HIGH MODULUS ASPHALT: 
Introduction and French Experience

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OUTLINE

Introduction

Purpose
- Pavement design
- Base course (EME)
- Wearing course (BBME)

What is a high modulus HMA?
- Formulation
- Specifications

Good practices with high mod. HMA
- Working temperatures
- Field practices (Compaction…)
- Limitations

Examples of performances
- EME with hard pure binder and PMBs
- BBME with hard pure binder and PMBs

Optimization of pavement design with EME

Examples of job sites
PURPOSE
INTRODUCTION

High modulus HMA in France:

- **EME** (Enrobé à Module Elevé) since early 1980’s
  - European standard EN 13108-1
- **BBME** (Béton Bitumineux à Module Elevé) since early 1990’s
  - European standard EN 13108-1

Developed by:

- French Administration (LCPC)
- Bitumen producers (Total, Elf,…)
- Roads Contractors (Via France…)

PURPOSE OF HIGH MODULUS HMA

Performance:
- **Reduction of pavement thickness**
- **Resistance to rutting** of subbase / base layers (EME)
- Resistance to superficial rutting (BBME)

When should High modulus HMA be used?
- Heavy traffic (Highways, slow lanes)
- Super-high loads
- Weak / cracked subbase

How reduce pavement thickness?
- Increase the stiffness of the material
  - reduce deflection (strains) under given load
  - possibility to reduce thicknesses under given traffic
1-6 cm: WEARING COURSE
6-8 cm: BINDER COURSE
10-35 cm: BASE COURSE
15-80 cm: « FOUNDATION COURSE »
PROTECTION / WATERPROOFING
SHAPE LAYER
GROUND
PRINCIPLES OF FRENCH PAVEMENT DESIGN METHOD

- Fatigue resistance
- Stiffness
- High Modulus Mixture
- Uncertainties, variability, risk
- Climate, Température
- Traffic
- Expected life duration
- For base courses only

Calculation of layer thickness
COMPLEX MODULUS (EN12697-26)
TRACTION/COMPRESSION TEST

Traction/Compression at 15°C-10Hz

- Oscillation motion on cylindrical specimens (cut in asphalt mix slabs)
- Displacement ($\varepsilon$) registered depending on solicitation ($\sigma$)

\[
\sigma(t) = \frac{F(t)}{S}
\]
\[
\varepsilon(t) = \frac{l(t)}{L_0}
\]

- Calculation on complex modulus (stiffness):

\[
E = \frac{\sigma_0}{\varepsilon_0}
\]
FATIGUE TEST (EN12697-24)  
2 POINT BENDING ON TRAPEZOIDAL SPECIMEN

Lifetime quantification:

\[
F_0
\]

\[
F_0/2
\]

Microcracks formation

Trapezoidal specimens cut in asphalt mix slabs

Max strain \( \rightarrow \varepsilon_i \) constant

10°C, 25 Hz

Calculation of deformation to obtain a force /2 within 1 million cycles:

\( \rightarrow \varepsilon_6 \)
WHAT IS A HIGH MODULUS ASPHALT?
Formulation:

- **Very hard binder: 10-25 pen**
  - Use of PmB is even better but still rarely used
- **Aggregates:**
  - **Crushed aggregates**
  - No particular requirements
- **Gradation**
  - **Continuous**
  - 0/10, 0/14 or 0/20
  - 0/20 (rarely used because risk of heterogeneity)
EME

Gradation curve:

~8% filler
EME

Volumetrics:

EME Class1:
- Low binder content: 4 ppc (3.85%)
- Average void content: Up to 10%

EME Class2:
- High binder content: 6 ppc (5.66%)
- Low void content: < 6%
**EME - SPECIFICATIONS 2007 (EN 13108-1)**

