Laboratory and field implementation of high modulus asphalt concrete

Wojciech Bańkowski  IBDiM Poland
Task 4.2 leader

Ljubljana, Slovenija
WP4. Road upgrading methods - Marjan Tušar

- 4.2 Material Recommendations and Performance-based Requirements for High Modulus Asphalt Mixtures and Flexible Pavement Design

- IBDiM POLAND
- ZAG SLOVENIA
- VTI SWEDEN
- TECER ESTONIA
- IGH CROATIA
- IP SERBIA
- CRBL BULGARIA
Outline of presentation

• Objectives of WP4.2
• High modulus asphalt concrete (HMAC) in Poland
• Results of laboratory tests
• ALT on test fields in Poland (HVS)
• Conclusions
Objectives of WP 4.2

• To develop concept of high modulus asphalt concrete for implementation in Central and Eastern European countries
• Laboratory tests
• Field validation
• Preparation of general requirements for HMAC for different countries taking into account climate conditions, materials and available test methods
Outline of presentation

• Objectives of WP4.2
• High modulus asphalt concrete (HMAC) in Poland
• Results of laboratory tests
• ALT on test fields in Poland (HVS)
• Conclusions
History

• France – EME + BBTM
• Research works in IBDiM, 1999-2006
• First trial section 2001
• Poland – BAWMS (HMAC) Zeszyt 70 „Execution principles for asphalt pavement with better resistance to rutting and fatigue” ZW-WMS-2006”
• First edition 2002
• Second edition 2007
• SPENS 2006-2009
• National document for EN 13108 (2009)
HMAC - general rules

- Designed for binder course and base course
- Mix design only according to fundamental approach (EN 13108-1)
- Improved properties
  - High stiffness
  - Resistance to rutting
  - High resistance to fatigue
HMAC – general rules (2)

Grading 0/11 - 0/16 mm
Grading as for AC wearing course
Binder content around 5,0 % m/m
PMB or harder bitumen

Fatigue resistance
Rutting resistance
Stiffness
## Requirements and materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Traffic category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KR3-6</td>
</tr>
<tr>
<td>Upper sieve size $D$, mm</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Binder</td>
<td>20/30, 15/25, 10/20</td>
</tr>
<tr>
<td></td>
<td>PMB 10/40-65</td>
</tr>
<tr>
<td></td>
<td>PMB 10/40-75</td>
</tr>
<tr>
<td>Aggregates</td>
<td>As for AC base course</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Właściwość</th>
<th>AC WMS 11</th>
<th>AC WMS 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve size#, mm Passing:</td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>22,4</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>11,2</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>0,125</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>0,063</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Minimum binder content, $B_{\text{min}}$</td>
<td>$B_{\text{min 4,8}}$</td>
<td>$B_{\text{min 4,8}}$</td>
</tr>
</tbody>
</table>
## HMAC - requirements

<table>
<thead>
<tr>
<th>Properties</th>
<th>Compaction (PN-EN 13108-20)</th>
<th>Method and test conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum and maximum air voids</td>
<td>C.1.3, impact 2x75</td>
<td>PN-EN 12697-8, p. 4</td>
</tr>
<tr>
<td>Rutting resistance</td>
<td>C.1.20, roller, P_{98} - P_{100}</td>
<td>PN-EN 12697-22, method B in the air, PN-EN 13108-20, D.1.6, 60 °C, 10 000 cycles</td>
</tr>
<tr>
<td>Watersensitivity</td>
<td>C.1.1, impact 2x25</td>
<td>PN-EN 12697-12, conditioning at 40 °C, one freeze cycle, test at 15 °C</td>
</tr>
<tr>
<td>Stiffness</td>
<td>C.1.20, roller, P_{98} - P_{100}</td>
<td>PN-EN 12697-26, 4PB-PR, 10ºC, 10Hz</td>
</tr>
<tr>
<td>Fatigue resistance</td>
<td>C.1.20, roller, P_{98} - P_{100}</td>
<td>PN-EN 12697-24, 4PB-PR, 10ºC, 10Hz</td>
</tr>
</tbody>
</table>
Typical structures – typ A
Main advantages of HMAC

• Improved and controlled properties of the AC
  ▪ High stiffness
  ▪ Resistance to rutting
  ▪ High resistance to fatigue
• Better durability and designed life of the pavement
• Possible reduction of layer thickness
Outline of presentation

• Objectives of WP4.2
• High modulus asphalt concrete (HMAC) in Poland
• Results of laboratory tests
• ALT on test fields in Poland (HVS)
• Conclusions
Laboratory tests

1. HMAC with different binders and grading

2. HMAC with different aggregates (including local or lower quality)
HMAC with different binders and grading

• Binders:
  • 35/50, 20/30;
  • PMB: DE 30B;
  • multigrade binder (MP 10/20).

