Monitoring Setting of Geopolymers

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Background

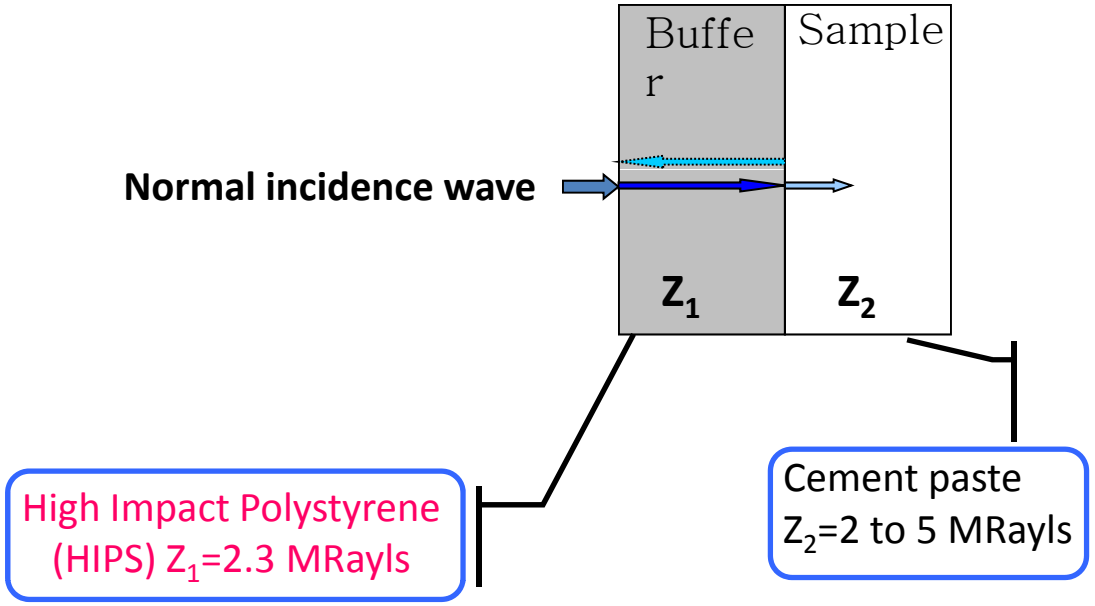
- Geopolymer aluminosilicate, made by reaction amorphous aluminosilicate powder with concentrated alkali hydroxide solution
- Geopolymer initially fluid
- Reacts via dissolution/gelation/polymerization
- Setting presumed to be associated with gelation (unlike portland cement)

Experimental details

- Precursors
  - Metakaolin
  - Class F fly ash
  - Slag
  - Class C fly ash
- Activator
  - sodium hydroxide, sodium silicate, water
- Procedure
  - Pastes mixed in paddle mixer
  - Cured at ambient temperature
  - Varied Si/Al and Ca content
- How setting measured
  - Ultrasonic shear wave reflection (UWR)
  - Proctor penetration resistance (PR)

Ultrasonic shear wave reflection

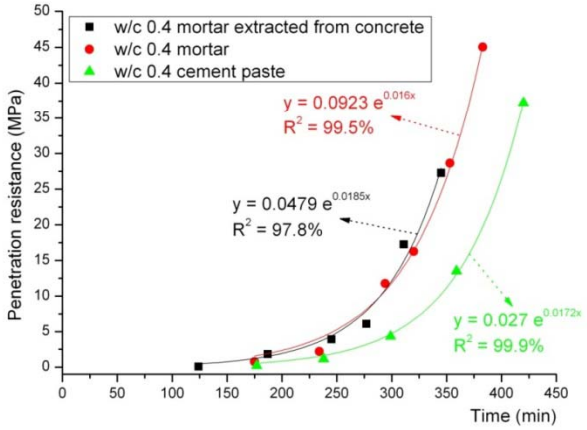
$$R = \left| \frac{Z_2 - Z_1}{Z_2 + Z_1} \right|$$



Low impedance buffer is sensitive to small changes in cement paste impedance

- Previously developed and applied to portland cement paste (Chung et al. 2011)
- Waves partially transmitted and partially reflected at boundary between two materials and reflected energy at boundary between 'buffer' and geopolymer monitored
- Shear waves do not transmit through liquids, but transmit through solids
- R decreases from unity as geopolymer becomes solid

