USE OF MANUFACTURED SAND IN CONCRETE MIXTURES
AND APPLICATIONS IN TRANSPORTATION

Alabama Transportation Conference
February 10, 2017
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Overview
- Factors Influencing Increased Use of Manufactured Fine Aggregate
- Natural and Manufactured Fine Aggregate Properties
- Effects on Mixture Proportioning and Concrete Properties
- High Fines Manufactured Sands in Concrete

Concrete Section

Concrete Materials Proportions

Manufactured Sand
- Fine aggregate composed of fragments of high quality rock/stone having angular crushed faces
- Well-graded with increased dust of fracture and the same mineralogy as the parent rock and having minimal or no clay material present
- May be a washed or unwashed product
- May not meet the grading requirements for ASTM C 33

Surface Geology of the United States
Due to diminishing supply and transportation costs, natural sand is in short supply. Many local crushed stone plants supply the Atlanta market. Blends of manufactured and natural sand are prevalent (60:40, 70:30) and often 100% manufactured sand.

- **Chicago**
  - Due to diminishing supply and transportation costs, natural sand is in short supply.
  - Manufactured sand has been used successfully in concrete pavement on I-290 reconstruction.
  - Plainfield, IL concrete test sections.
  - Now allowed for use in ILDOT and Chicago Tollway projects.

**Sustainability**
- Increases options for using additional resources.
- Extend resources in short supply.
- Reduce transportation costs and fuel consumption.

**Particle Shape**

**Natural Sand**
- Angular Particles: Provides interlock and improves strength and stiffness in asphalt, concrete, base, etc. May reduce workability – not as easy to manipulate and place.

**Manufactured Sand**
- Rounded Particles: Less interlock, lower bond strength. Good workability – easy to manipulate.

**Particle Shape**
**Angularity**

ASTM C1252 Test Method for Uncompacted Voids
(Fine Aggregate Angularity – FAA)

Used in Superpave Specifications for Asphalt Mixtures
  e.g. High Traffic FAA > 45

Example FAA Values:
- Rounded Natural Sand 38
- Limestone Manufactured Sand 43
  (Soft, Impact Crusher)
- Limestone Manufactured Sand 47
  (Hard, Cone Crusher)
- Granite Manufactured Sand 49

**Mineralogy**

- Typically no fine aggregate restrictions for general use cast in place, precast, etc. concrete
- Restrictions vary for pavements, bridge decks, etc. with vehicular traffic

Examples:
- ALDOT No limestone
- GADOT No limestone
- ILDOT No restrictions
  (dolomite for HMA coarse)
- TXDOT 60% acid insoluble requirement
  (can blend limestone \(\frac{(A_1 + P_1) + (A_2 + P_2)}{100}\) ≥ 60%)

**ASTM C33 - Fine Aggregate Grading**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
<th>ASTM No. 57</th>
<th>ASTM C 33</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 mm (3/8 - in.)</td>
<td>100</td>
<td>100</td>
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<tr>
<td>4.75 mm (No. 4)</td>
<td>95 - 100</td>
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<tr>
<td>2.36 mm (No. 8)</td>
<td>80 - 100</td>
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<tr>
<td>1.18 mm (No. 16)</td>
<td>50 - 85</td>
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<tr>
<td>600-µm (No. 30)</td>
<td>25 - 60</td>
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<td></td>
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<tr>
<td>300-µm (No. 50)</td>
<td>10 - 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150-µm (No. 100)</td>
<td>2 - 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75-µm (No. 200)</td>
<td>3 or 5 max (natural)</td>
<td>5 or 7 max (manufactured)</td>
<td></td>
</tr>
</tbody>
</table>

**Combined Aggregate Grading**

Percent Passing

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>ASTM No. 57</th>
<th>ASTM C 33</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/2 – in.</td>
<td>100</td>
<td>95 – 100</td>
</tr>
<tr>
<td>1 – in.</td>
<td>95 – 100</td>
<td></td>
</tr>
<tr>
<td>3/4 – in.</td>
<td>25 – 60</td>
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</tr>
<tr>
<td>1/2 – in.</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>3/8 – in.</td>
<td>0 – 5</td>
<td>95 – 100</td>
</tr>
<tr>
<td>No. 4</td>
<td>0 – 10</td>
<td>80 – 100</td>
</tr>
<tr>
<td>No. 8</td>
<td>50 – 85</td>
<td></td>
</tr>
<tr>
<td>No. 16</td>
<td>25 – 60</td>
<td></td>
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<tr>
<td>No. 30</td>
<td>10 – 30</td>
<td></td>
</tr>
<tr>
<td>No. 50</td>
<td>2 – 10</td>
<td></td>
</tr>
<tr>
<td>No. 100</td>
<td>3/5 (natural)</td>
<td>5/7 (manfd)</td>
</tr>
<tr>
<td>No. 200</td>
<td>3/5 (natural)</td>
<td>5/7 (manfd)</td>
</tr>
</tbody>
</table>

**Effect on Total Grading**

**Optimum Graded Mixture**
Aggregate Blend Grading Methods
- 0.45 power curve
- Coarseness factor chart
- Optimized grading chart
Now in ACI 211 - Proportioning

Coarseness Chart
Desirable zones

Workability factor = particles passing N8
Coarseness factor = part. retained on 3/8" / part. retained on N8