• Grading
  • HMAC 12, HMAC 16, HMAC 20
## Basic properties

<table>
<thead>
<tr>
<th>No.</th>
<th>Property</th>
<th>Unit</th>
<th>HMAC 12</th>
<th>HMAC 16</th>
<th>HMAC 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum density</td>
<td>g/cm³</td>
<td>2,605</td>
<td>2,578</td>
<td>2,532</td>
</tr>
<tr>
<td>2</td>
<td>Bulk density</td>
<td>g/cm³</td>
<td>2,615</td>
<td>2,573</td>
<td>2,540</td>
</tr>
<tr>
<td>3</td>
<td>Air void content</td>
<td>% v/v</td>
<td>2,8</td>
<td>3,3</td>
<td>2,8</td>
</tr>
<tr>
<td>4</td>
<td>Stability</td>
<td>kN</td>
<td>17,5</td>
<td>15,5</td>
<td>13,3</td>
</tr>
<tr>
<td>5</td>
<td>Flow</td>
<td>mm</td>
<td>3,6</td>
<td>3,5</td>
<td>3,9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>Property</th>
<th>Unit</th>
<th>HMAC 12</th>
<th>HMAC 16</th>
<th>HMAC 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum density</td>
<td>g/cm³</td>
<td>2,578</td>
<td>2,532</td>
<td>2,540</td>
</tr>
<tr>
<td>2</td>
<td>Bulk density</td>
<td>g/cm³</td>
<td>2,573</td>
<td>2,540</td>
<td>2,540</td>
</tr>
<tr>
<td>3</td>
<td>Air void content</td>
<td>% v/v</td>
<td>3,3</td>
<td>3,1</td>
<td>3,1</td>
</tr>
<tr>
<td>4</td>
<td>Stability</td>
<td>kN</td>
<td>16,5</td>
<td>18,0</td>
<td>16,9</td>
</tr>
<tr>
<td>5</td>
<td>Flow</td>
<td>mm</td>
<td>3,8</td>
<td>3,7</td>
<td>4,0</td>
</tr>
</tbody>
</table>
## Performance properties

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Rut depth, %</th>
<th>Stiffness, MPa</th>
<th>Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\varepsilon_6$, [$\mu$m/m]</td>
</tr>
<tr>
<td>HMAC12 20/30</td>
<td>4.8</td>
<td>17813</td>
<td>137</td>
</tr>
<tr>
<td>HMAC12 35/50</td>
<td>&gt;15</td>
<td>12671</td>
<td>-</td>
</tr>
<tr>
<td>HMAC12 DE 30B</td>
<td>5.3</td>
<td>12823</td>
<td>195</td>
</tr>
<tr>
<td>HMAC12 MP10/20</td>
<td>5.0</td>
<td>16537</td>
<td>139</td>
</tr>
<tr>
<td>HMAC16 20/30</td>
<td>5.2</td>
<td>17950</td>
<td>127</td>
</tr>
<tr>
<td>HMAC16 35/50</td>
<td>&gt;10</td>
<td>11651</td>
<td>-</td>
</tr>
<tr>
<td>HMAC16 DE 30B</td>
<td>2.8</td>
<td>14037</td>
<td>174</td>
</tr>
<tr>
<td>HMAC16 MP10/20</td>
<td>4.2</td>
<td>14286</td>
<td>140</td>
</tr>
<tr>
<td>HMAC20 20/30</td>
<td>4.5</td>
<td>16009</td>
<td>133</td>
</tr>
<tr>
<td>HMAC20 35/50</td>
<td>&gt;12</td>
<td>12792</td>
<td>-</td>
</tr>
<tr>
<td>HMAC20 DE 30B</td>
<td>4.5</td>
<td>14107</td>
<td>196</td>
</tr>
<tr>
<td>HMAC20 MP10/20</td>
<td>4.2</td>
<td>13993</td>
<td>137</td>
</tr>
</tbody>
</table>
HMAC with different aggregates

• Binder 20/30
• Aggregates:
  • Basalt – HMAC 16 B (for comparison)
  • Cobblestone - HMAC16 – C
  • Granite - HMAC16 – G
  • Limestone - HMAC16 – L
  • Steel slag - HMAC16 – S
Results

