New Measurement Technologies for Construction Aggregates

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International Center for Aggregates Research (ICAR)

• Joint operation of the University of Texas at Austin and Texas A&M University
• Mission: to find the most efficient and effective uses for aggregates
• Activities: research, education, information exchange
• Concrete, asphalt, and unbound applications
Research Approach for Examining Aggregate Characteristics

Characterization of Aggregate Properties

Modeling

Performance of HMA, PCC, and Unbound Applications
Completed and Ongoing Research

• Characterization
  – Laser-Based Aggregate Scanning System (Project 503)
  – Characterization of Microfines (Project 107)

• Modeling
  – Virtual Cement and Concrete Testing Laboratory (Project 106)

• Performance
  – Workability and Rheology of Concrete (Project 105)
Aggregate Microfines

• Dust-of-fracture material (<75 µm) produced when rock from quarry is crushed to sand size.

• Current specifications (ASTM C 33) limit microfines content to 7% of fine aggregate mass for concrete (5% if exposed to abrasion).
  – Concerns about presence of clays
  – Flow properties different (higher water demand results in lower strength, higher drying shrinkage)

• Research shows concrete can be made successfully with up to 15 to 20% microfines.
Aggregate Microfines

- Aggregate producers must wash microfines from sand to achieve ASTM C 33 grading.
- Uses for microfines are limited.
- Improved understanding will promote use of microfines.
ICAR 503: Rapid Test to Establish Grading of Unbound Aggregates

ICAR 107: Correlating Minus #200 Fine Aggregate Characteristics to Field Performance of Concrete
Characterizing Aggregates: Relevant Properties

- Mineralogy
- Size
- Shape
- Texture
- Microfines Characteristics
Size, Shape, and Texture

• **Size**
  – Sieve analysis for larger aggregates (>75 \( \mu m \))
  – Many methods available for smaller aggregates

• **Flatness and Elongation**
  – Determined by measuring aggregate principle dimensions (ASTM D 4791)

• **Angularity**
  – Often determined subjectively: Angular, subangular, subrounded, rounded, well rounded
  – Measure number of fractured faces (ASTM D 5821)

• **Texture**
  – Typically determined subjectively

• **Size, shape, and texture indirectly characterized with packing.**
Effects of Aggregate Characteristics on Performance

• **Concrete**
  – Angular, rough particles result in higher strength
  – Rounded, smooth particles result in improved flow properties

• **Asphalt**
  – Equidimensional, angular, rough particles increase strength and durability
  – Flat and elongated particles cause segregation
2D Digital Image Analysis (DIA)

• Image of particle digitized, then shape and size analyzed by computer
• Several commercially available machines
• Problems
  – Algorithms needed to convert 2D data to “pseudo-3D” information and mass
  – Touching particles appear as one
  – Range of sizes limited by camera settings
Laser-Based Aggregate Scanning System (LASS)

- 3D automated aggregate sampling system
  - Aggregate, concrete, HMA plants
- Developed at University of Texas at Austin
  - Carl T. Haas, Alan F. Rauch
LASS Capabilities

• Resolution
  – X – 0.3 mm
  – Y – 0.1 mm
  – Z – 0.5 mm

• Provides traditional measurements (comparable accuracy)

• Provides new objective measurements not possible with existing tests
Traditional Measurements

- Virtual Sieve

- Virtual Caliper
New Measurements

- Shape Index
- Angularity Index
- Texture Index

All indices would be zero for a smooth sphere.
Characterization of Aggregate Microfines

• Determine size, shape, texture, mineralogy, presence of clays

• Correlate microfines characteristics to concrete performance
  – Flow properties
  – Strength
  – Durability

• Identify microfines that are bad actors in concrete
Characterization Tests

• Sophisticated laboratory equipment for **study**
  – X-ray diffraction
  – X-ray computed tomography
  – Laser diffraction
  – Scanning electron microscopy
  – Thermogravimetric analysis

• Simple characterization tests for **industry**
  – Blaine fineness
  – Methylene blue
  – Packing
  – Settling time (hydrometer)
  – Others…
- Characterize 2D shape (image analysis software)
- Energy Dispersive Spectroscopy (EDS) for mineralogy, presence of clays
ICAR 106: Adapting the Virtual Cement and Concrete Testing Laboratory to Optimizing the Selection of Aggregates for Concrete
Modeling of Concrete

- Concrete structures designed with sophisticated computer models.

