Bridging the Gap: Using microstructural properties to predict macroscopic behavior of lime-stabilized clays

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Background

Problem

Clay swelling damages in pavement = $1 billion costs annually

Treatment: Clay + Water + Lime (CaO) = Concrete-like soil

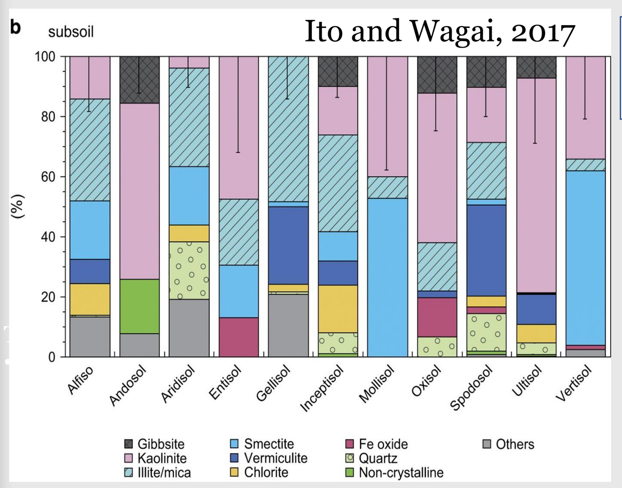

Civil Engineer


Materials Scientist

Take soil from site → Create different mixes with lime or cement → Measure strength at 28 days

Analyze soil properties → Study reactions over time → Create kinetic model to predict strength

Approach



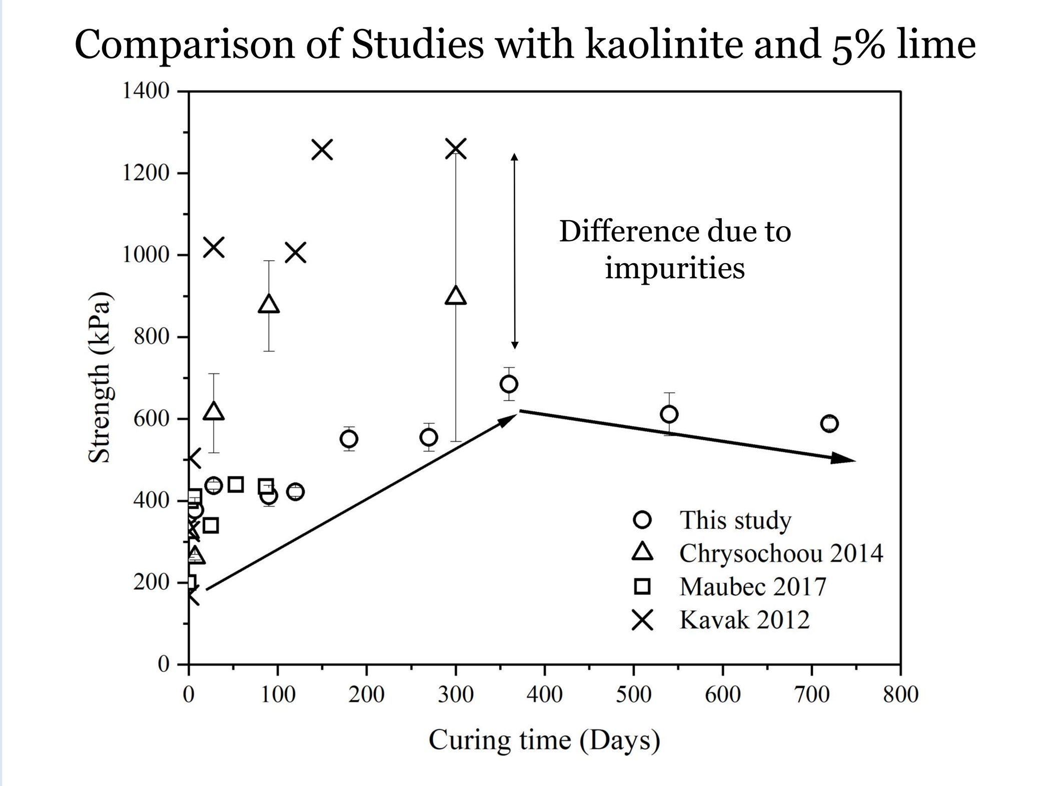
Kaolinite — Risk → Bentonite

Pure materials:

