Recent Advances and Field Applications Using Alternative Cementitious Binders

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Unconventional Concrete
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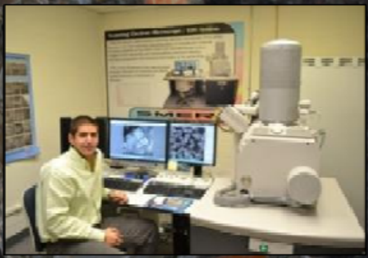

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ERDC
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Outline

- Problems from Dust Production
- Dust, Corrosion, and Soil Stabilization
- Location of Test Area
- Local Materials
- Chemically-Bound Soil Technologies for Soil Stabilization
- Test Road Sections
- What's Going On…
- Summary and Questions

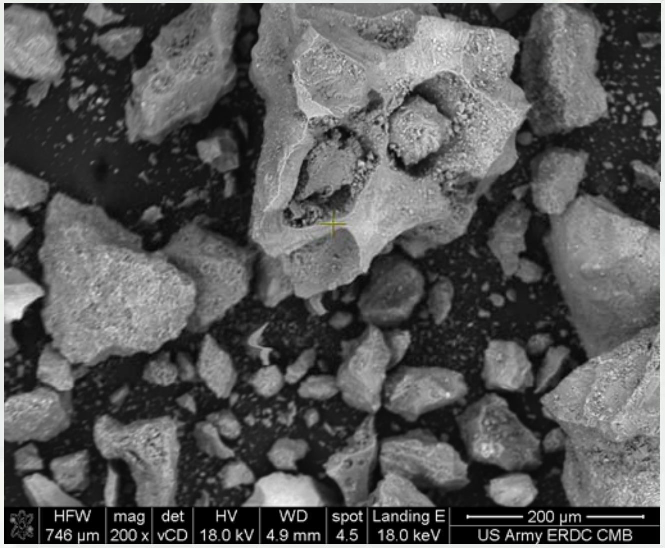
Dust Production in Army Training Areas

- Unsurfaced roads and landing zones are major problems in arid terrain
- Dust introduces abrasives into the vehicle systems and clogs air filters
- Dust control agents are frequently inorganic salts (chloride-containing) that can produce additional corrosion problems
- Conventional paving is not practical in many locations

Pohakuloa Training Area (PTA) Test Site

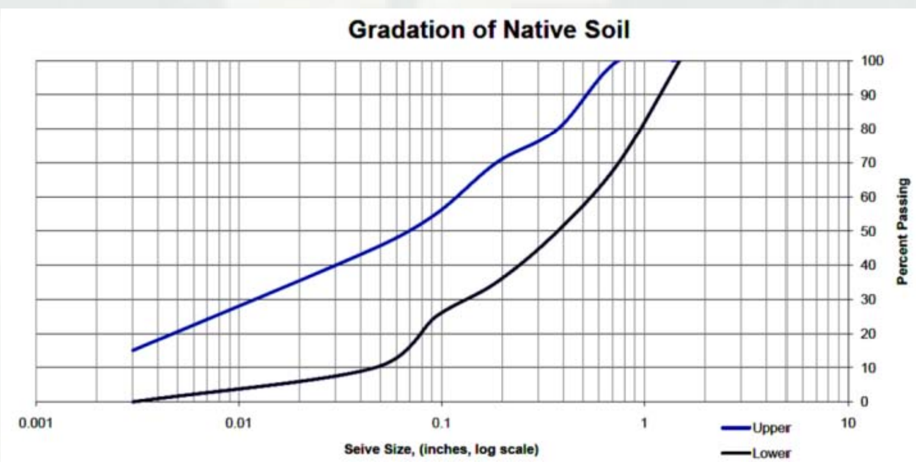
- Serious dust problem at site
- Abrasive, corrosive dust
- Moderate traffic
- Soil is largely volcanic glass that is reactive in an alkali-activated geopolymer
- Cementation should be more durable than dust palliatives

