Bitumen Stabilised Materials
MIX DESIGN OVERVIEW

Kim Jenkins
Pre-Conference Course
ISAP 2012, Fortaleza
30 Sep 2012
Factors influencing mix selection

- Temperature
- Traffic
- Moisture
- Binders
- Aggregates
- Support

Greater flexibility
Greater rut resistance

Factors influencing mix selection

Pavement Materials & Behaviour

- Bitumen binder
- “Linear-elastic”
- Stress dependent
- Time, temp dependent
- Greater flexibility
- Fatigue
- Flexural
- Less economical mixes

Lean Mix Concrete
Lightly cemented

Unbound
Crushed stone / gravel / soil

BSM
Visco-elastic

Visco-elastic
Cemented

Primary Design Objectives

• Load spreading
  – Resilient Modulus (Mr)
• Rut resistance
  – Shear Strength
• Flexibility
  – Displacement at Ultimate Strength
• Durability
  – Moisture resistance
Recycling Additives

- Aggregate
- Chemical Additives
- Active Filler
- Bitumen Emulsion
- Foamed Bitumen
- Granular and RAP Materials

BSM Binder

**BITUMEN EMULSION**
- Colloidal Mill
- Acid or Caustic Soda
- Surfactants
- Water
- Bitumen
- 5 microns

**FOAMED BITUMEN**
- Expansion chamber
- Hot bitumen
- Water
- Air
Foaming in laboratory

Half-life
- time (seconds) for the foam to collapse to half of its maximum volume
- measure of the stability of the foam

Expansion Ratio
- maximum volume of foam relative to the original volume of bitumen
- a measure of the viscosity of the foam
- indicates how the bitumen will disperse

Foamed bitumen characteristics
FOAMING CHARACTERISTICS

Expansion Ratio (times)

Bitumen Temperature 175°C

Water addition (% by mass of bitumen)

Optimum foaming water content

Half-Life (seconds)

8 MIN

6 MIN

1.5

4.1

1

2

3

4

Water addition (% by mass of bitumen)

AGGREGATES
Microscopic Analysis

BSM-emulsion  BSM-foam

Grading and PI requirements

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>BSM-emulsion</th>
<th>BSM-foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>0.15</td>
<td>0.3</td>
</tr>
<tr>
<td>0.63</td>
<td>1.18</td>
<td>2.36</td>
</tr>
<tr>
<td>4.75</td>
<td>6.7</td>
<td>9.5</td>
</tr>
<tr>
<td>13.2</td>
<td>2%</td>
<td></td>
</tr>
</tbody>
</table>

Low %RAP 4%  High %RAP 2%

Foam  Emulsion

PI<10%  PI<7%
Optimisation of grading curve

Indirect Tensile Strength (kPa)

- Emulsion: 3.3% bitumen
- Foam: 3.5% bitumen

Without blending
With 10% fines blend

BSM: RAP Influence

Bitumen Stabilised
Non-continuously bound

<30  RAP: Recovered penn
<5%  RAP: Recovered BC (%)
<2%  Emulsion Residual BC
No   Rejuvenating Agent
TG2/Wirtgen  Mix Design
Classes of RAP

- **Active**
  - Pen: >35
  - Pen: 30
  - Pen: 20
  - Pen: 15
  - Pen: <15

- **Inactive**
  - Pen: >25
  - Pen: 20
  - Pen: 15
  - Pen: 10
  - Pen: <5

**Changes**
- Bitumen State
  - Elastic
  - Visco-elastic
  - Viscous

- Adhesion
  - Not Sticky
  - Some Stickiness
  - Stickiness

**Increasing Ageing**

Wirtgen, 2010

---

Visco-elastic properties
Beam tests on BSM-foam $T_{ref} = 20^\circ C$

- **HMA**
- **HW**
- **Fatigue cracks**
- **Rutting**

**HOT T or Slow Traffic**
**COLD T or Fast Traffic**
TEMPERATURE

BITUMEN DISPERSION

Particles < 0.075 mm
(# 200 sieve)

± 100°C

Tiny bitumen “pieces”

± 20°C
Aggregate Temperature vs Particle coating (BSM-foam)

Aggregate Mixing Temperature (degC)

Maximum Particle Size (mm)

Practically no coating
Partial coating
Complete coating

Foam > 25ºC
Foam 15ºC
Emulsion 10ºC
Foam <15ºC
Emulsion <10ºC

Jenkins, 2000
MOISTURE

Mr (field) versus cure

NT PSPA Mr Analysis over 7 Months

- B1-B3
- B4-B6
- Poly. (B4-B6)
MOISTURE DAMAGE

MIX DESIGN

HVS Cape Town on BSM

Water introduction into 2.3% foamed bitumen stabilised base

PERMEABILITY
BSM Mix Design & Classification

Level 1
100mmφ
Aggregate blend
Compaction fluids
Act filler – type & cont

Level 2
150mmφ
Strength & moisture resistance
Binder cont 0.2% inc

Level 3
150mmφ
σ₂ = σ₃
Final mix selection
Reliable performance related properties
300mmH
Shear properties & resilient modulus
Flexibility?

