Cold Recycling & Bitumen Stabilised Materials BSMs Research and Implementation?

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Outline

1. What is BSM?
2. Mix Design
3. Structural Design
4. Application
5. Where to now?
BSM Binder Options

BITUMEN EMULSION

Colloidal Mill

FOAMED BITUMEN

Expansion chamber

Acid or Caustic Soda

Surfactants

Water

Bitumen

Mill

5 microns

Hot bitumen

Water

Air

Cement %

Bitumen %

Cement stabilised

Bound

Granula

Unbound

BSM

Asphalt

Bound

Orientation on BSM

Fatigue

Rutting

Flexibility

RGA, NZ +

N-Hemiss+

Non-continuously Bound

Individuals

Bound

Unbound
Influence of Active Filler

Strength versus Flexibility

**Cement < 1%**

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

*Values plotted at an arbitrary ratio of 1.25 for 2 percent cement and 1.2 for 1 percent cement.

**BSM Triaxial Tests Shear properties**
( monotonic tests at 25°C)

<table>
<thead>
<tr>
<th>Cohesion C</th>
<th>Friction Angle $\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-75C-0</td>
<td>E</td>
</tr>
<tr>
<td>B-75C-0</td>
<td>F</td>
</tr>
<tr>
<td>C-75C-0</td>
<td>F</td>
</tr>
<tr>
<td>A-75C-1</td>
<td>E</td>
</tr>
<tr>
<td>B-75C-1</td>
<td>E</td>
</tr>
<tr>
<td>C-75C-1</td>
<td>E</td>
</tr>
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<td>A-75M-0</td>
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<td>F</td>
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Jenkins, 1999 & Ebels, 2006
Resilient Modulus of BSM

**Stress dependency:** Foamed BC = 2%

![Graph showing the relationship between sum of principal stresses and resilient modulus](image)

- **Sum of Principal Stresses q (kPa):** 0.0, 200.0, 400.0, 600.0, 800.0, 1000.0
- **Resilient Modulus Mr (MPa):** 12kPa, 24kPa, 48kPa, 72kPa

**Research:** Visco-elasto-plastic & flexural properties on BSM-foam

- **Fatigue cracks**
- **Rutting**

![Graph showing flexural stiffness and reduced frequency](image)

- **Equiv HOT T or Slow Traffic**
- **Equiv COLD T or Fast Traffic**

- **HMA/WMA**
- **HW**
- **BSM**

- **Equiv**

- **Reduced frequency**

- **Fatigue cracks**

- **75C-0**
- **75C-1**
- **75M-0**
BSM test methods

Mix Design Flowchart

Sampling → Sample preparation → Preliminary tests → Blend

Optimum bitumen addition → Effect of active filler → ITS

SUITABLE? → Yes → TRIAXIAL

Determine shear properties

Specification

<table>
<thead>
<tr>
<th>C (kPa)</th>
<th>φ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;250</td>
<td>&gt;40</td>
</tr>
</tbody>
</table>
Standardised Mixing Method

FOAMED BITUMEN UNIT

Lab Compaction: Vibratory Hammer

<table>
<thead>
<tr>
<th>Vibratory hammer</th>
<th>Power rating (W)</th>
<th>Frequency (Hz)</th>
<th>Mass (Kg)</th>
<th>Point Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kango 637°</td>
<td>750</td>
<td>45.83</td>
<td>7.5</td>
<td>27</td>
</tr>
<tr>
<td>Bosch GSH 11E°</td>
<td>1500</td>
<td>15 - 31.5</td>
<td>10.1</td>
<td>16.8</td>
</tr>
<tr>
<td>Bosch GSH 11VC°</td>
<td>1700</td>
<td>15 - 30</td>
<td>11.4</td>
<td>23</td>
</tr>
</tbody>
</table>

★ For PI >8%, cannot achieve 100% Mod. AASHTO density
Influence of Frame

Comparison of refusal density for G2 and G4 material

<table>
<thead>
<tr>
<th>FRAME TYPE</th>
<th>Rigid</th>
<th>Loose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
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<td></td>
</tr>
<tr>
<td>Loose</td>
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</table>

Refusal Density

- 80% OMC, RFR, 10kg Surcharge
- 80% OMC, LFR, 10kg Surcharge
- 80% OMC, RFR, 20kg Surcharge
- 80% OMC, LFR, 20kg Surcharge

Material Type

- G2
- G4

Density (kg/m³)

2050
2100
2150
2200
2250
2300
2350
2400

(std test method)
Inter-Layer Roughening (ILR) Device

Inventor: Wynand van Niekerk

CT Scans
BSM-emulsion

Poor attention to interlayer preps
Why is curing important?
Mr (field) versus cure

N7 PSPA Mr Analysis over 7 Months

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

% OMC

Why is curing important?
Mr (field) versus cure

New Triaxial
Apply Load (stress $\sigma_1$)

Test at 25°C

Confining Pressure $\sigma_3$ (inflate tube)
Validation
Research Triaxial Test RTT versus Simple Triaxial Test STT

BSM Crushed Hornfels with 3.3% Emulsion

$\sigma_3 = 50 \text{ kPa and 1\% Cement} \quad \sigma_3 = 200 \text{ kPa and 0\% Cem}$
Determine shear properties (C and φ)

