Capillary Stress During Cement Drying Shrinkage

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PROBLEM

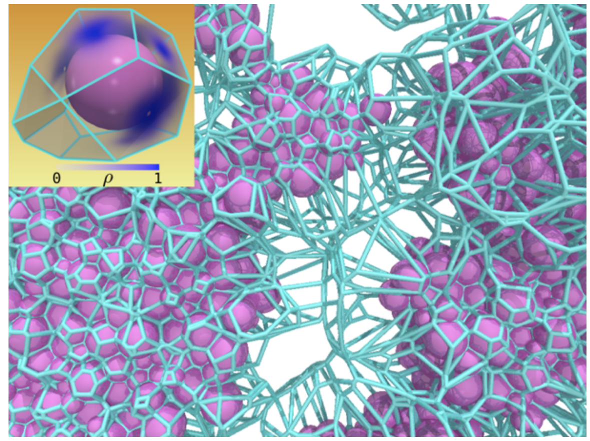
Imagine a household sponge lying next to a kitchen sink. The sponge looks and feels different when it is wet versus when it is dry. When a sponge dries, it shrinks, curls and hardens due to suction forces (called “capillary stress”) which change its mechanical properties. Although the material compositions are different, the same mechanism occurs in cement paste. The process takes considerably longer for cement paste but, like a sponge, the material is quite porous and when there are changes to outside relative humidity, due to rain or a series of dry days, the pores inside cement can be filled with water or become empty. The water can generate high stresses as the pores expand (when very wet) and shrink (when dry), which in turn affects the properties of the material. This research proposes a general and accurate framework to calculate the consequences of these stresses and explain the cement drying shrinkage curve (drying above 40% relative humidity) based on a model of the pore structure.

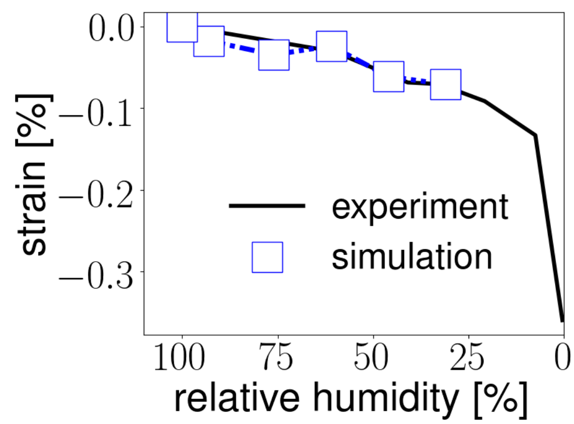
APPROACH

We predict the drying shrinkage of cement paste due to capillary force in its complex pore structure by proposing a general and quantitative framework to calculate the liquid distribution and capillary stress field in a 3D structure of any granular material. We then investigate the consequences of the capillary stress on the local displacements of particles via molecular dynamics simulations and calculate the average shrinkage strain on the scale of micrometers arising from these local capillary forces.

FINDINGS

Understanding the mechanism of cement paste drying shrinkage requires a good description of the interaction between its solid and liquid constituents. We find the shrinkage strain on the first drying cycle can be well explained by capillary stresses acting on its heterogeneous pore structure. The capillary forces on the nano-particles show an asymmetric distribution with a long tail, indicating local particle rearrangements and irreversibility during cement paste drying, resulting in shrinkage, which becomes more prominent as paste becomes drier. On the other hand, cohesive capillary forces vanish when all pores are filled with water. From this perspective, we understand how cement paste is weakened under extreme (very dry or near saturation) conditions.





Upper: A depiction of the scheme proposed in this work to calculate the capillary forces in the pore structure. The C-S-H nano-particles (the main binding component of cement paste) are shown in maroon, tessellation cells are shown by blue-green columns. Inset showing water density distribution on the cell surfaces. Lower: cement paste first drying shrinkage strain curve.

WHY DOES THIS RESEARCH MATTER?

- Water adsorption can induce very high local stresses that affect the transport and rheological properties of nano-porous materials, including cement, which can lead to fracture and damage.
- Cement paste displays characteristic macroscale drying shrinkage curves that can be understood through capillary stresses on the nm scale acting on the heterogeneous pore structure.

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