- But the material is designed based on trial-and-error, empirical procedures.
The Virtues of Virtual

- Physical Testing
  - Time consuming
  - Labor intensive
  - Results available in weeks, months, or years
  - Limited usefulness of results

- Virtual Testing
  - Faster
  - Cheaper
  - Scientific
  - Allows optimization
Virtual Cement and Concrete Testing Laboratory (VCCTL)

• Web-based virtual laboratory for evaluating and optimizing concrete
• NIST-led industry consortium started in 2001
• Based on more than 10 years of research at NIST
• Version 1.1 currently available to public: http://vcctl.cbt.nist.gov
• Later versions available to consortium members
### Inputs and Outputs

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Degree of hydration</td>
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<tr>
<td>Aggregates</td>
<td>Setting time</td>
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<tr>
<td>Supplementary</td>
<td>Shrinkage</td>
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<td>Heat rise</td>
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<tr>
<td>Mixture proportions</td>
<td>Strength development</td>
</tr>
<tr>
<td>Curing conditions</td>
<td>Flow properties</td>
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</tbody>
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Challenges

• Material Characterization
  – Accurate methods needed for raw materials
  – Variations in material properties must be taken into account

• Computational Models
  – Concrete is a tremendously complex material
  – Computational results must be related to concrete
Aggregates in the VCCTL

- VCCTL began with cement hydration model
- Spherical and ellipsoidal aggregates added later
- ICAR’s role: incorporate true aggregate properties into VCCTL
Determination of Aggregate Characteristics

- X-ray computed tomography for 3D data
- Analyzed with spherical harmonic method to obtain coefficients that can be used to create virtual aggregates for computer models
ICAR 105: Measuring the Workability of High Microfines Concrete
Concrete Workability

• Concrete Workability: The ease and homogeneity with which concrete can be mixed, placed, consolidated, and finished (ACI 116R).

• Rheology: The study of the flow and deformation of matter.
Slump Test

• Measures one aspect of workability: consistency
• Can give misleading or false results for certain concrete mixtures.
• Not appropriate for high microfines mixtures.
Concrete Rheology: An Emerging Approach

Measure Fundamental Flow Properties

Yield Stress = $\tau_0$
- Stress to start flow

Plastic Viscosity = $\mu$
- Time for concrete to flow once yield stress is exceeded

Bingham Equation
$$\tau = \tau_0 + \mu \dot{\gamma}$$

Shear Stress, $\tau$ (Pa)

Shear Rate, $\dot{\gamma}$ (1/s)
ICAR Rheometer

- Fully portable rheometer
- Operated by hand or mounted above container
- Designed for routine field measurements
  - Simple
  - Fast
  - Accurate
  - Low-cost
- Adds energy—useful for high microfines concrete
First Generation Prototype

- Proof of Concept - developed with off-the-shelf components
- Successfully tested on wide range of concrete mixtures with workability ranging from slump of 2 inches to self-consolidating concrete
- Seeking commercialization partner
Applications of ICAR Rheometer

• Useful throughout the concrete production process
  – Research and development
  – Mixture proportioning
  – Field quality control

• Low cost and portable form factor enables laboratory measurements in the field

• Also useful for coarse grained suspensions other than concrete
Self-Consolidating Concrete (SCC)

• Flows and consolidates without vibration
• Significant benefits
  – Labor savings
  – Improved hardened properties
• Flow properties must be carefully controlled
• ICAR rheometer is well suited for SCC
Field Testing
Conclusions

• ICAR research projects are improving the characterization of aggregates and enhancing the performance of concrete, HMA, and unbound applications.
• LASS can provide real-time characterization of aggregate properties in industrial setting.
• Improved characterization techniques for microfines will help industry discriminate between good and bad microfines.
• VCCTL will improve the concrete mixture design process.
• ICAR rheometer will make routine field measurement of concrete rheology a viable option.