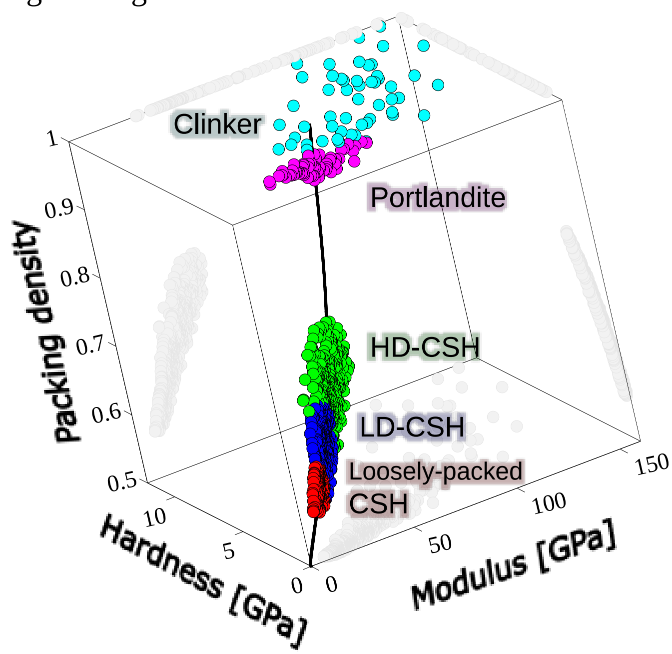
Concrete Sustainability Hub@MIT – Research Profile Letter – April 2011

What's in Your Concrete? (Part 2)

Problem

In the transition from liquid to stone, the complex chemical hydration reactions in concrete define a highly heterogeneous composite. The multiscale nature of the hardened material, with solids and pore spaces occurring across the nano-to-macro length spectrum, poses a challenge when linking the contributions of different constituents to the overall mechanical performance. Particularly difficult is pinning down the mechanical properties of the calcium silicate hydrate (C-S-H) phase. A dedicated experimental arrangement with high resolution is required to assess in situ the engineering properties of the components in the cement binder. The direct probing of cement at the scale of C-S-H, where mechanics meets chemistry, will allow decoding the effects of mix design and environmental exposure on material performance, and thus help the nano-engineering of future blends.



In situ assessment of cement mechanics by statistical cluster analysis of nanoindentation properties for a portland cement. Colors represent different mechanical phases in the hardened cement paste, with low (LD) and high-density (HD) CSH being dominant by volume fraction. Hardness and modulus measurements relate to strength and elastic properties, respectively.

Approach

We employ a statistical clustering algorithm and micromechanics models to translate experimental measurements into a mechanical assessment of each cement paste. The experiments involve instrumented indentations at many locations on the sample surface. Stiffness and hardness properties are inferred from the load-deformation response measured in each experiment. Although probing the surface, an indentation probe effectively senses a material volume, or voxel. A massive array of indentations are conducted and analyzed via clustering statistics, which assign each voxel to a most probable cluster representative of a mechanically distinct phase within the hardened cement paste.

Findings

The dominating phases of C-S-H reveal a unique mechanical signature expressed in two material packings, a low density (LD) and a high density (HD) C-S-H phase. A small volume fraction of loosely-packed C-S-H can be found in regions affected by capillary pores. LD C-S-H dominates in high w/c ratio materials, while HD C-S-H prevails in low w/c materials; which shows that the packing of C-S-H translates directly into macroscopic strength and durability performance.

Impact

This research combines nanoindentation and multivariate statistics to characterize quantitatively the mechanical response and volume fractions of phases in hardened cement paste. The comparable size of voxels in this mechanical analysis and our chemical characterization provides a formidable tool to relate mechanical performance to cement and concrete chemistry.

More

Research conducted by Muhannad Abuhaikal, graduate student in the CSHub, in collaboration with Dr. J.A. Ortega, and supervised by Profs. K.J. Van Vliet and F-J. Ulm.

This research was carried out by the CSHub@MIT with sponsorship provided by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research & Education Foundation. The CSHub@MIT is solely responsible for content. For more information, write to CSHub@mit.edu.