Gravel HMA Study

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Acknowledgements

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- Zoeb Zavery (Project Manager) and Technical Working Group of project at NYSDOT Materials Bureau
- Chris Ericsen (graduate student) and staff at Rutgers Asphalt Pavement Laboratory (RAPL)
- Allen Cooley, Burns Cooley Dennis
Acknowledgements

- Gravel and aggregate suppliers (you know who you are)
- NuStar Asphalt for supplying the asphalt binder
Objective

- Determine whether gravels with 100/95 angularity can be used for pavements of >30M ESALs
  - Currently, aggregates with 100/100 (crushed stone) to 100/98 allowed
    - 100/98 recently allowed based on NCAT Lopke Study
  - Use laboratory rutting tests to compare rutting properties of the different angularities
  - Evaluate the potential use of different angularity tests to index aggregate angularity
  - What happens if “bumping” binder grade?
Materials Used in Study
Aggregates Selected

**Gravels**

- **G2**
  - CAA: 1’s: 100/99.5; 1A’s: 100/99.9

- **G3**
  - CAA: 1’s: 100/99.2; 1A’s: 100/99.4

- **G1**
  - CAA: 1’s: 100/92.9; 1A’s: 100/98.6

- **G4**
  - CAA: 1’s: 100/99.2; 1A’s: 100/99.4
Aggregates Selected

Crushed Stone

- Crushed stone sources all met 100/100 and were from NYSDOT approved list
  - R1
  - R2
  - R3
# Blending of Gravel Aggregates

Table 3.1 – Proposed Coarse Aggregate Angularity Blends

<table>
<thead>
<tr>
<th></th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/96</td>
<td>100/99</td>
<td>100/99</td>
<td>100/99</td>
<td>100/99</td>
</tr>
<tr>
<td>97/93</td>
<td>97/96</td>
<td>97/96</td>
<td>97/96</td>
<td>97/96</td>
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<tr>
<td>94/90</td>
<td>94/93</td>
<td>94/93</td>
<td>94/93</td>
<td>94/93</td>
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<tr>
<td>91/87</td>
<td>91/90</td>
<td>91/90</td>
<td>91/90</td>
<td>91/90</td>
</tr>
<tr>
<td>88/84</td>
<td>88/87</td>
<td>88/87</td>
<td>88/87</td>
<td>88/87</td>
</tr>
</tbody>
</table>

Blended crushed gravel with rounded gravel from same source
Permanent deformation (rutting) tests conducted on mixes of 3 different asphalt binder grades

- Neat PG64-22
  - MSCR @ 64C: Jnr = 2.42  (PG64S-22)
- PG64-22 with NYSDOT Elastic Recovery
  - MSCR @ 64C: Jnr = 0.80  (PG64V-22)
- PG76-22 with NYSDOT Elastic Recovery
  - MSCR @ 64C: Jnr = 0.53  (PG64V-22)
Aggregate Testing - Summary
Aggregate Testing

- Fractured Face Count (ASTM D5821)
  - Conducted by NYSDOT on split samples
  - Was the main basis for HMA rutting comparisons
Fractured Face Count
(2 Crushed Faces)

<table>
<thead>
<tr>
<th></th>
<th>Fracture Face Count (2-Faces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3</td>
<td>100</td>
</tr>
<tr>
<td>R1</td>
<td>100</td>
</tr>
<tr>
<td>R2</td>
<td>100</td>
</tr>
<tr>
<td>G1</td>
<td>95.8</td>
</tr>
<tr>
<td>G2</td>
<td>99.7</td>
</tr>
<tr>
<td>G4</td>
<td>98.5</td>
</tr>
<tr>
<td>G3</td>
<td>99.3</td>
</tr>
</tbody>
</table>
Aggregate Testing

- Uncompacted Void Content for Coarse Aggregates (AASHTO T326)
  - Showed greatest correlation to rutting in NCHRP Report 557 (NCHRP Project 4-19b)
  - Minimum of 45% recommended
Aggregate Imaging System (AIMS)

- Digitally imaging and analysis system to index angularity and texture of aggregates
Example of AIMS