Binder type & content – Level 1

ITS
BSM2
Min ITS_{dry}
Min ITS_{wet}
Min BC

ITS_{wet}
ITS_{dry}
# Level 1 and 2 Classification

<table>
<thead>
<tr>
<th>Test</th>
<th>Dia ( \phi ) mm</th>
<th>BSM1 (kPa)</th>
<th>BSM2 (kPa)</th>
<th>BSM3 (kPa)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{ITS}_\text{dry} )</td>
<td>100</td>
<td>&gt;225</td>
<td>175 to 225</td>
<td>125 to 175</td>
<td>Indicates OBC</td>
</tr>
<tr>
<td>( \text{ITS}_\text{wet} )</td>
<td>100</td>
<td>&gt;100</td>
<td>75 to 100</td>
<td>50 to 75</td>
<td>Indicates active filler type &amp; amt</td>
</tr>
<tr>
<td>TSR</td>
<td>100</td>
<td>Not applicable</td>
<td></td>
<td></td>
<td>Prob mat TSR &lt; 50 % ( \text{ITS}_\text{dry} &gt; 400 \text{ kPa} )</td>
</tr>
<tr>
<td>( \text{ITS}_\text{equil} )</td>
<td>150</td>
<td>&gt;175</td>
<td>135 to 175</td>
<td>95 to 135</td>
<td>OBC refined</td>
</tr>
<tr>
<td>( \text{ITS}_\text{soaked} )</td>
<td>150</td>
<td>&gt;100</td>
<td>75 to 100</td>
<td>50 to 75</td>
<td>Adjusted to ( \text{ITS}_\text{wet} )</td>
</tr>
</tbody>
</table>

## Vibratoty Compaction Hammer

**To prepare specimens**

- **Sleeve**
- **Vibratory Hammer**
- **Zero Line**
- **Side of Mould**
- **Steel Rod**
- **Base Plate**
- **Wooden base**

**Rear View of Frame**

- **Kango Hammer**
- **Mould**

_Kelfkens_
Influence of Tamping Foot

Effect of Tamping Foot at 80% OMC and 20Kg Surcharge

<table>
<thead>
<tr>
<th>Layer</th>
<th>Time (sec)</th>
<th>Compaction time (vibratory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>5</td>
<td>ITS</td>
</tr>
<tr>
<td>Layer 2</td>
<td>10</td>
<td>ITS</td>
</tr>
<tr>
<td>Layer 3</td>
<td>15</td>
<td>Triaxial</td>
</tr>
<tr>
<td>Layer 4</td>
<td>20</td>
<td>Triaxial</td>
</tr>
<tr>
<td>Layer 5</td>
<td>25</td>
<td>Triaxial</td>
</tr>
</tbody>
</table>

### Compaction time (vibratory)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>ITS</td>
<td>ITS</td>
<td>Triaxial</td>
</tr>
<tr>
<td>Foot φ</td>
<td>100mm</td>
<td>150mm</td>
<td>150mm</td>
</tr>
<tr>
<td>Height</td>
<td>65mm</td>
<td>95mm</td>
<td>125mm</td>
</tr>
<tr>
<td>Layers</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Surchg</td>
<td>5 kg</td>
<td>10 kg</td>
<td>10 kg</td>
</tr>
<tr>
<td>Foam</td>
<td>10 sec</td>
<td>25 sec</td>
<td>5 sec</td>
</tr>
<tr>
<td>Emuls</td>
<td>10 sec</td>
<td>15 sec</td>
<td>5 sec</td>
</tr>
</tbody>
</table>
Testing the Material

Bitumen Stabilised Material
- Non-continuously bound

Asphalt
- Continuously bound

DIFFERENT BEHAVIOUR PATTERNS

Nature of BSM e.g. foam
Critical Material Properties

- Tri-axial test to determine:
  - Shear parameters (C & ϕ)
  - Resilient modulus (M_r)
  - Permanent deformation behaviour