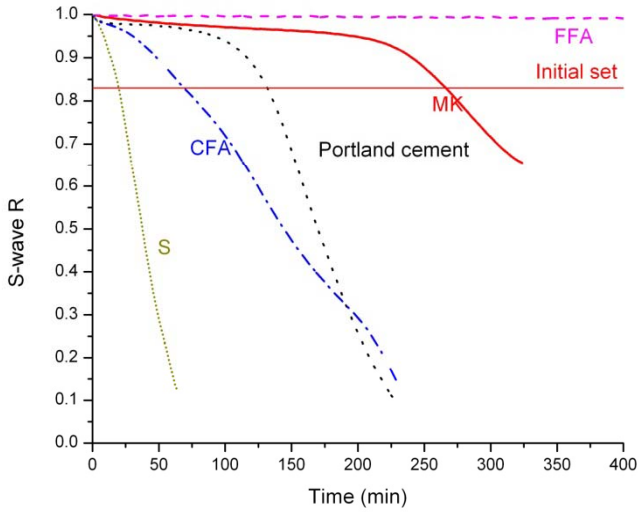
Proctor penetration resistance

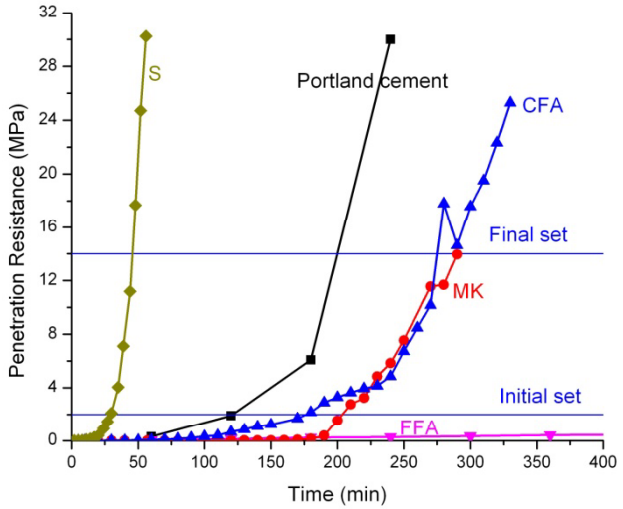


- Standard (ASTM C403) test for set of mortar, adapted for pastes using initial and final set at penetration resistance values of 2 and 14 MPa (Chung et al. 2010)
- Penetration resistance negligible when fluid, substantial when solid
- Penetration resistance increases as geopolymer becomes solid

Geopolymer setting behavior

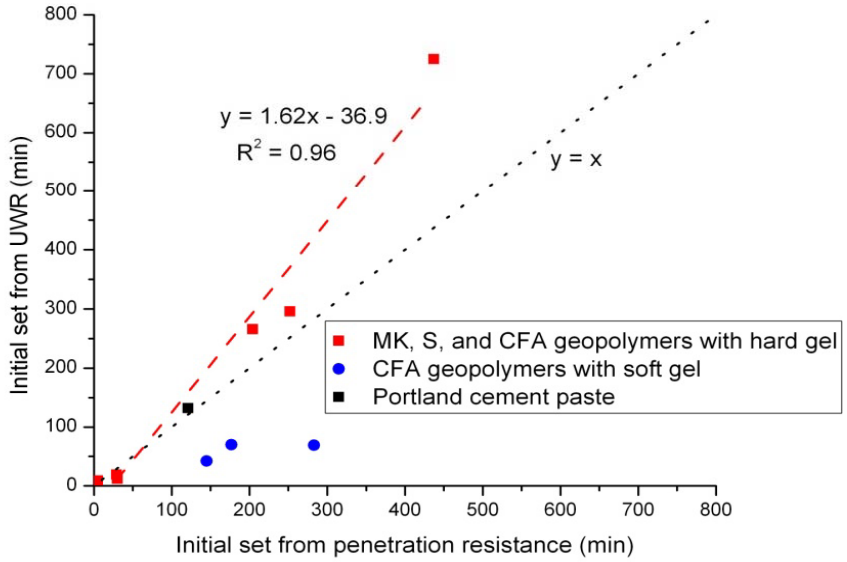
- Stiffening behavior of different types of geopolymers monitored, compared to portland cement paste
- S set more quickly than cement paste
- MK set more slowly than cement paste
- F FA set very slowly
- C FA set more quickly by UWR but more slowly by PR