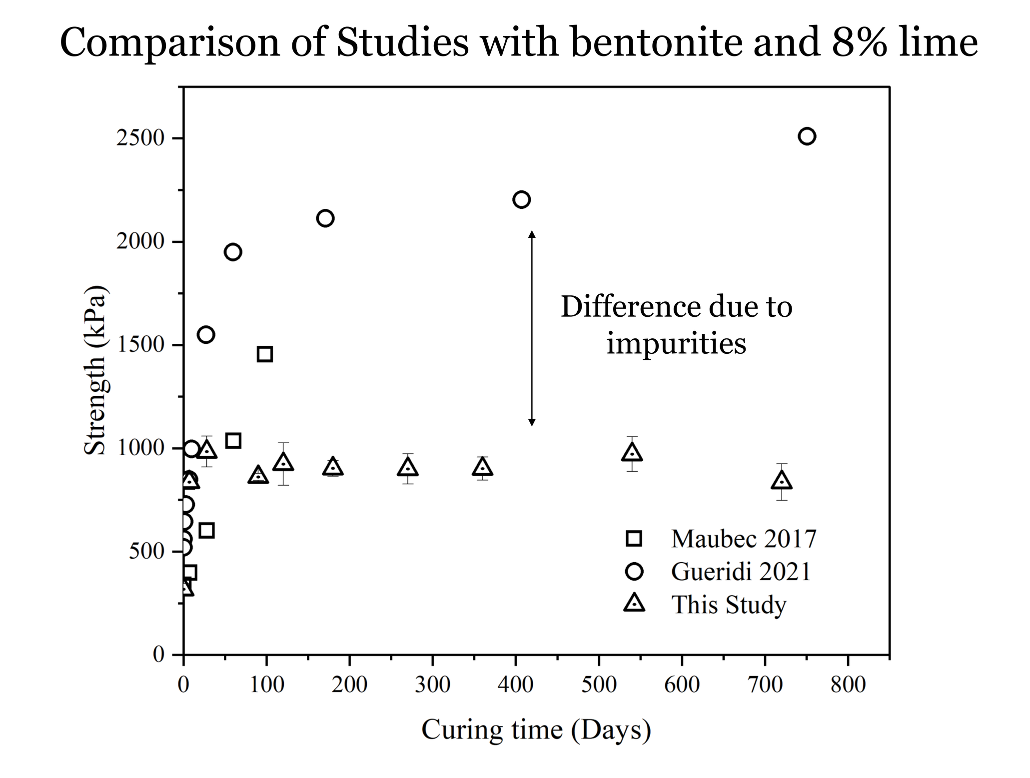
- Most common clays along risk continuum
- Pure bentonite cannot be obtained in large quantities (~20% other minerals present)
- Lime (CaO) most basic stabilizer

Compaction and strength ⟷ MODELING ⟷ Pore water extraction and analysis; Solid Analysis (NMR, TGA, XRD)

Macrostructural Analysis (Strength data)



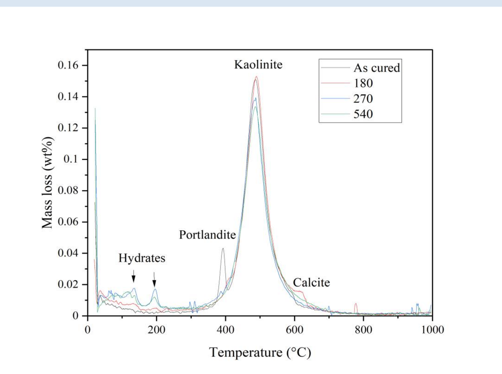
Kaolinite Strength continues to evolve beyond 1 year of curing

