Assessing the Mechanical Stability of Coal Ash via Enzyme Induced Calcium Carbonate Precipitation

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MOTIVATION

- Coal ash impoundments have diverse stability concerns. Failure of impoundments cause various environmental threats, such as contamination of heavy metal in soil, groundwater, and freshwater ecosystems. Contamination can harm plants, wildlife, potable water, and health of humans.
- Increased mechanical stability of coal ash could reduce possibilities for contamination and could potentially immobilize trace elements found in coal ash.
- Microbial induced calcite precipitation (MICP) is a biomediated ground improvement technique with a variety of different applications including: strengthening soils to support structures, mitigation of earthquake-induced liquefaction, prevention of soil erosion, improvement of slope stability, and immobilization of divalent cation contaminants.
- Coal ash treated with MICP experienced mechanical improvement, but significant filtering of ureolyic bacterium during treatment led to non-uniform biocementation.
- Urease (EC 3.5.1.5) is several orders of magnitude smaller than common ureolytic bacterium and is not expected to be filtered during treatment, thus improving uniformity of biocementation.
- Enzyme induced calcite precipitation (EICP) of coal ash has yet to be investigated and this study assesses the potential for mechanical improvement.

Urea Hydrolysis (kinetic)

$$(NH_2)_2CO + H_2O \rightleftharpoons 2NH_3 + H_2CO_3$$

Ammonia to Ammonium (equilibrium)

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

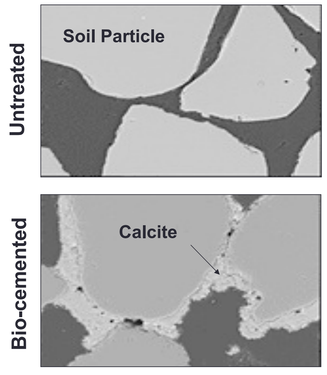
Carbonic Acid Deprotonation (equilibrium)

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{-2} + 2H^+$$

Calcite Precipitation (kinetic)

$$Ca^{+2} + CO_3^{-2} \rightleftharpoons CaCO_3\,(solid)$$

Above: EICP biogeochemical reaction network used to precipitate calcite between coal ash particles (Source: DeJong et al. 2006).



Above: Scanning electron microscopy of untreated and biocemented soil particles (Source: DeJong et al. 2006).

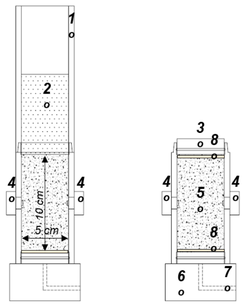
Above: Kingston coal ash spill in Tennessee where 1.1 billion gallons of coal ash slurry was released (NY Times. J. Miles Carey. 2008).

Trace Elements Found in Coal Ash:

- Arsenic
- Barium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Mercury
- Nickel
- Selenium

EXPERIMENTAL SET-UP

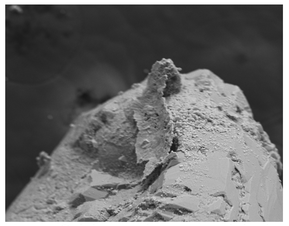
- **General Soil Column Set-up**
  - Acrylic cylindrical soil columns (5 cm in diameter and 5.5 cm in height) were used for all column tests excluding one which used a taller column (5 cm in diameter and 10 cm in height).
  - Coal ash was pluviated in a slurry and supernatant was removed.
  - All columns were placed under 100 kPa confinement.
  - Specimens were treated using a peristatic pump to control injection flow rate.
  - Piezoceramic bender elements were placed in columns to measure shear wave velocity, which is indicative of soil stiffness.
  - Calcite was quantified using gravimetric hydrochloric acid washing.
  - Scanning Electron Microscopy was used to determine location of calcium carbonate precipitation.



1- Column Extension
2- Supernatant solution
3- Acrylic Cap
4- Bender Elements
5- Specimen
6- Acrylic Base
7- Outlet drain
8- Porex filter

Left: Schematic of soil column preparation used in tests (Source: Safavizadeh).