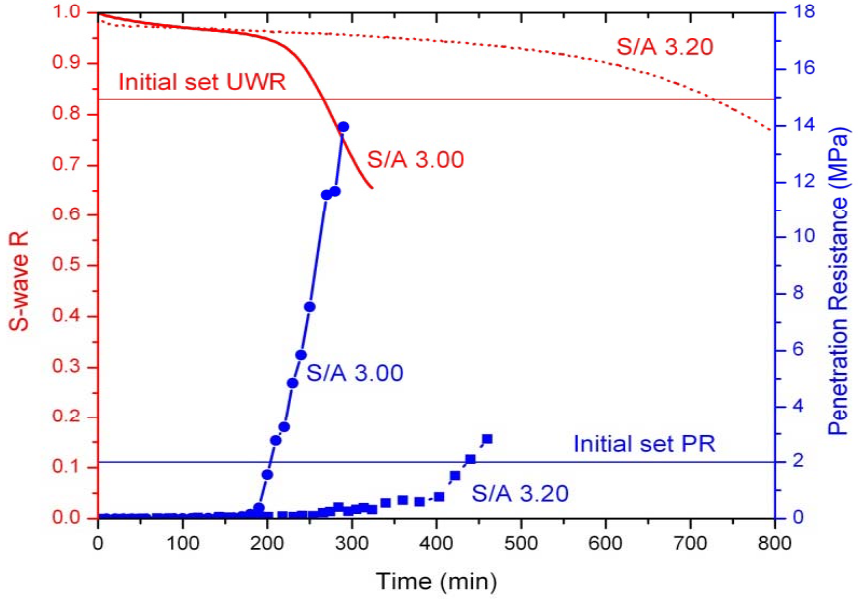
Agreement between methods

- Agreement good except for C FA geopolymers
- Based on these results, appears UWR measures gelation and PR measures strength



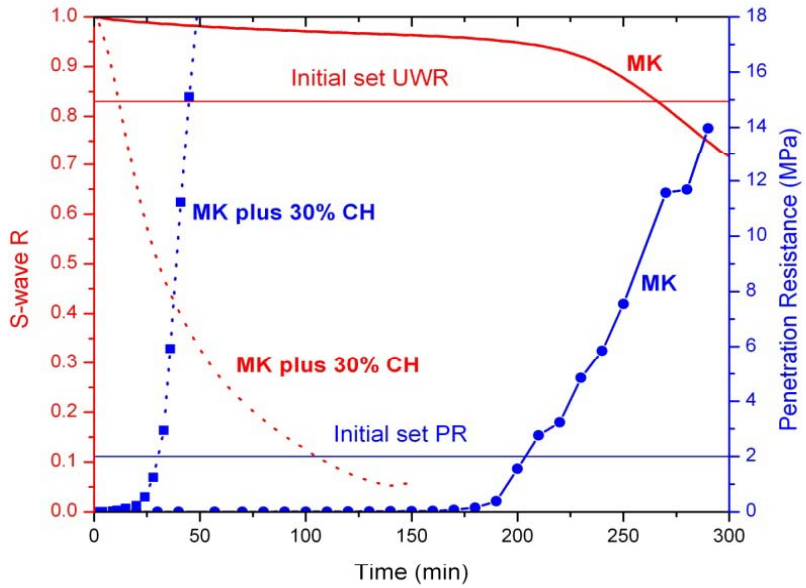
Effect of Si/Al

- Tested MK geopolymers with different ratios
- Si/Al 3.0 gelled and strengthened quickly
- Si/Al 3.2 gelled and strengthened slowly



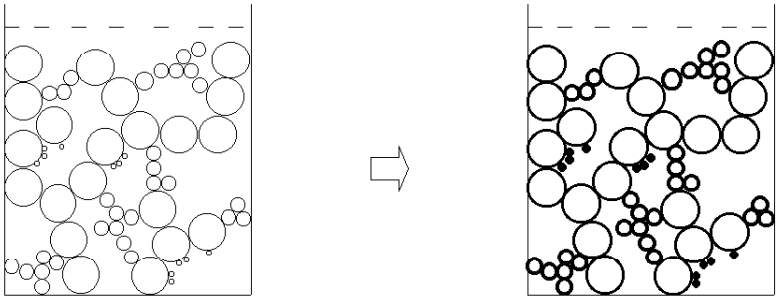
Effect of calcium

- Calcium hydroxide (30%) added to metakaolin geopolymer
- With Ca, gelled and strengthed very rapidly
- Behavior probably associated with C-S-H
- Behavior provides explanation for FA results

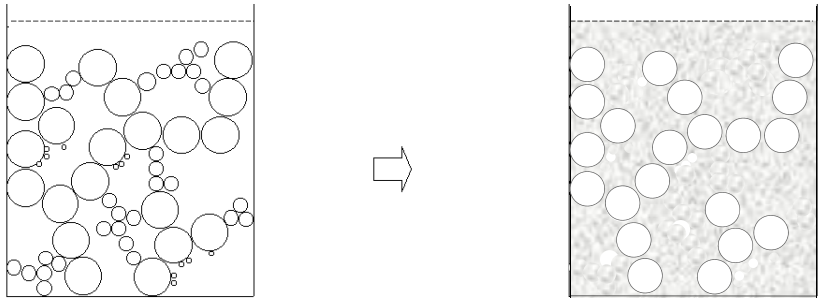


Set in cement paste versus geopolymers

- Cement paste set produced by hydration product linking particles into network
- Geopolymer set produced by gelation



cement paste



geopolymer

Conclusions

- Ultrasonic shear wave reflection and penetration resistance can be used to monitor set of any geopolymer
  - UWR monitors gelation
  - PR monitors strength gain
- Precursor affects gelation and strength gain
- Lower Si/Al accelerates set
- Ca accelerates set