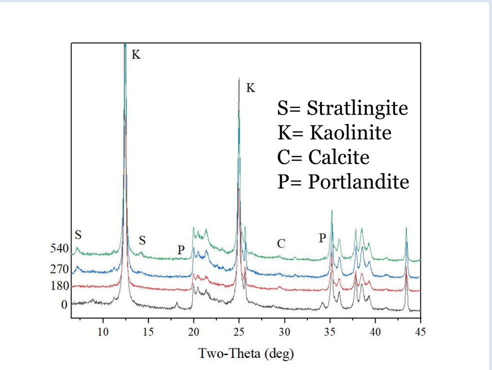


Bentonite Strength development is significantly quicker and almost complete within 28 days

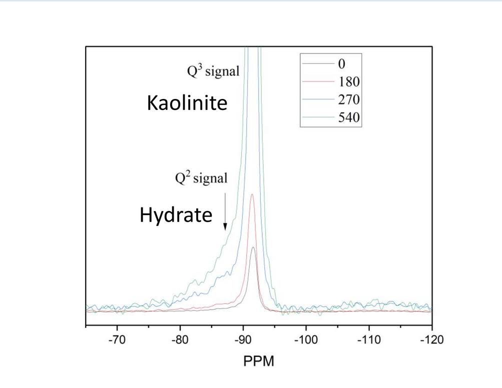
Microstructural Analysis (Kaolinite)

Qualitative Analyses


TGA Spectra



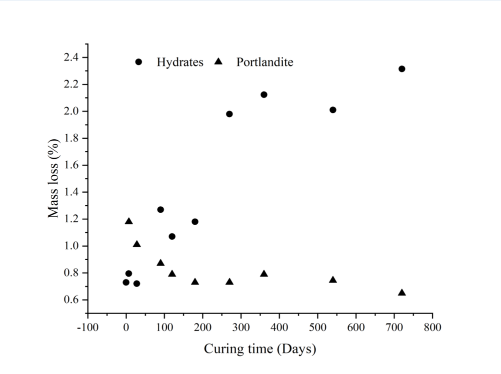
XRD Spectra

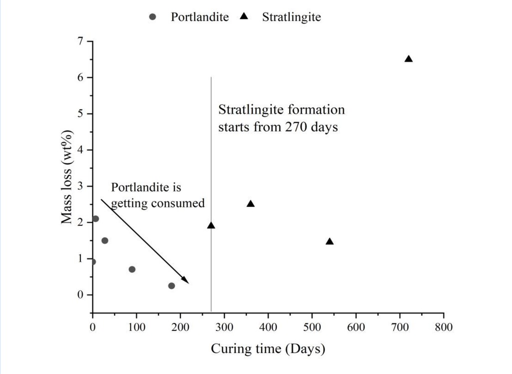


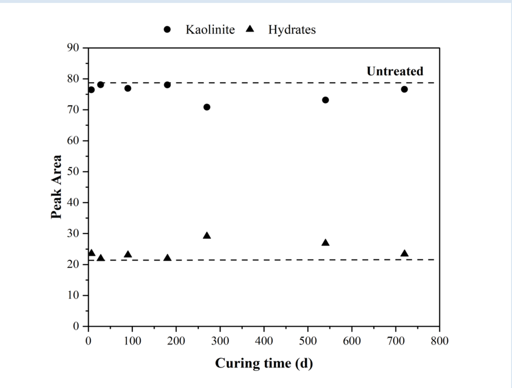
^{29}Si NMR

TGA data shows formation of 2 distinct hydration products whereas XRD shows only one hydrate formation
XRD shows formation of stratlingite, a calcium alumino silica hydrate

