Modeling Moisture Infusion in Ceramic Tiles: A Numerical Simulation Study
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INTRODUCTION
- Ceramics are widely used in filtration system, residential tiling, biomedical engineering etc.
- Understanding how water affects the physical and mechanical properties of ceramics is crucial.
- Moisture modeling is essential for this.
- Moisture resistance is crucial for durable building materials.
- Modeling moisture infusion has implications for development of new materials and technologies.
- Fields like biomedical and energy storage could benefit from a better understanding of moisture infusion in ceramics.

BACKGROUND
- Advanced Cement-Based Materials Laboratory at UWM recently conducted research on developing superhydrophobic ceramic material.
- Water imbibition modeling was required to aid comprehension of water absorption in ceramics with and without coatings.
- Richards’ equation models moisture movement and saturation distribution from the water table to unsaturated soil.
- Present study modifies Richards’ equation for water incorporation in ceramic.

MATHEMATICAL MODELLING

Governing Equations
- Mass balance:
  \[ \frac{\partial S}{\partial t} + \nabla \cdot (\bar{V}_w) = 0 \]
- Momentum balance:
  \[ (\bar{V}_w)_{\text{ave}} = -k_r K_H \cdot \nabla \left( \frac{\rho_w}{\rho_g} \frac{\partial p}{\partial S} \right) + \bar{z} \]
- Pore averaged pressure:
  \[ \bar{p}(\bar{V}_w)^{\text{ave}} = p_{\text{atm}} - \bar{p}_c \]
- Richards equation for ceramic tile:
  \[ \frac{\partial S}{\partial t} = \nabla \cdot \left( \frac{0.04 K_s}{\mu} \frac{k_r}{1-s} \nabla S + \frac{\rho_w \phi}{\mu} \frac{k_r}{1-s} \frac{\partial S}{\partial t} \right) \]
- Above equations gives Richards equation [1]:
  \[ \epsilon \frac{\partial S}{\partial t} = \nabla \cdot \left( \frac{0.04 K_s}{\mu} k_r \frac{\partial p}{\partial S} + \frac{\rho_w \phi}{\mu} k_r \frac{\partial S}{\partial t} \right) \]
- Richards equation for ceramic tile:
  \[ \epsilon \frac{\partial S}{\partial t} = \nabla \cdot \left( k_r K_s \frac{\partial p}{\partial S} + \frac{\rho_w \phi}{\mu} k_r \frac{\partial S}{\partial t} \right) \]

NUMERICAL SIMULATION

Mesh Generation
- Mesh type: Hybrid mesh elements (18,948)

Grid Independence
- Variation of saturation value (S) at (4, 4, 5) at times: t = 1 min

CODE VALIDATION

Numerical Simulation
- Neutron imaging (IMI) experiments were performed on a ceramic tile sample at the Paul Scherrer Institute in Switzerland.
- Sample underwent neutron beam exposure while water droplet was added.
- Experimental results (top) is compared to the simulation results of water saturation (bottom).

RESULTS

Three cases were investigated for the saturation distribution over time.

CONCLUSION
- The saturation level of water is influenced by the amount of water received over time.
- Saturation levels in the first 2.5 minutes are the same for all cases.
- The first scenario maintains a constant saturation level of 1 on the top surface.
- 2nd case demonstrates a continuous drop of saturation at the top surface.
- In the third scenario, saturation levels fluctuate, beginning at 1 and dropping gradually, before returning to 1 and lowering again.

REFERENCES
2. COMSOL. Multiphysics user manual.