<table>
<thead>
<tr>
<th></th>
<th>Standard Mix.</th>
<th>EME Cl. 1</th>
<th>EME Cl. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>5% to 10%</td>
<td>&lt; 10%</td>
<td>&lt; 6%</td>
</tr>
<tr>
<td>Duriez ratio (moisture damage)</td>
<td>&gt; 0.70</td>
<td>&gt; 0.7</td>
<td>&gt; 0.70</td>
</tr>
<tr>
<td>Rutting @ 30 000 cycles</td>
<td>&lt; 10%</td>
<td>&lt; 7.5%</td>
<td>&lt; 7.5%</td>
</tr>
<tr>
<td>Stiffness (15°C, 10Hz)</td>
<td>&gt; 7000 MPa</td>
<td>&gt; 14000 MPa</td>
<td>&gt; 14000 MPa</td>
</tr>
<tr>
<td>Fatigue resistance ((\varepsilon_6))</td>
<td>&gt; 100\mu def.</td>
<td>&gt; 100\mu def.</td>
<td>&gt; 130\mu def.</td>
</tr>
</tbody>
</table>
BBME
Formulation:

• **Hard binder: 20-30 pen** (esp. for Cl2 and Cl3)
  – *Use of PmB is even better*
• Same as regular HMA except for stiffness
• Aggregates:
  – **Crushed aggregates**
  – No particular requirements
  – **Resistance to polishing** is important
• Gradation
  – **Continuous**
  – 0/10, 0/14
• Volumetrics
  – Identical to regular HMA
  – **Typical binder content: 5.8 ppc**
BBME
Gradation curve:

BBME – SPECIFICATIONS 2007 (EN13108-1)

<table>
<thead>
<tr>
<th></th>
<th>Standard Mix.</th>
<th>BBME Cl.2</th>
<th>BBME Cl.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void content</td>
<td>5% to 10%</td>
<td>5% to 10%</td>
<td>5% to 10%</td>
</tr>
<tr>
<td>Duriez ratio (moisture damage)</td>
<td>&gt; 0.70</td>
<td>&gt; 0.8</td>
<td>&gt; 0.8</td>
</tr>
<tr>
<td>Rutting @ 30 000 cycles</td>
<td>&lt; 5% to 7.5%</td>
<td>&lt; 7.5%</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Stiffness (15°C, 10Hz)</td>
<td>&gt; 7000 MPa</td>
<td>&gt; 11000 MPa</td>
<td>&gt; 11000 MPa</td>
</tr>
<tr>
<td>Fatigue resistance ($\varepsilon_6$)</td>
<td>&gt; 100µdef.</td>
<td>&gt; 100µdef.</td>
<td>&gt; 100µdef.</td>
</tr>
</tbody>
</table>
## COMPARISON EME / BBME

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>EME cl 2</th>
<th>BBME cl 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular curve</td>
<td>0/10 – 0/14 – 0/20</td>
<td>0/10 – 0/14</td>
</tr>
<tr>
<td>Binder content (typical)</td>
<td>5,6 %</td>
<td>5,8 %</td>
</tr>
<tr>
<td>Void content</td>
<td>&lt; 6 %</td>
<td>5 – 10 %</td>
</tr>
<tr>
<td><strong>Performances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture resistance</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Rutting resistance</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Stiffness</td>
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</table>
EXAMPLES OF PERFORMANCES
PURE HARD GRADES IN EME (1/2)

Importance of hard grade nature in EME

- Comparison of 10/20 bitumen bases, of different suppliers, in the same EME formula:
  - same aggregates nature
  - same granular curve
  - same binder content

<table>
<thead>
<tr>
<th>Commercial 10/20 #1</th>
<th>Commercial 10/20 #2</th>
<th>Commercial 10/20 #3</th>
<th>Commercial 10/20 #4</th>
<th>Commercial 10/20 #5</th>
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</thead>
<tbody>
<tr>
<td>Stiffness @ 15°C, 10 Hz (Mpa)</td>
<td>14500</td>
<td>16000</td>
<td>16300</td>
<td>17100</td>
</tr>
<tr>
<td>Fatigue @ 10°C (ε6, μdef)</td>
<td>140</td>
<td>115</td>
<td>133</td>
<td>140</td>
</tr>
</tbody>
</table>