XRD & TGA Quantitative Analysis

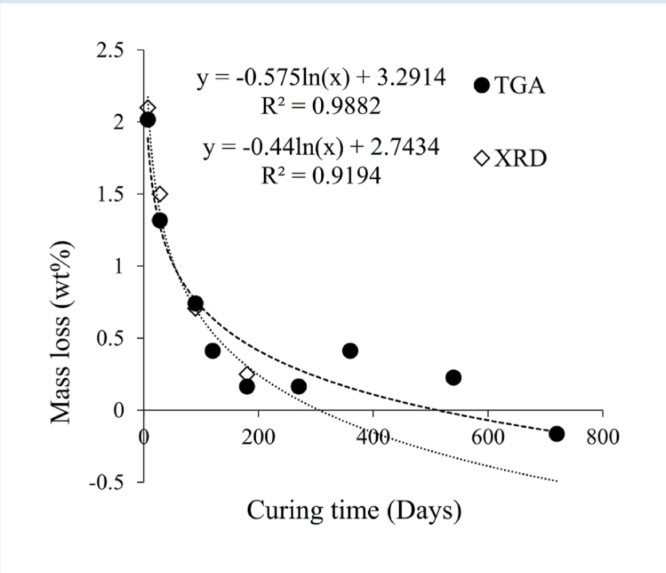

TGA Data


XRD Data

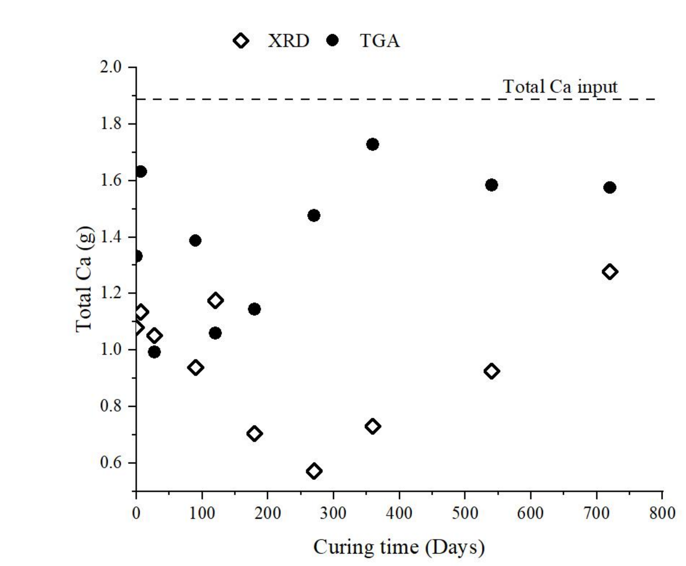


- Both TGA and XRD data show a decrease in the hydrate concentration at 540 days.
- ^{29}Si NMR data shows significant hydrate formation from 270 days and the concentration decreases gradually from 360 days whereas in XRD stratlingite concentration increases from 360 days with an exception at 540 days.

Ca consumption & Fate



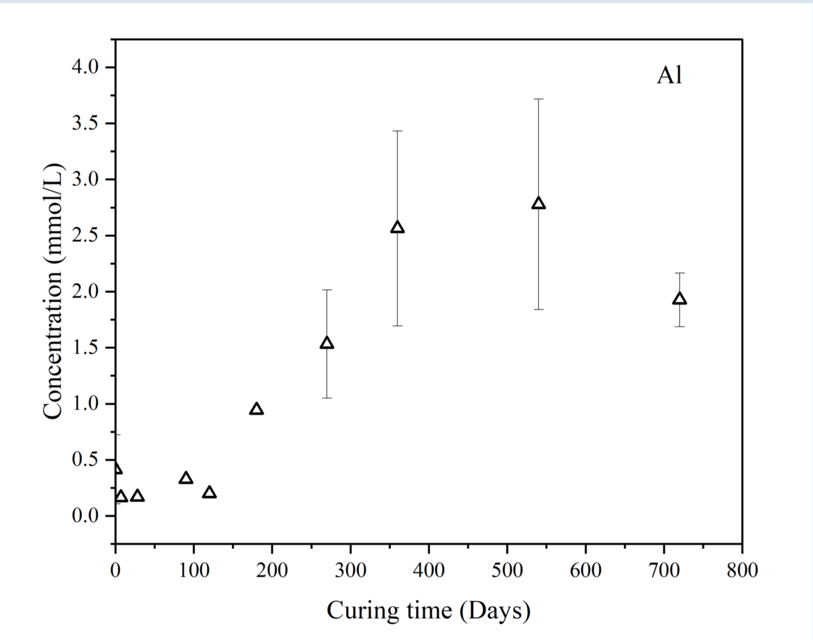
Ca consumption in the system calculated from both TGA and XRD data