Triaxial Testing
Shear properties
(monotonic triaxial at 25°C)

Cohesion C

Friction Angle \( \phi \)

Ebels

New “Simple triaxial”
BSM Classification into Shear Properties

<table>
<thead>
<tr>
<th>Equivalent BSM Class</th>
<th>Angle of Internal Friction (°)</th>
<th>Cohesion (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1</td>
<td>&gt; 40</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>BSM 2</td>
<td>30 to 40</td>
<td>100 – 250</td>
</tr>
<tr>
<td>BSM 3</td>
<td>&lt; 30</td>
<td>50 – 100</td>
</tr>
</tbody>
</table>

Permanent Deformation (Triaxial)
BSM-emulsion with 75% RAP (A-75M-0)
Permanent Deformation (Triaxial)
BSM-foam with 75% RAP (C-75M-0)

Deviator stress ratio:
- 25% RAP
- 75% RAP

Permanent Deformation (Triaxial)
BSMs Mr change:
Effective Long Term Stiffness

BSMs Mr change:
Effective Long Term Stiffness

<table>
<thead>
<tr>
<th>Equivalent Stiffness (Mpa)</th>
<th>1% cem CTSB</th>
<th>1% cem G5SB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>2000</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>3000</td>
<td>1500</td>
</tr>
<tr>
<td>4</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
<td>2500</td>
</tr>
<tr>
<td>6</td>
<td>6000</td>
<td>3000</td>
</tr>
<tr>
<td>7</td>
<td>7000</td>
<td>3500</td>
</tr>
<tr>
<td>8</td>
<td>8000</td>
<td>4000</td>
</tr>
<tr>
<td>9</td>
<td>9000</td>
<td>4500</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>5000</td>
</tr>
</tbody>
</table>

Years

0 1 2 3 4 5 6 7 8 9 10
BSMs Mr change: Effective Long Term Stiffness

(Prelim) Effective Long Term Mr for BSM base

<table>
<thead>
<tr>
<th>BSM Class</th>
<th>C3 Subbase</th>
<th>G5/G6 Subbase</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1 (RAP + G1 or G2)</td>
<td>900 – 1750</td>
<td>700 – 1200</td>
</tr>
<tr>
<td>BSM 1 (G1 or G2)</td>
<td>800 – 1200</td>
<td>600 – 900</td>
</tr>
<tr>
<td>BSM 2</td>
<td>400 – 750</td>
<td>300 – 500</td>
</tr>
<tr>
<td>BSM 3</td>
<td>Not in use</td>
<td>Not in use</td>
</tr>
</tbody>
</table>

ELT Mr = f (aggregate type and quality, RAP %, bitumen %, support, traffic, climate)
FLEXIBILITY

Purpose of Active Filler

- Improve adhesion
- Improve dispersion
- Modify plasticity
- Increase stiffness & strength
- Accelerate curing

Emulsion                         Foam
• Breaking time                  Dispersion!
• Improve workability
Influence of Active Filler

Strength and flexibility

Cement : Foamed Bitumen Ratio

Strain-at-break

Unconfined Compressive Strength (kPa)

Foamed bitumen, Strain
Cement, Strain*
Foamed bitumen, UCS
Cement, UCS*

Cement < 1%?

Can 1.5% cement work?

BSM-foam + 1.5% cem using cracked CTB
2 years of traffic
Dissipated Energy

\( W = 0.5 \sigma \varepsilon \)

BSM+2%cem

BSM+1%cem
**ITS displacement at $\sigma_{\text{max}}$**  
(from Mix Design)

Vertical Displacement at ITSmax (mm)

Active Filler Content (%)

**Similar trend for triaxial On Foam & Emulsion Mixes**

**Triaxial data from Mix Design**

Monotonic Triaxial BSM 1

Vertical Strain at $\sigma_{\text{max}}$ (Microstrain)

Cement Content (%)

Can refine by separating data based on $\sigma_3$
Conclusions

• Understanding of material behaviour of BSMs has increased significantly
• Flexibility is NB! Active filler versus bitumen content!!
• More advanced test evaluation (triaxial = shear properties)
• Mix Design is linked to Structural Design method for BSMs

Thank you

Roads & Enviro!
WHOLE OF LIFE ENERGY & COST

US$ / m²  MJ / m²

Patch & Overlay  Mill & Replace  Cem Stab & Gran Overlay  Dom Overlay

Resilient Modulus of BSM

Granular Type Behaviour: Foamed BC = 2%