Combined Grading - Gap

Good Workability

Poor Workability

Combined Optimized Grading

Optimized Grading
Example Specification - Texas Department of Transportation
Optimized Aggregate Gradation for Hydraulic Cement Concrete Mix Designs (TXDOT Designation TEX-470-A)
- "4 -20" min to max range on combined grading chart
- Sum of percent retained on No. 8 to No. 30 sieves > 15 %
- Sum of percent retained on No. 30 to No. 200 sieves 24 – 34 %
- Uses blend of coarse, fine and "intermediate" aggregates to achieve

"8 to 18"
(There are other variations)
**Minus 75-µm (No. 200) Specifications for Manufactured Sand – Other Countries**

- Australia: normally 10% but 25% if agreed by owner
- France: 12 to 18% depending on use
- India: normally 15% but 20% if tested
- Spain: 15%
- Europe: 16% passing 63-µm
- South Africa: 10%
- United Kingdom: 16%
- ASTM C 33 is 5 to 7%

**ICAR Research Projects**

- High Fines Manufactured Sands
- Optimization and Proportioning
- Workability
- Characterizing Minus No.200
- Optimizing Aggregate Grading to Reduce Cement Content
- Blending Manufactured and Natural Fine Aggregate

**28-day Compressive Strength of Concrete for Different Aggregates (Fixed W/C)**

**7-day Flexural Strength of Concrete for Different Aggregates (Fixed W/C)**

**Gradings of Sands Evaluated in ICAR Project 102 Mortar**
Good quality concrete can be made with MFA with high microfines:
- Higher compressive strength for same w/c
- Higher flexural strength for same w/c
- Higher resistance to Cl ion penetration
- Higher abrasion resistance
- Slight increase in drying shrinkage

ASTM C33 PROPOSED GRADING REVISION FOR MANUFACTURED SAND

Standard Specification for Concrete Aggregates

- Removal of minus No. 200 limits from the fine aggregate deleterious substances table
- Transfer of minus No. 200 limits to the fine aggregate grading
- New note in alternate grading section giving guidance on quality of high fines materials
High Microfines Sands

Since microfines have similar size as cementitious materials, they are more appropriately considered part of paste.

Paste must be provided to fill voids between aggregates

Proportioning High Microfines Sands

ICAR Results

Cost Comparison

NEW ASTM STANDARD

ASTM C1797

Standard Specification for Ground Calcium Carbonate and Aggregate Mineral Fillers for Use in Hydraulic Cement Concrete
Plainfield, IL Project

- Vulcan Materials Company Midwest Division
- Illinois Department of Transportation
- K-Five Construction Corporation
- Holnam Corporation
- Ozinga Illinois Corporation
- W. R. Grace and Company

Plainfield Paving Demonstration Mix Data

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>Fly Ash*</th>
<th>GGBF Slag</th>
<th>Mortar Factor</th>
<th>Fine Aggregate</th>
<th>Air Content</th>
<th>Slump</th>
<th>W.C. Ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>375</td>
<td>100</td>
<td>100</td>
<td>0.90</td>
<td>Natural Sand</td>
<td>5.0</td>
<td>2.75</td>
<td>0.44</td>
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<tr>
<td>2</td>
<td>375</td>
<td>100</td>
<td>100</td>
<td>0.90</td>
<td>Manteno High Fines Stone Sand</td>
<td>7.0</td>
<td>2.75</td>
<td>0.56</td>
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<tr>
<td>3</td>
<td>460</td>
<td>100</td>
<td>145</td>
<td>0.78</td>
<td>Manteno High Fines Stone Sand</td>
<td>6.8</td>
<td>1.5</td>
<td>0.47</td>
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<tr>
<td>4</td>
<td>460</td>
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<td>0</td>
<td>0.83</td>
<td>McCook Med Fines Stone Sand</td>
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<td>1.5</td>
<td>0.48</td>
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<tr>
<td>5</td>
<td>375</td>
<td>0</td>
<td>115</td>
<td>0.83</td>
<td>McCook Med Fines Stone Sand</td>
<td>6.0</td>
<td>1.5</td>
<td>0.46</td>
</tr>
</tbody>
</table>

*For Mixes 1 and 2, fly ash was from ISG Resources at Gary, IN. For Mixes 3 and 5, fly ash was from Mineral Solutions at Romeoville, IL. See Attachment #7 for chemical and physical test results.

Plainfield, IL Project

- Five sections on a quarry entrance road using natural sand and manufactured sands (5.5% and 16% minus No. 200)
- Both manufactured sand products worked well
- Use of slump test not beneficial
- Mixture met IDOT strength requirements
- Very good salt scaling rating, better than natural sand control mix
- High fines sections performed best when mortar factor reduced (coarse aggregate volume increased)

PLAINFIELD CONCRETE PAVING DEMONSTRATION

<table>
<thead>
<tr>
<th>AVERAGE GRADATIONS</th>
<th>SSD GRAVITIES</th>
<th>ABSORPTION</th>
<th>F.M.</th>
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<tr>
<td>Plainfield</td>
<td>Mccook</td>
<td>Manteno</td>
<td>Powder</td>
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<tr>
<td>1.5&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>1&quot;</td>
<td>56</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>74</td>
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<tr>
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Plainfield PAVEMENT SURVEY: 3 YEARS LATER
**SUMMARY**

- Manufactured sands are readily available for use in concrete, and especially important in areas of decreasing natural sand supplies.
- Particle shape and grading of manufactured sand influence fresh and hardened concrete properties.
- Mineralogy may be an important consideration for certain applications.
- Manufactured sands can be beneficial for optimizing overall aggregate grading.
- Research and demonstration projects have shown viability and benefits of high microfines manufactured sands and mineral fillers.