The In-Situ State: The Elusive Ingredient in Lunar Simulant

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• Modular Regolith Characterization Instrument Suite for Construction and In Situ Resource Utilization Surveys
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• In-Situ Investigation of Lunar Surface and Subsurface Material Properties
Key Issues

• Past Lunar Mission Exploration
  – Primarily shallow depths (< 0.5 m)
    • Shallow excavation (scoops)
    • Few deep probes
• New Lunar Missions
  – Primarily deep depths (2 m)
    • Deep probes – Coring
    • Excavation – Mining

WHAT’S BELOW THE SURFACE?
Regolith Deposition

- **Comminution (Meteor Impact)**
  - Impact fragmentation
  - Mineral melting (Breccias)
  - Consolidation

- **Agglutination**
  - Melting
  - 30-50% of regolith

- **Mixing**
  - Interlocking of fragments, breccia and agglutinates
Structure

• Common in Terrestrial Soils
  – Loess
  – Glacial Till
  – Quickclays

• Present in lunar soils
  – Partial regolith induration $\Rightarrow$ Quickclay
  – Regolith breccia $\Rightarrow$ Glacial Till
  – Agglutinates $\Rightarrow$ Loess
Typical Lunar Structure

Intermediate layer, 2, represents complex response due to influence of structure on strength, compressibility and removal

**Depositional Colluvium**

**Comminuted Regolith**

**Megaregolith**

**Intact Bedrock**

- Very loose material
- Considerable structure and stability
- Very hard material at depth
- Beyond range of interest
What do we measure?

- **Strength**
  - Friction angle
  - Cohesion
  - Angle of Repose

- **Compressibility**
  - Indices
  - Modulus

- **Rippability**
  - Energy

All these properties have been measured from past missions on reconstituted material.

**WHAT’S MISSING?**
Influence of Structure

- **Strength increases**
  - Maturity
    - overconsolidation,
    - induration
  - Aggregate interlock
- **Compressibility varies**
  - Stiff initial response
  - Collapse potential
    - void ratios higher than simulant
    - natural formation prevents achievement of most stable configuration
What does this mean to ISRU

- Higher energy requirements
  - Probe insertion
  - Rippability/Excavation
  - In-situ strength
- Durability
  - Abrasion
- Drillability
  - What tools work best on the moon
  - What materials should the tools consist of
Current Lab Formation

- Not represented by simulant compaction
  - Lacks natural interlock
  - Lacks induration of mature regolith
- Oxidation of terrestrial basalt simulant alters surface texture from lunar basalts
- Need to create structure with in-situ material!
Creating Structure

• Crushing of larger aggregate in-situ
  – Can create impact framentation
  – Fill gaps with compacted regolith
  – Allows for larger void structure
Creating Structure

- **Cementation agents**
  - Creates bonding within compacted aggregate
  - Simulates induration or melting
  - Allows for increased resistance to excavation

- **Heating**
  - Temperature indurate simulant
  - Heat activated epoxy resin coatings

![Diagram of contact melting]
Why should we care?

- **Energy** is the #1 Issue
  - Conservation is critical to mission success
- We do not want to underestimate
  - Limits the potential of extra-terrestrial instruments
  - Can cause premature failure
- Cost $$ if we are wrong
What to do?

- Literature can tell us ranges of influence between in-situ and reconstituted terrestrial material
  - Provides factor of safety in instrument design for added resistance
- Attempt to simulate structure in laboratory environment
- Use of DEM to predict behavior of soil structure
Conclusions

• New lunar missions seek to explore deeper into the subsurface
• Structure of in-situ regolith will play a role in affecting exploration
• There is a need to account for structure in development of simulant/additives
Questions?