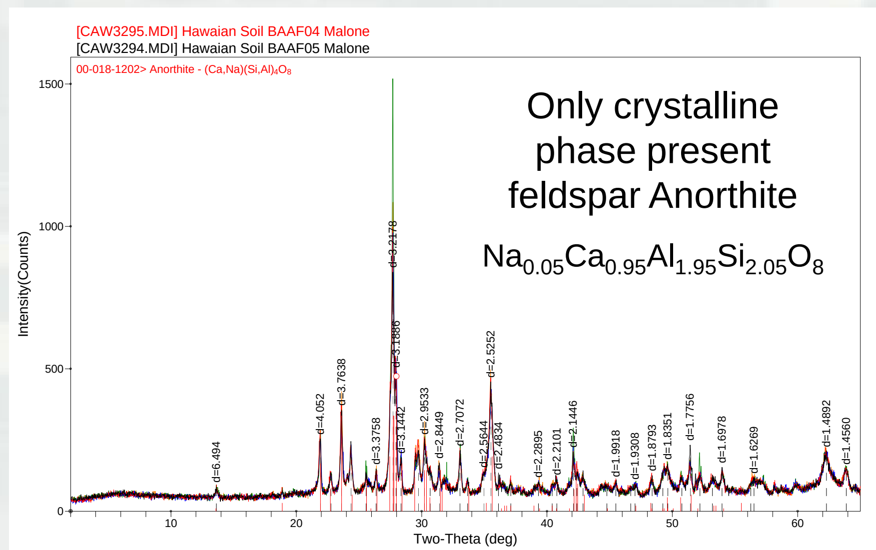
Soils at PTA Test Site



SEM Micrograph of Soil

- Alumino/siliceous aggregates with limited crystallinity
- Amenable to formation of chemically-bound geopolymer
- Sharp edges, and corners
- Wide range of particle sizes





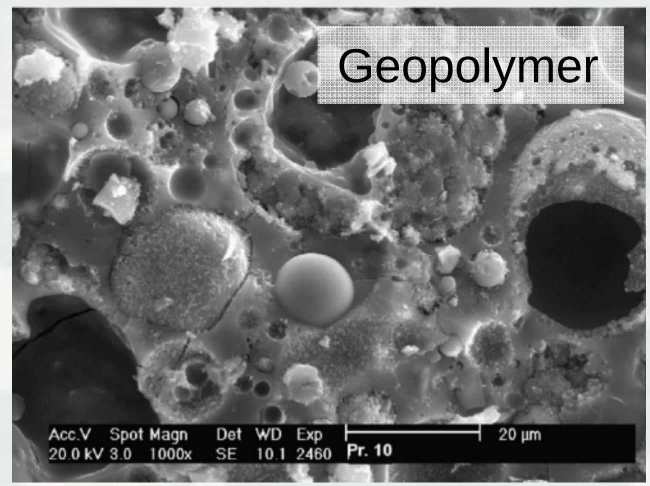
Alkali-Activated Geopolymer: An Alternative

- Alkali-activated geopolymers are special cements formed by mixing a concentrated alkaline solution with a finely-divided reactive aluminosilicate (sometimes with Ca too)
- Alkali-activated geopolymeric cements are strong, fast-setting, inexpensive, and very versatile
- Manufactured from glassy silicates like slag, fly ash, metakaolin, and volcanic ash
- Can use waste alkalis from manufacturing operations
- No portland cement is involved!

Soil solidified with alkali-activated mixture using slag

Why Use an Alkali-Activated Alternative?

- Fast: mixture sets in hours and gets ultimate strength in days
- Easy to Obtain Materials: suitable raw materials are available almost everywhere (eg, fly ash, slag)
- Economical: uses waste/local materials or low-fired clay soils
- Versatile: basic chemistry adapts from a wide variety of glassy aluminosilicates
- Variation of natural weathering process that occurs in volcanic ash deposits



Skvara et al, 2006

Previous Usage Worldwide

- Widely used in Australia
- Marketed by Blue Circle Cement Company and Boral Cement
- Used in over 100 projects of 10,000 to 150,000 m^2 (2.5 to 37 acres)
- Reported to use Na-rich kiln dust, slag, and activator such as lime
- Broad range of compositions