Shear stress

Normal stress (kPa)

Cohesion

Durability of BSM

Shear stress

Normal stress

Cohesion

Effect of Moisture

Cohesion Loss = 25% max

Retained Cohesion $C_R = \frac{C_R}{C_{BSM}}$

$C_{BSM}$

$C_R$
Structural Design Considerations

250mm CIPR: 2.5% Foam 1% Cem

90mm Asphalt

BSM Design for Max Rut Depth
(same principle as Granular Design)

Permanent deformation (rutting) design for granular material

Lab Triaxial Analysis

Permanent deformation (rutting) design for granular material

Design Life for 10mm rut
Design Function for BSM

\[ N = f(RD, RetC, PS, SR) \]

Relative Density \hspace{2cm} Plastic Strain (a/b) \hspace{2cm} Retained Cohesion \hspace{2cm} Stress Ratio

Mr change with trafficking (triaxial)

Resilient Moduli (MPa) \hspace{2cm} Load repetitions

Jenkins et al, IJPE

Jenkins, TU Delft, 1999
In service behaviour of Mr Influence of support & traffic

![Graph showing effective stiffness over years for different support types and traffic levels.]

Effective Long Term Mr for BSM base
Mr from FWD back-calcs

![Graphs showing stiffness modulus for foamed and emulsion-treated sections over days since construction for northbound traffic.]

SAPDM - R35 : Theyse, 2015 & Lynch, 2014
### Effective Long Term Mr Stiffness (MPa) for BSM base

#### Supporting Layer

<table>
<thead>
<tr>
<th>BSM Class</th>
<th>Cemented Subbase</th>
<th>Granular Subbase</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM (RAP + GCS)</td>
<td>900 – 1750</td>
<td>700 – 1200</td>
</tr>
<tr>
<td>BSM (GCS Grade Crushed Stone)</td>
<td>800 – 1200</td>
<td>600 – 900</td>
</tr>
</tbody>
</table>

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

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#### Case Study – Ayrton Senna Highway

Brazil’s most heavily-trafficked highway

8-lanes / divided
Key Data

AADT > 200,000 vpd (15% heavy)
(> 15,000 heavies / day in each direction)

Milling & Replacing 100mm HMA lasts < 3 months

Lane closure only between 21:00 – 05:00

Results from Pavement Investigation

8 HOURS

HMA ± 100mm

CEMENTED CRUSHED STONE ± 250mm

6% CEMENT

GRADED CRUSHED STONE

SELECTED COARSE GRAVEL (CBR > 25)

EMBANKMENT (RIVER LEEVEE) (CBR > 15)
Rehabilitation Options?? (8-hour working window)

Step 1. Mill off asphalt layers
Impact crusher (20mm setting)
Grading Correction using Single Stage Crushing

**Wirtgen KMA 220 plant mixer**

- 2.0% / 2.1% Foamed Bitumen
- 1.0% OPC

Mixed material placed in stockpile
Step 2. Mill and remove CTB layer
Step 5. Import / pave / compact 130mm BSM layer
Step 6. Import / pave / compact 20mm HMA
31st January 2012

Currently (3.75 years later)

Not yet rehabilitated

REHABILITATED LANE
> 100 lane-km rehabilitated using this method

**Problem Solved!**

**Way Forward: Research**

Monotonic Load Cycle (triaxial)

(Bredenhann & Jenkins, 2016)
Way Forward: Research
Dynamic Conditioning (triaxial)

(Bredenhann & Jenkins, 2016)

Way Forward: Research
Dynamic Triaxial – Permanent Deformation

(Bredenhann & Jenkins, 2016)
Flexural Strain-at-break

- All beams compacted in a mould
- **Testing temperature:** 25°C
- LVDT on top of the beam to accurately measure displacement in the middle of the beam.

![Image of beams](image-url)

(Campher, 2014)

<table>
<thead>
<tr>
<th>Specimen specification</th>
<th>Material parameter</th>
<th>Average Maximum Stress (kPa)</th>
<th>Average Strain-at-break (µE)</th>
<th>Average Dissipated energy (Pa)</th>
<th>Average stiffness (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9% Emulsion; 1% Cement</td>
<td></td>
<td>174.4</td>
<td>376.5</td>
<td>39.1</td>
<td>524.2</td>
</tr>
<tr>
<td>2.4% Emulsion; 1% Cement</td>
<td></td>
<td>254.9</td>
<td>537.2</td>
<td>89.8</td>
<td>473.1</td>
</tr>
<tr>
<td>2.4% Emulsion; 2% Cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Campher, 2014)

![Graph showing flexibility related parameters](graph-url)
Flexibility (triaxial)

(Llewellyn, 2016)
Factors Influencing BSM Flexibility
Analysis of Variance

Summary of P values for variables in ANOVA analysis

Conclusions

- Mix design system in place
  - Aim for flexibility not high strength
  - Update of equipment (vib hammer & triax)

- Pavement design
  - New ME design function
  - Link of mix- and pavement-design (C & φ)

- Application (field performance data)

- Way forward: flexibility focus
Research on BSM Flexibility
How can we benefit from?

Strain at break vs Fatigue
25%RA & 0%Cem

Stellenbosch University