Above: Experimental set-up and oscilloscope used to measure shear wave velocity through treatment.



Above: Calcium carbonate precipitation between soil particle treated with EICP solution containing enzyme stabilizer (milk).

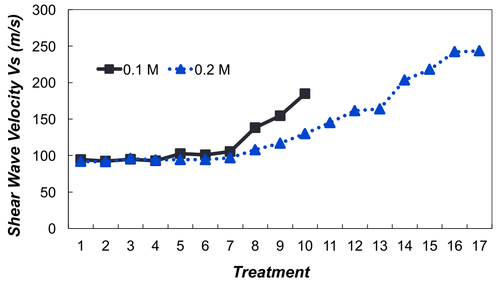
Left: Sand column after one treatment of EICP solution containing enzyme stabilizer (milk).

Left: Coal ash column after EICP treatment.

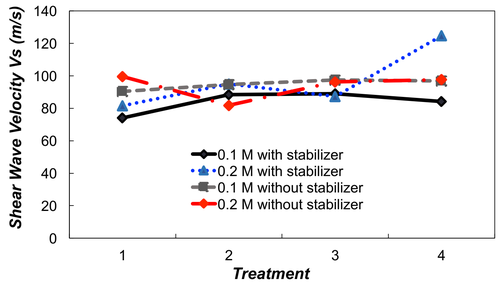
CONCLUSION

- Fisher Scientific's urease, enzyme stabilizer (dry non-fat milk), and 0.2 M $CaCl_2$ in EICP treatment solution is optimal for increasing the mechanical stability of coal ash.
- Urease stabilizer (dry non-fat milk) acts as a nucleation point for calcium carbonate precipitation between particles.
- Hydrolyzed urea was found to be more uniform in EICP treated columns than MICP treated columns.

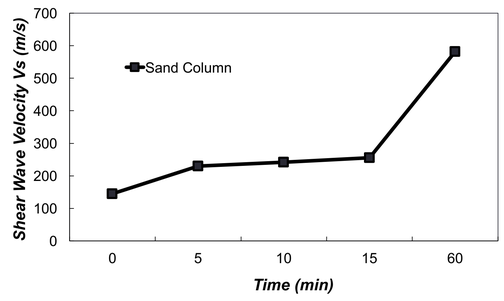
RESULTS



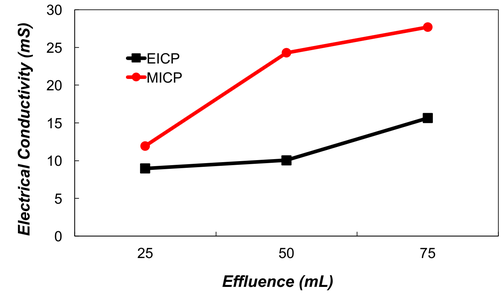
Left: Increased shear wave velocity (Vs) of coal ash treated with 0.1 M and 0.2 M $CaCl_2$ throughout treatment. Column treated with 0.1 M $CaCl_2$ experienced plugging on tenth treatment while the column treated with 0.2 M $CaCl_2$ plugged on the seventeenth treatment. Plugging was due to biofilm which encases enzyme from manufacturer.



Left: Shear wave velocity (Vs) monitored during treatment demonstrates an increase in 0.2 M $CaCl_2$ treatment solution containing the enzyme stabilizer (milk). Plugging occurred on treatment day 5 and soil columns were disassembled. Plugging due to enzyme film was not observed, indicating that calcium carbonate was the reason of plugging.



Left: Shear wave velocity (Vs) monitored after one injection of EICP treatment solution containing urease stabilizer (milk) in Ottawa 20/30 sands. Treatment without urease stabilizer had a similar increase in shear wave velocity but was not cemented when extruded from column.



Left: Electrical conductivity (mS) of solution effluence after a single treatment of EICP or MICP. EICP showed less urea hydrolysis than MICP treatment solution as well as more uniform concentrations. Slow increases in shear wave velocity in EICP treated columns may have been due to the low urea hydrolysis rates.

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