All hard grades are not equivalent
PURE HARD GRADES IN EME (2/2)

Statistical results

- Comparison of 10/20 bitumen bases, of different suppliers, in **different asphalt mix formulas**

![Diagram showing comparison of fatigue and stiffness](image)

- **It can be sometimes difficult to meet EME 2 specifications**, depending on:
  - **Binder type**
  - **Aggregates nature, especially for stiffness**
ADVANTAGES OF STYRELFL IN EME (1/2)

Fatigue in base course (EME = high modulus asphalt)

- Same asphalt mix formula

Styrelf 13/20 in base course

**Higher fatigue resistance** / pure hard grade
ADVANTAGES OF STYRELF IN EME (2/2)

Fatigue in base course compared to stiffness

- Different asphalt mix formulas

<table>
<thead>
<tr>
<th>Type</th>
<th>Aggregate size (mm)</th>
<th>Binder</th>
<th>Grade EN 14023</th>
<th>PEN grade (dmm)</th>
<th>Stiffness @15°C, 10 Hz (Mpa)</th>
<th>Fatigue @10°C (ε 6, μdef)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EME 2</td>
<td>0/20</td>
<td>Styrelf® 11/20</td>
<td>10/40-60</td>
<td>20</td>
<td>17000</td>
<td>131</td>
</tr>
<tr>
<td>EME 2</td>
<td>0/14</td>
<td>Styrelf® 13/20</td>
<td>10/40-65</td>
<td>20</td>
<td>14572</td>
<td>149</td>
</tr>
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<td>EME 2</td>
<td>0/20</td>
<td>Styrelf® 11/20</td>
<td>10/40-60</td>
<td>20</td>
<td>14405</td>
<td>147</td>
</tr>
</tbody>
</table>

- Styrelf® 13/20 in base course
  - Higher fatigue resistance
  - High stiffness
    enables thickness decrease and resistance to higher loads
ADVANTAGES OF STYRELF IN BBME (1/2)

**Statistical results**

- Comparison **different asphalt mix formulas** with
  - **pure binder 20/30**
  - **hard Styrelf → same stiffness, higher fatigue resistance**

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<tr>
<td>BBME 3 0/10</td>
<td>Azalt® 20/30</td>
<td>-</td>
<td>25</td>
<td>12800</td>
<td>124,5</td>
<td></td>
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<tr>
<td>BBME 3 0/10</td>
<td>Azalt® 20/30</td>
<td>-</td>
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ADVANTAGES OF STYRELF IN BBME (2/2)

Statistical results

- Comparison different asphalt mix formulas with
  - pure binder 20/30
  - hard Styrelf \(\rightarrow\) same stiffness, higher fatigue resistance

![Graph showing comparison of stiffness and fatigue resistance between different asphalt mix formulas.](image-url)
GOOD PRACTICES WITH HMA
GOOD PRACTICES

EME (1/2):

• Should not be used as surface or binder layer
  – Thermal cracking
  – Too smooth surface texture

• Thickness range:
  – 6 to 8 cm for 0/10 graded EME
  – 7 to 13 cm for 0/14 graded EME
  – 9 to 15 cm for 0/20 graded EME

– Possibility to make multiple layers of EME
  (CAUTION: good bonding is CRUCIAL!!)

