. - "On modelling of thermo-mechanical concrete for the finite element analysis of structures submitted to elevated temperatures", Proc. of Fracture Mech. of Concrete Struct., de Borst, Mazars, Pijaudier-Cabot, van Mier Eds., 2001, pp. 271–278.