G1 - \( \frac{3}{4}'' - \frac{1}{2}'' \) Angularity = 1175.84

G1 - \( \frac{3}{4}'' - \frac{1}{2}'' \) Angularity = 2897.35

G1 - \( \frac{3}{4}'' - \frac{1}{2}'' \) Texture = 253.5

G1 - \( \frac{3}{4}'' - \frac{1}{2}'' \) Texture = 217
Example of AIMS

R1 - $\frac{3}{4}'' - \frac{1}{2}''$ Angularity = 3447.6

R1 - $\frac{3}{4}'' - \frac{1}{2}''$ Angularity = 2676.83

R1 - $\frac{3}{4}'' - \frac{1}{2}''$ Texture = 658.5

R1 - $\frac{3}{4}'' - \frac{1}{2}''$ Texture = 351
Gravels had AIMS Angularity 18% lower than Crushed Stone
Gravels had AIMS Texture 45% lower than Crushed Stone
<table>
<thead>
<tr>
<th>Gravel Source</th>
<th>Percent One-Faced Crushed</th>
<th>Percent Two-Faced Crushed</th>
<th>Average Texture</th>
<th>Average Angularity</th>
<th>Uncompacted Voids Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>88</td>
<td>88</td>
<td>83.8</td>
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<td>91</td>
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<tr>
<td>94</td>
<td>94</td>
<td>89.8</td>
<td>268.1</td>
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<tr>
<td>97</td>
<td>97</td>
<td>92.8</td>
<td>267.9</td>
<td>2323.5</td>
<td>46.7</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>95.8</td>
<td>267.2</td>
<td>2228.6</td>
<td>46.8</td>
</tr>
<tr>
<td>G2</td>
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<td></td>
</tr>
<tr>
<td>88</td>
<td>88</td>
<td>87.7</td>
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<td>99.7</td>
<td>293.3</td>
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<td>45.5</td>
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<td></td>
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<td>87.3</td>
<td>281.7</td>
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<tr>
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<td>97</td>
<td>96.3</td>
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<td>2422.1</td>
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<td>99.3</td>
<td>311.0</td>
<td>2447.5</td>
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<td>88</td>
<td>87.3</td>
<td>298.0</td>
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<td>91</td>
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<td>46.3</td>
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<tr>
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<td>94</td>
<td>93.3</td>
<td>301.9</td>
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<tr>
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<td>100</td>
<td>99.3</td>
<td>303.8</td>
<td>2265.3</td>
<td>46.9</td>
</tr>
</tbody>
</table>
Aggregate Testing - Conclusions

- ASTM D5821 (CAA) had no correlation with UVC or AIMS
- AIMS and UVC correlated with baseline samples but not with blended gravels
  - Lack in sensitivity of AIMS
  - UVC showed slightly better sensitivity and proper trend
- Differences in ranking between UVC and ASTM D5821
  - G2: High CAA but lowest UVC
- Large discrepancy between AIMS Texture for crushed stone and gravels
  - Does texture play a large role in shear strength development?
Aggregate Testing - Conclusions

- UVC influenced by combination of angularity and texture – combination most desirable
- AIMS system currently does not have a way of combining both texture and angularity in one unique ranking measurement
Mixture Designs

- Mixture designs conducted according to NYSDOT 5.16
  - No TSR to expedite work

- Aggregates used for all mixes
  - Source Gravels 1 and 1A (combined 63 to 58%) – varied to maintain same gradation
  - Fine Aggregate (37 to 42%) – same fine aggregate for all mixes
Permanent Deformation Testing

- Asphalt Pavement Analyzer and Repeated Load (Flow Number)
- Test Temperature = 58°C
- Compacted Air Voids: 6 to 7%
- 3 Different Asphalt Binders
  - PG64-22, PG64-22ER, and PG76-22
- Total Samples Tested
  - APA = 396
  - Flow Number = 198
Asphalt Pavement Analyzer

- AASHTO TP 63
- 120 lb wheel load; 120 psi hose pressure
- Tested at 58°C for 8,000 loading cycles
- Samples at 6.5 +/- 0.5% air voids
APA Results

APA Rutting (mm)

