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Coupled heat and mass transfer in concrete in concrete subjected to fire

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Introduction

- Concrete is porous media (3 phases)
- When exposed to fire heat is transfered with conduction and convection
- Transport of water and water vapor is governed by the pressure and temperature gradient
- Model of heat and mass transfer according to Tenchev *et al.*
- Water and water vapour is treated separately

Governing equations

- The coupled system of diff. Eq. Is derived from the basic laws for mass and energy conservation:
  - Water conservation

$$\underbrace{\frac{\partial(\overline{\rho}_L)}{\partial t}}_{a} = \underbrace{-\nabla \cdot \mathbf{J}_L}_{b} - \underbrace{\dot{E}_L}_{c} + \underbrace{\frac{\partial(\overline{\rho}_D)}{\partial t}}_{d}.$$

  - Water vapor conservation

$$\frac{\partial(\varepsilon_G \tilde{\rho}_V)}{\partial t} = -\nabla \cdot \mathbf{J}_V + \dot{E}_L$$

  - Air conservation

$$\frac{\partial(\varepsilon_G \tilde{\rho}_A)}{\partial t} = -\nabla \cdot \mathbf{J}_A$$

  - Energy conservation

$$\underbrace{(\underline{\rho C})\frac{\partial T}{\partial t}}_{a} = \underbrace{-\nabla \cdot (-k_{\mathrm{eff}} \nabla T)}_{b} - \underbrace{(\underline{\rho C \mathbf{v}}) \cdot \nabla T}_{c} - \underbrace{\lambda_E \dot{E}_L}_{d} - \underbrace{\lambda_D \frac{\partial(\overline{\rho}_D)}{\partial t}}_{e},$$

Assumptions

- There is thermal equilibrium between all phases within an infinitesimal volume
- Water vapor, air and their gaseous mixture behave as ideal gases
- There is no diffusion of bound water. It diffuses and evaporates only after it is released as free water
- Amount of free water is determined with help of sorption curves

System of differential equations

- Summing up Eq. (1-2) for water conservation and water vapor conservation
- We get system of 3 differential equations:

$$\frac{\partial(\varepsilon_G \tilde{\rho}_A)}{\partial t} = -\nabla \cdot \mathbf{J}_A,$$

$$\frac{\partial(\varepsilon_G \tilde{\rho}_V)}{\partial t} + \frac{\partial(\varepsilon_{FW} \rho_L)}{\partial t} + \frac{\partial(\varepsilon_D \rho_L)}{\partial t} = -\nabla \cdot (\mathbf{J}_L + \mathbf{J}_V),$$

$$(\underline{\rho c})\frac{\partial T}{\partial t} - \lambda_E \frac{\partial(\varepsilon_{FW} \rho_L)}{\partial t} + (\lambda_D + \lambda_E)\frac{\partial(\varepsilon_D \rho_L)}{\partial t} = \nabla \cdot (k \nabla T) + \lambda_E \nabla \cdot \mathbf{J}_L - (\underline{\rho c \mathbf{v}}) \cdot \nabla T.$$

- Primary unknowns: temperature *T*, pore pressure P_G, water vapor content, ρ_V

System of differential equations

- After some algebraic manipulation we get form suitable for a finite element solution

$$C_{TT}\frac{\partial T}{\partial t} + C_{TP}\frac{\partial P_G}{\partial t} + C_{TV}\frac{\partial \tilde{\rho}_V}{\partial t} = \nabla \cdot (K_{TT}\nabla T + K_{TP}\nabla P_G + K_{TV}\nabla \tilde{\rho}_V)$$
$$C_{AT}\frac{\partial T}{\partial t} + C_{AP}\frac{\partial P_G}{\partial t} + C_{AV}\frac{\partial \tilde{\rho}_V}{\partial t} = \nabla \cdot (K_{AT}\nabla T + K_{AP}\nabla P_G + K_{AV}\nabla \tilde{\rho}_V)$$
$$C_{MT}\frac{\partial T}{\partial t} + C_{MP}\frac{\partial P_G}{\partial t} + C_{MV}\frac{\partial \tilde{\rho}_v}{\partial t} = \nabla \cdot (K_{MT}\nabla T + K_{MP}\nabla P_G + K_{MV}\nabla \tilde{\rho}_V)$$