Boral Roadment® application

Current Geopolymer Formulation

- Alkali Rich Glassy Aluminosilicate Aggregates
  - From local PTA volcanic soil
- Slag (ASTM C989) – Approx 6 wt%
  - Source: foundry located in Southern California
- Fly Ash (Direct from Coal Plant) – Approx 6 wt%
  - Plant located on the island of Oahu
  - Chemical composition close to Class F (not F or C)
- Hydrate Lime (ASTM C977) – Approx 6 wt%
- Sodium Carbonate (Soda Ash) – Approx 6wt%
- Water: w/cm of approx 0.17

Geopolymerization Reactions

Exchange Reaction

- Initial: $Na_2CO_3 + Ca(OH)_2$
- Final: NaOH and $CaCO_3$

Geopolymerization Rxn: Aggregates

- NaOH breaks down reactive surface of aggregates
- Forms A-S-H gel phase

Geopolymerization Rxn: Supplementary Cementing Materials

- Alkalis down fly ash and slag
- For C-A-S-H gel phase

Batch Mixing in Laboratory

Mixture Components

Blend Dry Components

Add Activator Solution

Blend Until Balling Occurs

Consolidation Methods

- Best performance observed when mixture is roller-compacted to consolidate

- Roller Compacted Method Pros:
  - Decreased Manpower
  - Faster Placement Times
  - Method Similar to Soil Compaction
  - Does Not Require Specialized Skill Set

- Roller Compacted Method Cons:
  - Does Not Produce the Highest Quality Surface
  - Density Depends on Compacted Effort
  - Somewhat Requires Continuous Placement

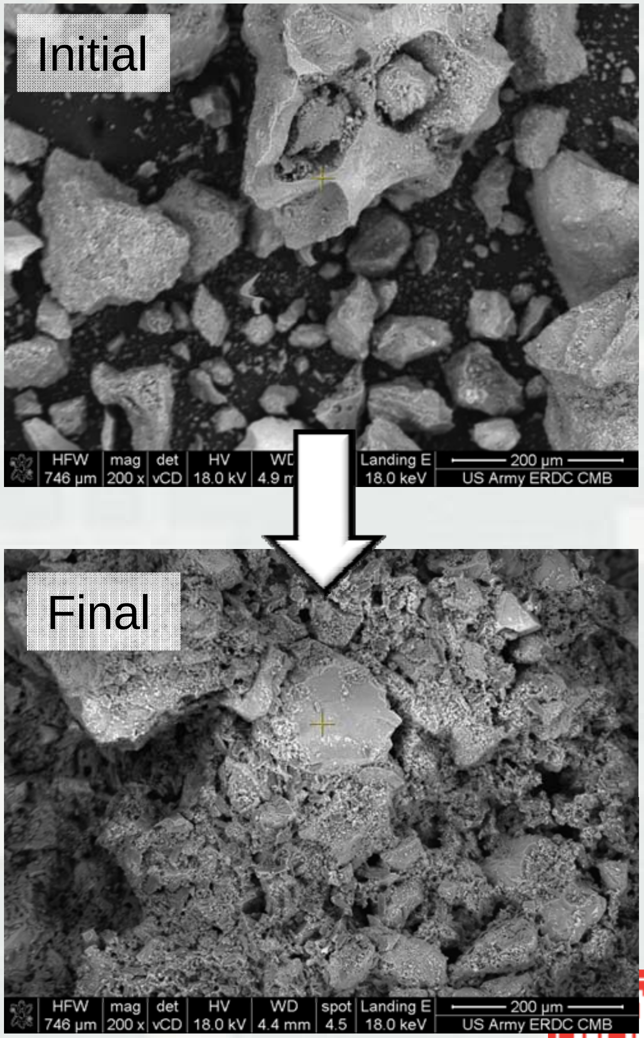
Trial Batching at Univ. of Hawaii and ERDC

- University of Hawaii test sections:

- Trial batching at ERDC Concrete & Materials Branch:

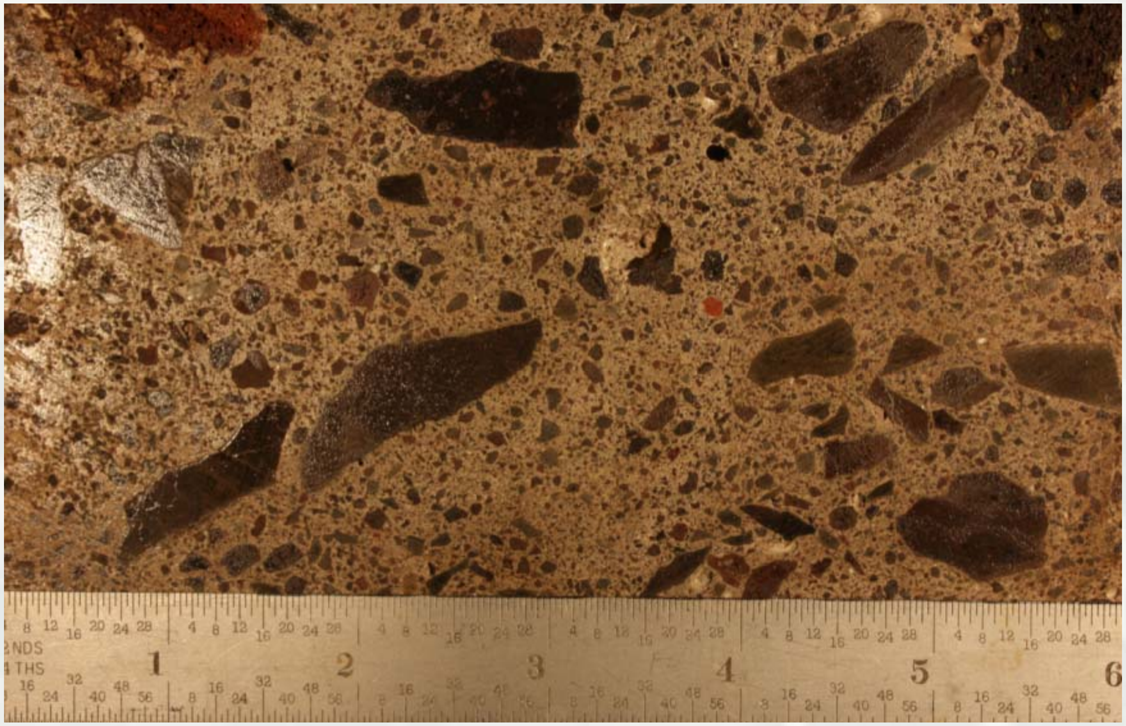
Resulting Microstructure

- Alkali attacks edges and corners of coarse volcanic aggregates
- Fines can react completely
- C-A-S gel phase acts as binder similar to C-S-H in Portland cement systems
- Secondary minerals (zeolites) also contribute to cementation



Resulting Microstructure

- Hardened chemically-bound soil microstructure similar to hardened Portland cement concrete



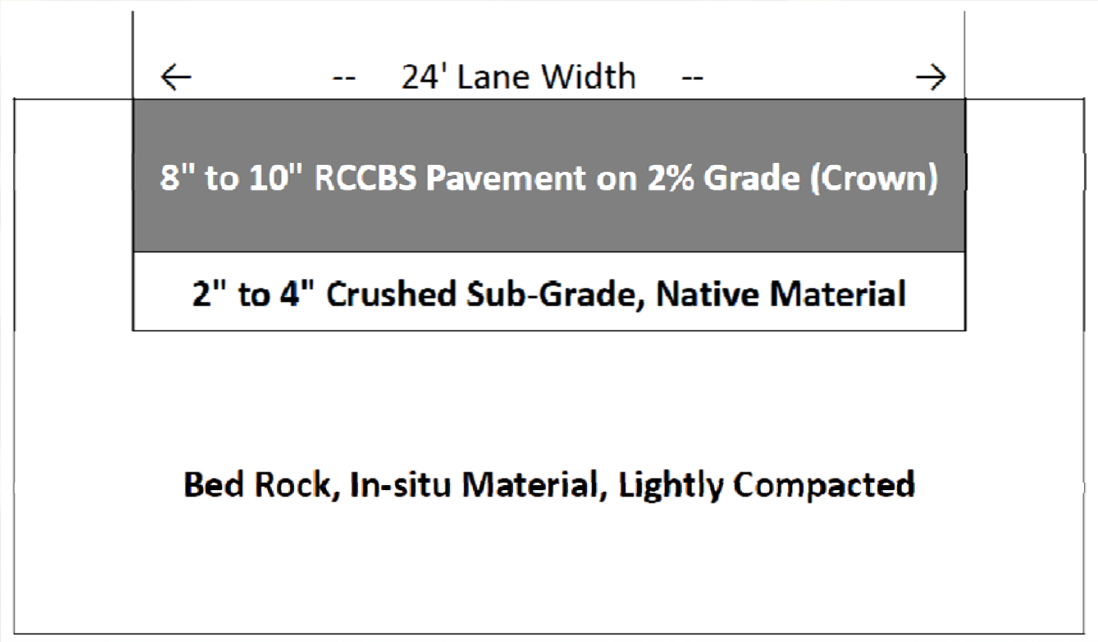
Polished Cross Section of Hardened Chemically-Bound Soil