– Sensitive to “under-design”
GOOD PRACTICES

EME (2/2):

• **Usually topped with thin to very thin wearing course**
  – Risk of cracking if wearing course brings insufficient thermal protection
• **Mixing temperature: 180°C**
• Compaction:
  – Temperature > 140°C
  – Watch for weather conditions and temperatures
  – **Use tire compactors and optionally vibrating cylinders** (watch for longitudinal cracking)
• Targeted void content
  – Class 1: 10% or less
  – Class 2: 6% or less
GOOD PRACTICES

BBME (1/2):

• Used as surface or binder layer
  – E.g. maintenance of cracked pavement
  – Watch for thermal cracking in case of high amplitude daily or yearly temperature variations

• Thickness range
  – 5 to 7 cm for 0/10 graded BBME
  – 6 to 9 cm for 0/14 graded BBME

• Surface texture IS important
GOOD PRACTICES

BBME (2/2):

• Mixing temperature: 180°C

• Compaction:
  – Temperature > 140°C
  – **Use tire compactors and optionally vibrating cylinders** (watch for longitudinal cracking)
  – Watch for weather conditions and temperatures

• Targeted void content: 4 to 8%
OPTIMISATION OF PAVEMENT DESIGN WITH EME
EXAMPLE 1

HYPOTHESES

Design for: 30 years

Traffic:
- 600 Trucks / day
- Geometric increase: 5% / yr
- No “super high” loads

No frost

Subbase stiffness: 120 to 200 MPa
EME ALLOW SIGNIFICANT REDUCTION OF LAYER THICKNESSES – EXAMPLE 1

Two alternative designs:

<table>
<thead>
<tr>
<th>Classical</th>
<th>With EME</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wearing course</strong>: 2.5cm</td>
<td><strong>Wearing course</strong>: 2.5cm</td>
</tr>
<tr>
<td><strong>Binder course</strong>: 6cm</td>
<td><strong>EME</strong>: 9cm</td>
</tr>
<tr>
<td><strong>Base course</strong>: 11cm</td>
<td><strong>EME</strong>: 10cm</td>
</tr>
<tr>
<td><strong>Base course</strong>: 12cm</td>
<td></td>
</tr>
</tbody>
</table>

**Total: 31.5cm**

**Total: 21.5cm**
EXAMPLE 2

HYPOTHESES:

Design for: 20 years

Traffic:

- 600 Trucks / day
- Arithmetic increase: 2% / yr
- No “super high” loads

No frost

Subbase stiffness: 120 to 200 MPa
EME ALLOW SIGNIFICANT REDUCTION OF LAYER THICKNESSES – EXAMPLE 2

Two alternative designs:

**Classical**
- Wearing course: 2.5cm
- Binder course: 6cm
- Base course: 9cm
- Base course: 9cm

**Total: 26.5cm**

**With EME**
- Wearing course: 2.5cm
- EME: 7cm
- EME: 9cm

**Total: 18.5cm**
EXAMPLES OF JOB SITES
REFERENCE JOB SITE

Marseille (France) harbour: plateforme exposed to high static load (presence of containers)

- 2 layers of 11 cm of EME 0/14 - Modulotal® 10/20
REFERENCE JOB SITE

Bordeaux-Mérignac airport (France) – Modulotal ® 10/20
REFERENCE JOB SITE

SAINT MEDARD EN JALLES - RD1215 between Bordeaux and Lacanau (France)

- EME 0/10 classe 2 with 20 % RAP - Styrelf® 11/20
- 2 layers of 8 cm of EME with Styrelf 11-20 covered by 6 cm BBSG
CONCLUSION
CONCLUSIONS (1)

There are different types of high-stiffness HMAs

- EME Cl1, EME Cl2
- BBME Cl1, 2 & 3

EME should NEVER be used as a surface layer

- Cracking
- Superficial rutting

EME Cl1 is VERY different from EME Cl2

- EME Cl1 is like a regular base layer, except stiffer
  - Good resistance to rutting of base course
- EME Cl2:
  - Dense (waterproofing)
  - Stiff
  - Extra resistant to fatigue

Ideal to reduce layer thicknesses / on weak subbase
CONCLUSIONS (2)

BBME is a stiffer version of regular HMA for binder and wearing courses

- Less stiff than EME to avoid cracking
- Fatigue resistance is not as important
- **Surface texture** (skid resistance) and resistance to moisture damage are important

BBME CI 1, 2 & 3 only differ by:

- Rutting resistance
- Fatigue resistance
THANK YOU FOR YOUR ATTENTION