- + boundary conditions

Finite element formulation

- The system of differential eq. to be solved is

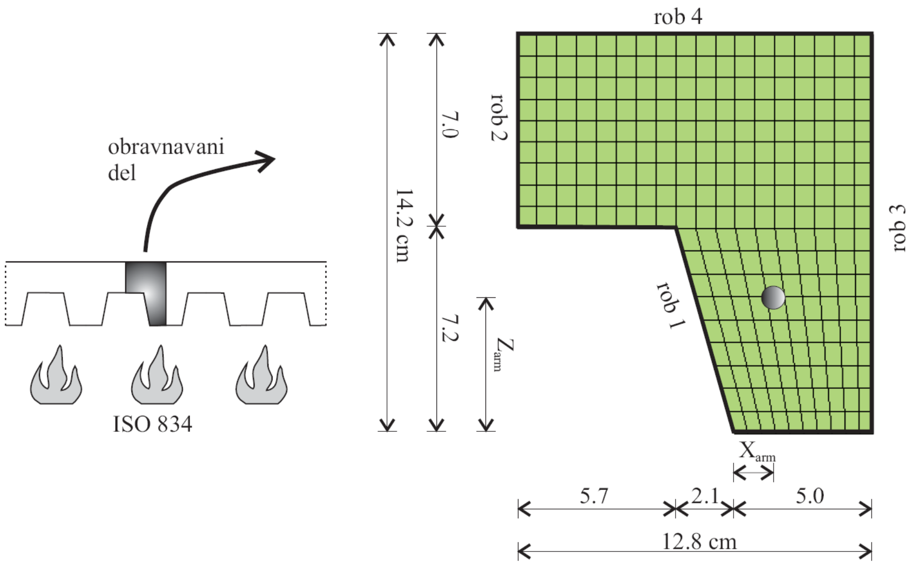
$$\mathbf{C}\frac{\partial \mathrm{Y}}{\partial t} - \nabla \cdot (\mathbf{K}\nabla \mathrm{Y}) + \mathbf{K}_V \nabla \mathrm{Y} = 0$$

- Solution is based on picewise approximation of the unknowns (isoparametric FE)
- Galerkin type of FE formulation
- integration by parts results a system of first-order differential equations

$$\hat{\mathbf{C}}\frac{\partial \mathrm{u}}{\partial t} + \hat{\mathbf{K}}\mathrm{u} = \hat{\mathbf{R}}$$

Numerical example

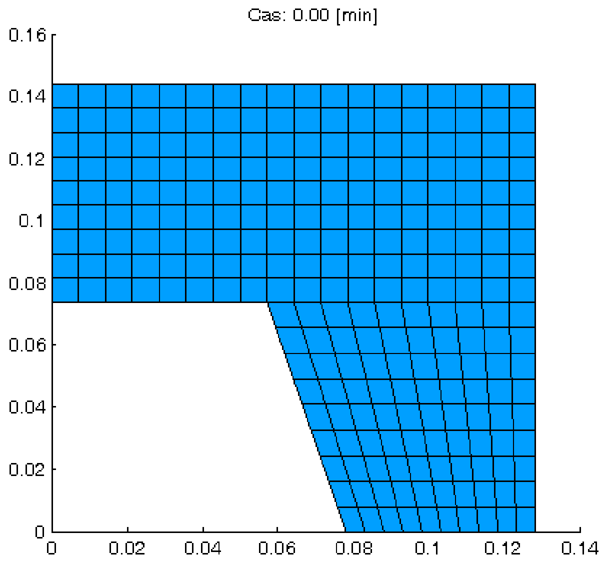
- Composite deck exposed to standard fire ISO 834
- 2 examples
  - Example 1: mass flux on exposed surface is not allowed
  - Example 2: mass flux on exposed surface is allowed