Current Mixture:

- ~6.4 MPa (927 psi) at 7 days
- ~12.4 MPa (1800 psi) at 28 days
- Highest compressive strengths when >135 pcf unit weight achieved during field compaction

From the Lab to the Field…

- Placement of chemically-bound soil mixture in the field using roller-compacted method:



Cross section of roller-compacted placement of chemically bound soil

Stats on PTA trial placement:

- Two 12ft lanes
- 6in compacted
- 8-10in placed
- 0.5mi in length

What's Happened!

- Placement at the PTA test site
- Photos from the field provided by Chris Moore and Samuel Craig (US Army ERDC – CMB)

What's Happened…

- Placement at the PTA test site
- Issues with high winds
- Iterative process to optimize placement

On-site equip. for placement

On-site batch plant

Spreading for roller-compaction

Summary and Conclusions

- Control of abrasive dust is a serious corrosion and equipment maintenance issue
- Alkali-activated geopolymerization is being investigated using glassy volcanic soils
- Reports in the literature support feasibility along with experience from Australian manufacturers
- ERDC has developed initial mixture designs and procedures for field placement
- Successful placement of test section at PTA site using chemically-bound soil stabilization technology

Future Directions

- Temporary storage pads for government facilities
  - Upcoming project in Charleston, SC to construct parking slabs for storage of MRAPs returning to US
  - Working with Intelligent Concrete to produce alternative cementitious material mixture proportions using the “less reactive soil” from local SC area
  - Include the use of nanoparticles to activate the system

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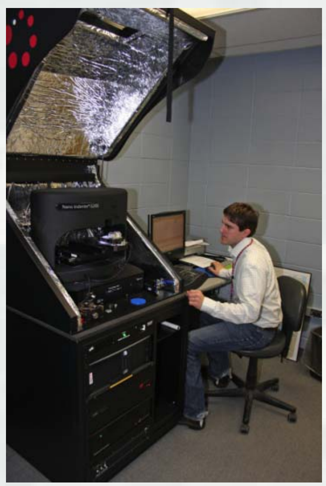
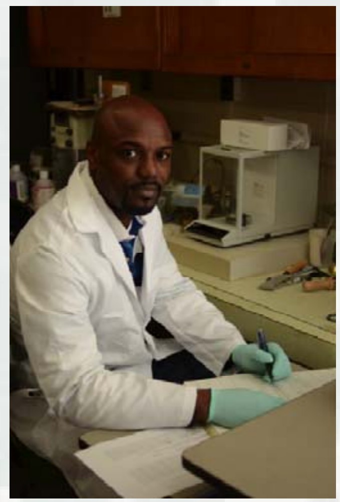
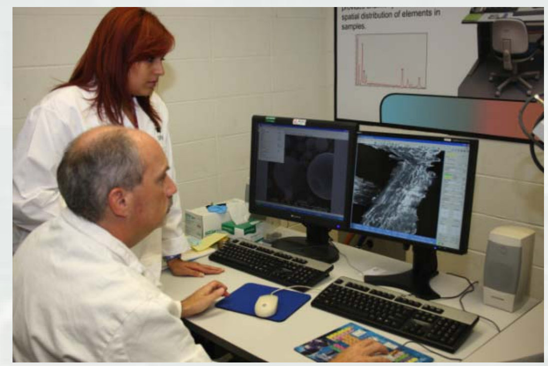


Paul G. Allison



Samuel L. Craig



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Thank You!

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