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T. Honorio, B. Bary, F. Benboudjema

▶ To cite this version:

T. Honorio, B. Bary, F. Benboudjema. Modelling the mechanical behavior at early-age influence of the boundary conditions at the structure scale and multiscale estimation of ageing properties. CMS Workshop "Cracking of massive concrete structures", Mar 2015, Cachan, France. cea-02509241

HAL Id: cea-02509241 https://cea.hal.science/cea-02509241

Submitted on 16 Mar 2020 $\,$

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Modelling the mechanical behavior at early-age: influence of the boundary conditions at the structure scale and multiscale estimation of ageing properties

Tulio HONORIO^{1,2}; Benoit BARY¹; Farid BENBOUDJEMA² ¹CEA, DEN, DPC, SECR, Laboratoire d'Etude du Comportement des Bétons et des Argiles, F-91191 Gif-sur-Yvette, France ²LMT (ENS Cachan, CNRS, Université Paris Saclay) 94235 Cachan, France





Concrete at early-age

Properties evolving at early age (ageing)
Phenomena taking place at different space and time scales:





Different strategies

bottom-up and top-down phenomenological and mechanistic approaches





Thermo-chemo-mechanical analysis

A phenomenological approach at the structure level



Chemo-thermal problem

Heat balance

$$\dot{T}(\mathbf{x},t) = D \nabla^2 T(\mathbf{x},t) + Q \qquad \begin{cases} T(\mathbf{x},0) = T_0 & \forall \mathbf{x} \in \boldsymbol{\Omega}_c \\ \lambda \nabla T(\mathbf{x},t) \cdot \mathbf{n} - k \left[T(\mathbf{x},t) - T_a\right] = q_i(t) & \forall \mathbf{x} \in \boldsymbol{\partial} \boldsymbol{\Omega}_i \end{cases}$$

Non-homogeneous PDE ... with non-homogeneous BC

Hydration

$$\dot{\alpha} = A(t) \cdot \exp[-Ea/T]$$

Boundary conditions $q_s - q_c - q_r - q_y = 0$ \downarrow Heat conducted into concrete Re-radiation by concrete Heat loss by convection Radiation absorbed





Analytical solutions Why?

Elucidates the role of the BC in the chemo-thermal problem

Validates and allows some extrapolations from the numerical results

$$l_{h} = \sqrt{\frac{D}{A(\xi)}} \exp\left[-\frac{E_{a}}{RT}\right]$$



Analytical solutions

After some hypothesis and simplifications...

1D solution in a semi-infinite domain non-homogeneous PDE with nonhomogeneous BC:





Solar flux

- Convection and reradiaiton
- T_a is kept constant.
 - Evolution of the temperatures at different distances from the surface ->







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FEM analysis

- Goal: Determine concreting temperatures
- Asymmetric thermal loading induced by solar flux
- Test different T scenarios
 - Precooling?





Solar flux



Ambient temperature

- Maximum <u>T</u> to prevent DEF problems T_{adm}=70°C
- Maximum temperature reached within the structure varies almost linearly with Ta









Mechanical model

 $\varepsilon_{in} = \varepsilon_{au} + \varepsilon_{th} + \varepsilon_{cr}$





Cracking index

Probability of cracking as a function of the CI:

 $CI = \max_{\Omega} \langle \frac{\sigma_{ii}(t)}{f_t(t)} \rangle_+$

$$P(CI) = 100 \times \left[1 - \exp\left[-\left(\frac{1}{CI}/0.92\right)^{-4.29}\right]\right]$$

The *CI* obtained from the simulation must be inferior to 54% so that $P(CI) \leq 5\%$

Other criteria existing \rightarrow B. Craeye (70%); Fairbairn (100%)

Damage model

Isotropic damage variable D

$$\boldsymbol{\sigma} = (1 - D) \widetilde{\boldsymbol{\sigma}}$$

- Equivalent strain $\hat{\varepsilon} = \sqrt{\langle \varepsilon_e + \beta \varepsilon_{bc} \rangle_+ : \langle \varepsilon_e + \beta \varepsilon_{bc} \rangle_+}$
- Coupling between damage and creep





Thermal conditions: Cracking Index





Coupling between creep and damage August temperatures; t = 15.08 days





Thermal conditions: Damage and Crack opening





Conclusions

- Phenomenological approaches:
 - It works!
 - Ad hoc character: difficult to extrapolate to other scenarios of interest
 - "enigmatic" parameter β
 - Small variations of β can lead to different damage patterns
- Mechanistic approaches to understand the underlying phenomena
 - Justify and improve phenomenological



Multiscale estimation of ageing properties



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Hydration kinetics

Goals

- Determine the kinetics in from the main driving mechanisms
- Estimate the evolution of volume fraction →

Approach

- 2 mechanisms gouverning hydration :
 - Boundary nucleation and spacefilling growth (BNG)
 - Diffusion controlled growth (DCG)

[Honorio et al. 2014c; Honorio et al. Submitted]





Microstructure representation



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1.0



VMortar

 ν_{Paste}

VITZ

0.4

Degree of hydration [-]

0.6

0.8

1.0

0.2

Solutions in elasticity









1.0

0.2

0.0

0.0

0.5

1.0

Ageing linear viscoelasticity

Opérateur Intégral de Volterra :

$$(f \circ g)(t,\tau) \equiv \int_{t'=-\infty}^{t} f(t,t') d_{t'}g(t',\tau)$$

[Volterra 1887; Maghous et al. 2003; Sanahuja, 2013]



- C-S-H : viscoelastic behavior o Intrinsically ageing?
 - Solidification \rightarrow ageing behavior

Mori-Tanaka

Generalized Self-Consistent

1.5

 t/τ

2.0

2.5

3.0

--- Diluted $t/\tau = 0$

--- Diluted $t/\tau = 0.5$

--- Diluted $t/\tau = 1.1$

--- Diluted $t/\tau = 1.5$ --- Diluted $t/\tau = 2$ MT $t/\tau = 0$ MT $t/\tau = 1.5$ MT $t/\tau = 2$ ---- GSGC₂ $t/\tau = 0$

- GSGC₂ $t/\tau = 0.5$

- GSGC₂ $t/\tau = 1.1$

- GSGC₂ $t/\tau = 1.5$

- GSGC₂ $t/\tau = 2$



Numerical homogeneization

8.00

6.00

2.00

0.00

4.00 ¢

Goals:

Investigate the influence of the aggregatesGet local information

Inclusions

Overall

4d]

201

Ð,

Honorio

1.00

Ageing linear

viscoelasticity

Study more complex microstructures

0.20

0.40

Dispersion on stresses within the

inclusions

0.60

Degree of hydration

0.80

Elasticité





[Bary et al. 2014]



• Equivalent diameters : 8-18 mm



Conclusions

Different strategies to investigate the behavior at early-age

Mechanistic approach:

- Some phenomena still need to be better understood (hot point!)
- Some tools still to be developed

Perspectives

- Contribution to the study of the ageing viscoelastic behavior
 - Influence of the ageing mechanisms at the paste level
 - Influence of the aggregates (shape, PSD, vol. fraction)
 - Mismatch of matrix-inclusions properties
 - Thermal effects





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FARME PROPERTY AND A CONTRACT OF SHALL BEENED. INCOME.

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Acknowlegments

This present work has been performed as part of the project on disposal of LILW-SL that is carried out by ONDRAF/NIRAS, the Belgian Agency for Radioactive Waste and enriched Fissile Materials