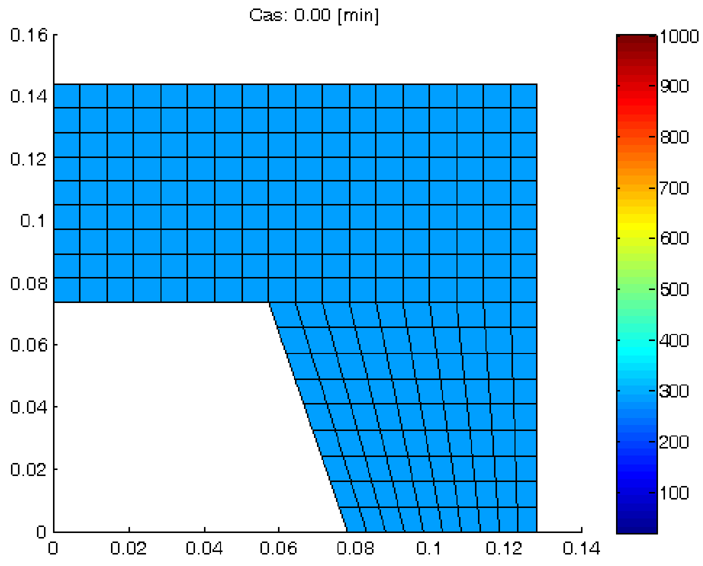
Results

- Distribution of temperature

Example 1



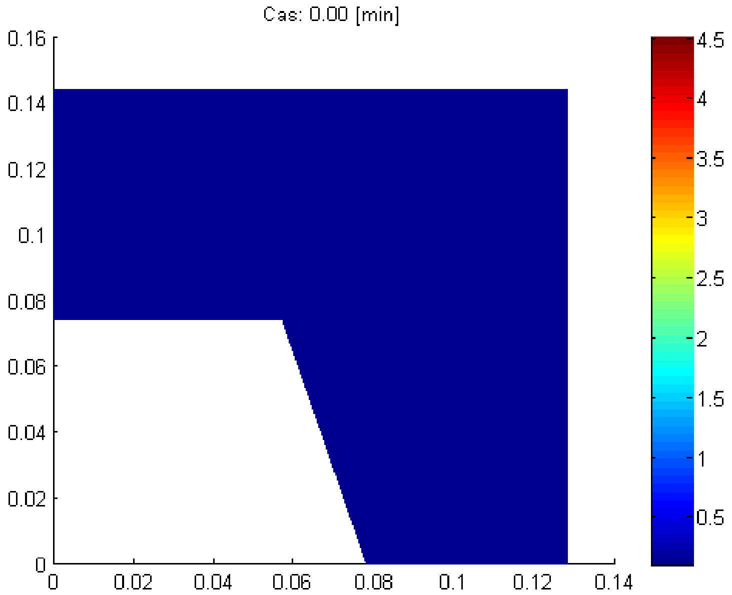
Example 2



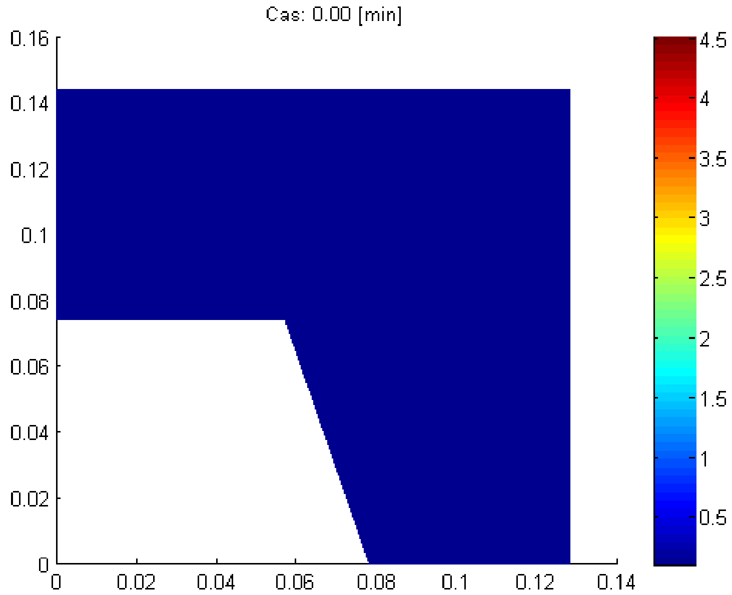
Results

- Distribution of pore pressure

Example 1



Example 2



Conclusions

- Coupled heat and moisture transfer in concrete was presented
- Governing equations are solved with finite element method (2D isoparametric FE)
- Results are time distribution of temperature, pore pressure and water vapour content over the cross-section.