Effect of Mixture Design on Densification

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Outline

- Background
- Objective
- Scope
- Mixtures Evaluation
- Results
- Concluding Remarks
Objectives of Mix Design

- Resist
  - permanent deformation.
  - fatigue cracking – repeated load
  - low temperature cracking
  - moisture induced damage
- Resist skid
- Workability
Steps Involved in the Mixture Design

1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Moisture Sensitivity

TSR
Superpave Mixture Design Concerns:

- Minimum VMA Criteria
- Difficulties
- Differentiate sound from unsound mixtures
- Higher VMA mixtures
  - Cannot guarantee
    - Durable
    - Rut resistant
Superpave Mixture Design Concerns:

- Aggregate Properties/Gradation selection
- 95 percent
- Aggregate Specification
  - Consensus – ETG
  - Little research
  - Aggregate Structure/Mixture Design and Performance
Superpave Mixture Design Improvement:

- Design Aggregate Structure
  - Mixture stability
- Rational approach to design aggregate structure
  - based on principles of aggregate packing concepts
Objective

• Critically examine Superpave mixture design criterion
• Effect of
  – NMS
  – Aggregate Gradation and type
Scope

- **Aggregate Types**
  - Two
    - Sandstone, Limestone

- **Aggregate Structure**
  - 12.5 mm NMS
  - 25 mm NMS

- **Aggregate gradation**
  - Coarse, Medium, Fine
  - Bailey Method
    - analytical method that enables blending aggregates using engineering principles and packing theory concepts
Scope

- Compaction Level
  - 125 gyrations

- Binder Type
  - PG 76 – 22M
Methodology

• Superpave Gyratory Compactor
  – Densification Indices, Slope
  – Locking Point

• Pressure Distribution Analyzer
  – Frictional Indices, Locking

• Loaded Wheel Tester
  – PMW
Combined Blend Gradation

<table>
<thead>
<tr>
<th>Sieve</th>
<th>% Passing</th>
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<tbody>
<tr>
<td>A</td>
<td>100</td>
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<tr>
<td>B</td>
<td>97</td>
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<tr>
<td>C</td>
<td>76</td>
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<td>D</td>
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<td>E</td>
<td>39</td>
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<td>F</td>
<td>25</td>
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<td>G</td>
<td>17</td>
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<td>H</td>
<td>11</td>
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<tr>
<td>I</td>
<td>7</td>
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<td>J</td>
<td>5</td>
</tr>
<tr>
<td>K</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Sieve Size (mm) Raised to 0.45 Power

0 10 20 30 40 50 60 70 80 90 100

% Passing

K J I H G F E D C B A

Coarse-graded

Coarse

Fine

1 2 3 4

Sieve Size (mm) Raised to 0.45 Power
Combined Blend Gradation

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<td>C</td>
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<td>K</td>
<td>4.4</td>
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</tbody>
</table>

Sieve Size (mm) Raised to 0.45 Power

% Passing

0 10 20 30 40 50 60 70 80 90 100

K J I H G F E D C B A

Fine-graded

Fine Coarse
Aggregate Gradation $\frac{1}{2}$ SS
Superpave Gyratory Compactor

Locking Point

- Number of gyration
  - Ht specimen remains constant for three consecutive gyrations

<table>
<thead>
<tr>
<th>No. Gyration</th>
<th>Height, mm</th>
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<tbody>
<tr>
<td>69</td>
<td>115.7</td>
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<td>70</td>
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<td>77</td>
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## Superpave Gyratory Compactor

### Locking Point

<table>
<thead>
<tr>
<th>N0. Gyrations</th>
<th>69</th>
<th>70</th>
<th>71</th>
<th>72</th>
<th>73</th>
<th>74</th>
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<td>115.5</td>
<td>115.4</td>
<td>115.4</td>
<td>115.4</td>
</tr>
</tbody>
</table>
Superpave Gyratory Compactor Slope

\[
\% G_{mm@N_{des}} - \% G_{mm@N_{ini}} \\
\log(N_{des}) - \log(N_{ini})
\]

\[
\begin{align*}
\text{No. of Gyrations} \\
0.1 & \quad 1 & \quad 10 & \quad 100 & \quad 1000 \\
\text{% Gmm} \\
80 & \quad 82 & \quad 84 & \quad 86 & \quad 88 & \quad 90 & \quad 92 & \quad 94 & \quad 96 & \quad 98
\end{align*}
\]
Superpave Gyratory Compactor Compaction Indices

- **CDI (Compaction Densification Index)**
- **TDI (Traffic Densification Index)**

<table>
<thead>
<tr>
<th>No. of Gyrations</th>
<th>% Gmm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 N=1</td>
<td>75%</td>
</tr>
<tr>
<td>50</td>
<td>80%</td>
</tr>
<tr>
<td>100</td>
<td>85%</td>
</tr>
<tr>
<td>150</td>
<td>90%</td>
</tr>
<tr>
<td>200</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

- **N=205**

- **92%**
Pressure Distribution Analyzer

- Measures the frictional resistance of mixtures during compaction
- Double plate assembly with 3 load cells equally spaced on the perimeter
Pressure Distribution Analyzer
Pressure Distribution Analyzer
Frictional Resistance