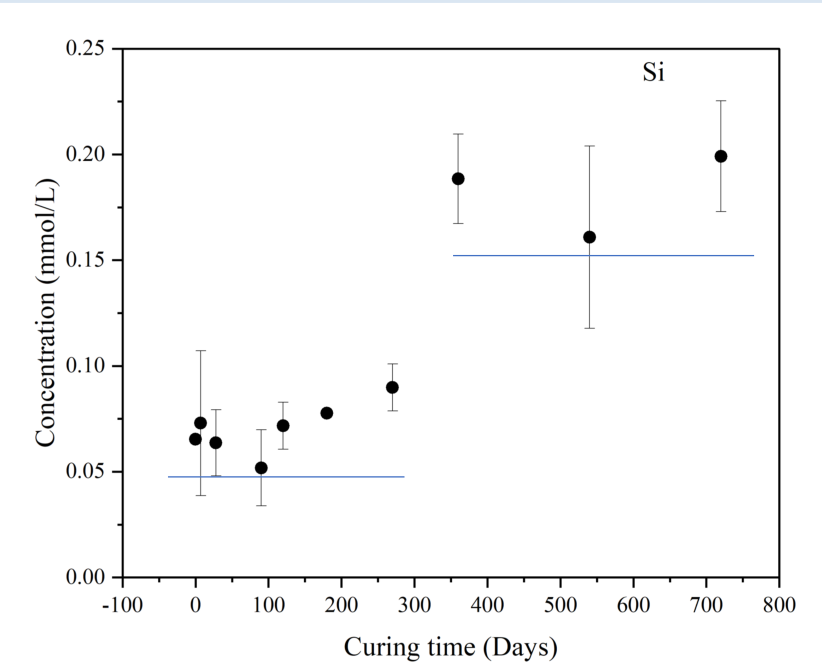


Ca mass balance in the system from TGA & XRD data

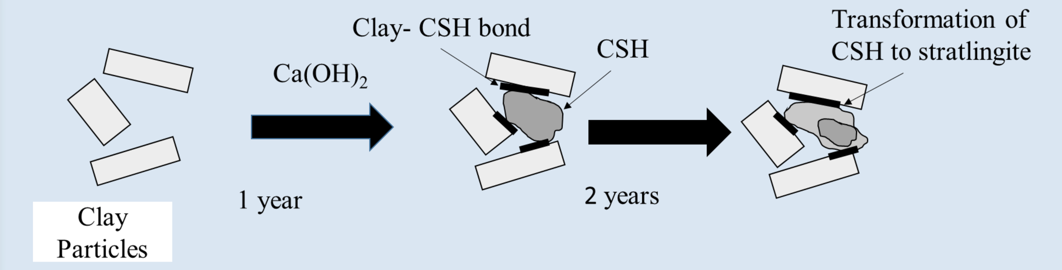
- Both TGA and XRD show complete consumption of Ca around 300 days
- XRD data is always well under the total Ca input line, indicating a missing amorphous phase.

Pore Water Analysis (Kaolinite)





Working Hypothesis for Mechanisms



- Due to incongruent dissolution of kaolinite, there was preferential release of Si over Al in the beginning, forming amorphous CSH which increased strength for the first year.
- After Al became more available, crystalline stratlingite was formed scavenging Ca from the previous amorphous CSH phase, disturbing the matrix and decreasing strength.

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