<table>
<thead>
<tr>
<th></th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-ER</td>
<td>2.40</td>
<td>3.31</td>
<td>4.11</td>
<td>2.84</td>
<td>2.91</td>
<td>3.73</td>
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<tr>
<td>64-22</td>
<td>4.14</td>
<td>4.74</td>
<td>5.99</td>
<td>4.76</td>
<td>3.72</td>
<td>4.14</td>
</tr>
<tr>
<td>76-22</td>
<td>2.08</td>
<td>2.52</td>
<td>3.73</td>
<td>2.26</td>
<td>2.37</td>
<td>3.71</td>
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</table>
### APA Rutting Results

<table>
<thead>
<tr>
<th></th>
<th>64-ER</th>
<th>64-22</th>
<th>76-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>2.65</td>
<td>3.60</td>
<td>1.75</td>
</tr>
<tr>
<td>G2</td>
<td>4.44</td>
<td>6.12</td>
<td>2.05</td>
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<td>G3</td>
<td>4.29</td>
<td>8.07</td>
<td>4.35</td>
</tr>
<tr>
<td>G4</td>
<td>5.25</td>
<td>5.37</td>
<td>2.69</td>
</tr>
<tr>
<td>R1</td>
<td>2.91</td>
<td>3.72</td>
<td>2.37</td>
</tr>
<tr>
<td>R2</td>
<td>3.73</td>
<td>4.14</td>
<td>3.71</td>
</tr>
</tbody>
</table>

**Note:** The values represent APA Rutting in millimeters (mm).
APA Rutting (mm)

<table>
<thead>
<tr>
<th></th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-ER</td>
<td>3.64</td>
<td>4.71</td>
<td>7.39</td>
<td>5.25</td>
<td>2.91</td>
<td>3.13</td>
</tr>
<tr>
<td>64-22</td>
<td>4.40</td>
<td>5.78</td>
<td>9.21</td>
<td>6.32</td>
<td>3.72</td>
<td>4.14</td>
</tr>
<tr>
<td>76-22</td>
<td>2.23</td>
<td>3.37</td>
<td>4.50</td>
<td>2.15</td>
<td>2.37</td>
<td>3.71</td>
</tr>
</tbody>
</table>
APA Testing - Conclusions

- APA rutting appeared to be more sensitive to asphalt binder grade than range in angularities tested
  - Sensitive at excessive angularity differences (100/100 and 88/87)
- Possibly due to testing temp of 58°C and lack of significant stress to mobilize aggregate
Repeated Load – Flow Number

- 58°C
- Deviatoric Stress \((\sigma_d)\) = 100 psi
- Confining Pressure \((\sigma_3)\) = 20 psi
- Confining pressure helps to “push” aggregates together during permanent deformation
## Flow Number

**Single Faced Crushed Count = 88%**

<table>
<thead>
<tr>
<th>Flow Number (cycles)</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-ER</td>
<td>186</td>
<td>103</td>
<td>296</td>
<td>219</td>
<td>514</td>
<td>425</td>
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<tr>
<td>64-22</td>
<td>121</td>
<td>45</td>
<td>147</td>
<td>113</td>
<td>323</td>
<td>381</td>
</tr>
<tr>
<td>76-22</td>
<td>438</td>
<td>296</td>
<td>414</td>
<td>422</td>
<td>705</td>
<td>593</td>
</tr>
</tbody>
</table>
Flow Number vs UVC – PG76-22

Flow Number (cycles) for PG76-22

Coarse Aggregate Angularity, CAA (AASHTO T324)

\[ y = 6E-11x^{7.723} \]

\[ R^2 = 0.4254 \]
Inter-relationship Between $J_{nr}$ and UVC

Flow Number = $k_1(UVC)^{k_2}(J_{nr})^{k_3}$

- $k_1 = 6.8E-19$
- $k_2 = 12.34$
- $k_3 = -0.755$
- $R^2 = 0.71$
- Standard Error = 0.4
Flow Number - Conclusions

- As with case of APA testing, ASTM D5821 did not rank similar to Flow Number ranking
- Flow Number correlated well with UVC with moderate correlation to AIMS Texture
  - As UVC increased, Flow Number increased
- Clear increase in Flow Number with increase in high temperature binder stiffness
Since only Flow Number values found to be sensitive to both aggregate and binder properties, statistical comparisons based on Flow Number results

The F- and t-Test procedures are to be used to determine if the permanent deformation properties of the various gravel and crushed stone mixes are statistically equal at a 95% confidence level.