FR, psi

Coarse
Medium
Fine

No. of Gyrations

0 100 200 300

12 17 22

FR, psi

Coarse
Medium
Fine
Pressure Distribution Analyzer
Locking Point

- Maximum interlock in the aggregate structure

Number of gyrations corresponding to the point of minimum rate of change in FR

FR Locking Point

Rate of Change of Frictional Resistance

FR, psi

Coarse  Medium  Fine

Pressure Distribution Analyzer

Locking Point
Pressure Distribution Analyzer
Indices

Compaction Force Index
Traffic Force Index

Frictional Resistance, psi

No of Gyations

200 gyrations

N=1
N@FR
Locking Point
Loaded Wheel Tracking Test
Loaded Wheel Tracking Test

Four parameters (indices) are measured from the data collected in the HWT test:
- Post Compaction Consolidation
- Inverse Creep Slope
- Stripping Inflection Point
- Stripping Slope
Superpave Gyratory Compactor Locking Point

- 1/2" LSC
- 1/2" LSM
- 1/2" LSF
- 1/2" SST C
- 1/2" SST M
- 1/2" SST F
- 1" LSC
- 1" LSM
- 1" LSF
- Spec
Superpave Gyratory Compactor

Locking Point

% of Ndes
Superpave Gyratory Compactor Compaction Slope
Superpave Gyratory Compactor Compaction Indices -- CDI
Superpave Gyratory Compactor Compaction Indices -- TDI
Pressure Distribution Analyzer
FR Locking Point

\[ N_{\text{des}} = 125 \]
Pressure Distribution Analyzer
FR Locking Point

% of Ndes

<table>
<thead>
<tr>
<th>Size</th>
<th>Locking Point</th>
</tr>
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<tbody>
<tr>
<td>1/2&quot;LS C</td>
<td>68.8</td>
</tr>
<tr>
<td>1/2&quot;LS M</td>
<td>60</td>
</tr>
<tr>
<td>1/2&quot;LS F</td>
<td>52.8</td>
</tr>
<tr>
<td>1/2&quot; SST C</td>
<td>67.2</td>
</tr>
<tr>
<td>1/2&quot; SST M</td>
<td>62.4</td>
</tr>
<tr>
<td>1/2&quot; SST F</td>
<td>56.8</td>
</tr>
<tr>
<td>1&quot; LS C</td>
<td>68.8</td>
</tr>
<tr>
<td>1&quot; LS M</td>
<td>46.4</td>
</tr>
<tr>
<td>1&quot; LS F</td>
<td>46.4</td>
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</table>
Frictional Resistance – Locking Point

![Bar Chart]

- FR, psi
- 1/2" LS C
- 1/2" LS M
- 1/2" LS F
- 1/2" SST C
- 1/2" SST M
- 1/2" SST F
- 1" LS C
- 1" LS M
- 1" LS F
- USB190 BC
Pressure Distribution Analyzer
FR -- CFI
Pressure Distribution Analyzer
FR -- DFI

[Bar chart showing pressure distribution for different models: 1/2" LS C, 1/2" LS M, 1/2" LS F, 1/2" SST C, 1/2" SST M, 1" LS C, 1" LS M, 1" LS F. The y-axis represents pressure values ranging from 0 to 5000, and the x-axis lists the models.]
Relationship: No. of Gyrations
SGC LP vs. PDA LP

\[ y = 1.0x - 4.0 \]

\[ R^2 = 0.95 \]
Relationship: VTM SGC LP vs. PDA LP

$y = 0.70x + 1.65$

$R^2 = 0.71$
Relationship: VMA vs SGC CDI & TDI

- Trends
- Increase VMA
  - Higher CDI
  - Lower TDI
- Is there a Min. VMA?
Relationship: Compaction Indices
SGC CDI vs PDA CFI

\[ R^2 = 0.91 \]
Relationship: Compaction Indices
SGC TDI vs PDA TFI

\[ R^2 = 0.19 \]
Relationship: SCG
Compaction Slope vs. CFI

\[ R^2 = 0.90 \]
LWT Test Results

![Graph showing test results for different materials and specifications.](image-url)
Relationship: Rut Dept vs. CDI & CFI

- CDI
  - HWT Rut, mm
    - 0, 1, 2, 3, 4, 5
  - 0, 100, 200, 300, 400

- CFI
  - HWT Rut, mm
    - 0, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800
Relationship: Rut Dept vs. TDI & TFI

![Graph showing the relationship between HWT Rut vs. TDI and HWT Rut vs. TFI.](image-url)
Relationship: Rut Depth vs. FR

FR at Locking Point, psi

HWT Rut Depth, mm
Relationship: LWT Rut Depth & Compaction Slope

![Graph showing the relationship between LWT Rut Depth and Compaction Slope with an R^2 value of 0.73.](image)
Conclusions

- SGC densification curves can provide valuable information about mixtures behavior during compaction
  - CDI, Slope
  - Coarse-grades mixtures had higher SGC LP
    - 50% - 70% of $N_{design}$
  - Coarse-grades mixtures had higher Compaction Slope:
    - 6-10
  - SGC CDI and PDA CFI indices were higher for Coarse-grades mixtures
  - PDA measured LP showed similar ranking as SGC LP
    - Lower
  - FR increased with an increased in the NMS
Conclusions

• Good correlation was observed B/W
  – SGC LP and PDA LP
  – SGC CDI and PDA CFI
  – SGC Slope and CDI
  – SGC Slope and LWT rut depth

• Poor correlation was observed B/W
  – SGC TDI and PDA TFI

• Mixtures evaluated performed well in the LWT
Thank You