Visualizing Hydration Products

Problem

The nucleation and growth rates of cement hydration products are still under debate, due in part to the lack of direct measurements. Quantifying the clinker dissolution and subsequent precipitation kinetics of different hydration products such as calcium-silicate-hydrates (C-S-H) would aid in experimental validation of mechanisms deduced from computational simulations of clinker dissolution and cement setting. Such direct observations could also aid in understanding and tuning of hydration kinetics via additives, such as the incompletely understood use of calcium chloride to accelerate setting.

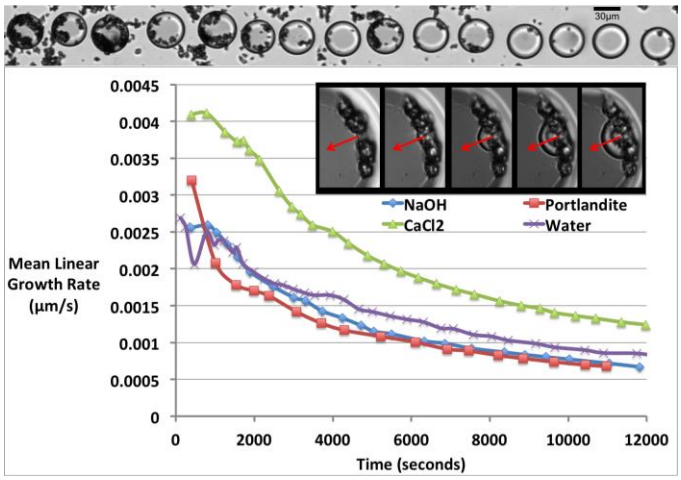

Figure 1. Picoliter-volume droplets allow visualization (top) and quantification (bottom) of clinker dissolution and hydration processes.

Approach

To establish a baseline study of hydration kinetics, we have quantified hydration of a model component of industrial clinker, lab-synthesized tricalcium silicate (C_3S) that dissolves to produce only portlandite (CH) and C-S-H. Using time-lapse video microscopy, we recorded C_3S particle hydration within droplets of 10 µm to 100 µm diameter. Lines of these picoliter-volume droplets comprising different aqueous solutions and C_3S particles were generated on glass cover slips and placed under inert oil that controlled evaporation (Fig. 1, top). This enabled real-time visualization of multiple hydration scenarios representing a range of solution/solid ratios (on the order of 100 to 1000) and conditions.

Findings

We observed the hydration process, including four distinct steps: homogeneous and heterogeneous nucleation, growth, and covering of C_3S particles with hydration products that then slowed the reaction. Figure 1 shows an example of growth kinetics in different solutions that contained either NaOH, $CaCl_2$, or previously formed portlandite. Mean growth rates of products (insert, red arrow) away from C_3S particles (dark grains) are quantified and compared. These rates exceed the few available literature reports by one to two orders of magnitude, and are clearly not a linear function of time. Additionally, calcium chloride is clearly shown to increase the growth rate compared to other solutions, but surprisingly doubles the time required to the cover C_3S particles by hydration products from ~1 h to ~2 h. Analysis of hydration product composition and structure is ongoing.

Impact

These experiments provide direct access to the kinetics associated with hydration mechanisms. Different parameters such as initial clinker composition and initial concentrations of calcium, silica or H^+ ions (pH) within the solution can be compared quantitatively to models under development for clinker dissolution and cement setting.

More

This research was conducted and analyzed by postdoctoral researcher Dr. R. Grossier and Prof. K. J. Van Vliet in the MIT Department of Materials Science & Engineering.

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