- Allowed for comparing individual sets of data instead of grouping results
Statistical Analysis of Aggregate Angularity

- **PG64-22**
  - Statistically Equal when the Uncompacted Voids Content > 46.9%

- **PG64-22(ER)**
  - Statistically Equal when Uncompacted Voids Content > 46.7%

- **PG76-22**
  - Statistically Equal when the Uncompacted Voids Content > 46.3%
In summary, Statistically Equal when Uncompacted Voids Content of 47% or greater (rounded up).

An Uncompacted Voids Content of 47% did not correlate to a specific CAA (correlation source specific), which is most likely a function of the raw stock gravel feed and crushing process of the gravel supplier.
Grade “Bumping” Conclusions

- “Bumped” from an unmodified PG64-22 to a polymer modified PG64-22(ER)
  - Uncompacted Voids Content of 45.9 or greater achieved permanent deformation Flow Number values Statistically Equal to the crushed stone mixtures (PG64-22)

- Asphalt suppliers could utilize gravel aggregates of a lesser Uncompacted Voids Content (greater than 45.9) than the crushed stone mixtures as long as the asphalt binder used was a polymer modified PG64-22(ER).
Grade “Bumping” Conclusions

- “Bumped” from an unmodified PG64-22 to a polymer modified PG76-22
  - Uncompacted Voids Content of 44.7 or greater achieved permanent deformation Flow Number values Statistically Equal to the crushed stone mixtures (PG64-22)

- Asphalt suppliers could utilize gravel aggregates of a lesser Uncompacted Voids Content (greater than 44.7) than the crushed stone mixtures as long as the asphalt binder grade used was a polymer modified PG76-22 asphalt binder.
Final Recommendations

- Recommending for NYSDOT to move away from ASTM D5821 and implement AASHTO T326 (Uncompacted Voids Content) to index aggregate angularity
  - Less user bias and found to be more sensitive to permanent deformation properties of asphalt mixtures than ASTM D5821
  - Includes effects of angularity and texture
  - Relatively inexpensive ≈ $700
  - Also being recommended by NCHRP Project 9-33
### Proposed Angularity Table for Gravel Mixes

<table>
<thead>
<tr>
<th>Minimum Uncompacted Void Content, % (AASHTO T326)</th>
<th>Minimum Asphalt Binder Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 47%&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Unmodified PG64-22</td>
</tr>
<tr>
<td>≥ 46%</td>
<td>Polymer Modified PG64-22 (ER)</td>
</tr>
<tr>
<td>≥ 45%</td>
<td>Polymer Modified PG76-22</td>
</tr>
</tbody>
</table>

<sup>1</sup> - When staying within binder grade and not "bumping"

<table>
<thead>
<tr>
<th>Minimum Uncompacted Void Content, % (AASHTO T326)</th>
<th>Minimum Jnr (Pa) at 64°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 47%&lt;sup&gt;1&lt;/sup&gt;</td>
<td>≤ 2.50 Pa</td>
</tr>
<tr>
<td>≥ 46%</td>
<td>≤ 1.0 Pa</td>
</tr>
<tr>
<td>≥ 45%</td>
<td>≤ 0.60 Pa</td>
</tr>
</tbody>
</table>

<sup>1</sup> - When staying within binder grade and not "bumping"
What Does This Do for Industry?

1. Allows supplier to increase binder grade/stiffness in lieu of lesser Uncompacted Voids Content (i.e. – lower angularity and texture)

2. Potentially modify crushing to increase fractured texture/angularity to increase Uncompacted Voids Content

For example:

- Two fractured faces can theoretically have only 40% of surface area fractured
- With ASTM D5821, 80% of fractured surface area still only classified as two faces – additional fractured surface area would increase Uncompacted Voids Content
What does this do for NYSDOT?

- Allows possibly more suppliers to supply HMA for >30M ESAL pavements without sacrificing rutting resistance of these pavements.
Thank you for your time!

Questions?

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