<table>
<thead>
<tr>
<th>Property</th>
<th>HMAC16-B, B=4,6 %</th>
<th>HMAC16-B, B=5,1 %</th>
<th>HMAC16-C, B=4,9 %</th>
<th>HMAC16-G, B=5,5 %</th>
<th>HMAC16-L, B=5,5 %</th>
<th>HMAC16-S, B=5,3 %</th>
<th>Requirement HMAC 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral mixture density, g/cm³</td>
<td>2,850</td>
<td>2,850</td>
<td>2,691</td>
<td>2,662</td>
<td>2,698</td>
<td>3,645</td>
<td>–</td>
</tr>
<tr>
<td>Asphalt density, g/cm³</td>
<td>2,636</td>
<td>2,617</td>
<td>2,493</td>
<td>2,448</td>
<td>2,479</td>
<td>2,312</td>
<td>–</td>
</tr>
<tr>
<td>Asphalt bulk density, g/cm³</td>
<td>2,550</td>
<td>2,568</td>
<td>2,419</td>
<td>2,375</td>
<td>2,403</td>
<td>3,115</td>
<td>–</td>
</tr>
<tr>
<td>Air voids content, % v/v</td>
<td>3,3</td>
<td>1,9</td>
<td>3</td>
<td>3</td>
<td>3,1</td>
<td>3</td>
<td>3,0 ÷ 5,0</td>
</tr>
<tr>
<td>Mean rut depth, %</td>
<td>2,7</td>
<td>6,3</td>
<td>2</td>
<td>2,6</td>
<td>3,7</td>
<td>2,3</td>
<td>≤ 5,0</td>
</tr>
<tr>
<td>IT-CY, 10 °C, MPa</td>
<td>21 118</td>
<td>19 272</td>
<td>18 918</td>
<td>17 241</td>
<td>23 511</td>
<td>19 325</td>
<td>–</td>
</tr>
<tr>
<td>4PB-PR, complex modulus, 10 °C, MPa</td>
<td>19 756</td>
<td>17 950</td>
<td>16 927</td>
<td>17 291</td>
<td>19 837</td>
<td>20 713</td>
<td>≥ 14 000</td>
</tr>
<tr>
<td>Fatigue damage D, %</td>
<td>&gt; 50</td>
<td>49</td>
<td>19,7</td>
<td>&gt; 50</td>
<td>31,7</td>
<td>15,3</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Water sensitivity, %</td>
<td>114,9</td>
<td>118,7</td>
<td>104,8</td>
<td>107,8</td>
<td>95,3</td>
<td>121,3</td>
<td>≥ 80,0</td>
</tr>
</tbody>
</table>
Outline of presentation

- Objectives of WP4.2
- High modulus asphalt concrete (HMAC) in Poland
- Results of laboratory tests
- ALT on test fields in Poland (HVS)
- Conclusions
Location & Bird’s eye view

Section C
Section D
Section B
Section A

Locations of sensors
Place for sensor cables

PA
POLBET

3 m
3 m
32,5 m
5 m
5 m

32,5 m
Section A & B

Section A
- SMA 8 DE80C
- HMAC 16 20/30
- Subbase 0/31.5 mm

Section B
- SMA 8 DE80C
- AC 16 W 35/50
- Subbase 0/31.5 mm

EMU  ACG  temperature sensor
Mixtures

SMA 8 DE80C (WT NA DiL 2008):
- DE80C
- Limestone filler
- Basalt (Sulików)
- Viatop Premium
- Wetfix BE
- Sasobit

AC 16 W 35/50 (WT NA DiL 2008):
- 35/50
- Limestone filler
- Dolomite (Radkowice)
Mixtures (2)

**AC WMS 16 20/30** (WT NA DiL 2008) *(fundamental approach)*
- 20/30
- Limestone filler
- **Limestone (Kujawy)**

**AP AF** (sand mix PN-S-96025) **antyfatigue**
- DE 80C
- Natural and crushed sand
- Limestone filler
- Fiber TOFIC
- Wetfix BE
- Sasobit

**Composite mix „STRABAPHALT”** (PA 11 50/70, WT NA DiL 2008)
- 50/70,
- Malphyre (Czarny Bór)
- Water-cement mortar
## Properties of designed mixes

<table>
<thead>
<tr>
<th></th>
<th>SMA 8 DE80C</th>
<th>AC 16 35/50</th>
<th>ACWMS 16 20/30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Am, % m/m</strong></td>
<td>7,1</td>
<td>4,3</td>
<td>5,5</td>
</tr>
<tr>
<td><strong>Wp, % v/v</strong></td>
<td>3,3</td>
<td>3,8</td>
<td>3,8</td>
</tr>
<tr>
<td><strong>WTS\textsubscript{AIR}</strong></td>
<td>0,04</td>
<td>0,03</td>
<td>0,08</td>
</tr>
<tr>
<td><strong>PRD\textsubscript{AIR}</strong></td>
<td>5,6</td>
<td>1,0</td>
<td>2,7</td>
</tr>
<tr>
<td><strong>P, % (LCPC)</strong></td>
<td>9,2</td>
<td>2,1</td>
<td>3,6</td>
</tr>
<tr>
<td><strong>ITSR, %</strong></td>
<td>92,6</td>
<td>90,2</td>
<td>91,8</td>
</tr>
<tr>
<td><strong>S, MPa</strong></td>
<td>-</td>
<td>19435</td>
<td>16312</td>
</tr>
<tr>
<td><strong>\varepsilon_{6}, \mu m/m</strong></td>
<td>-</td>
<td>116</td>
<td>180</td>
</tr>
</tbody>
</table>
Mix design results

Mix design according to WT NA 2008
All requirements fulfilled
Good performance:
- Fatigue
- Stiffness
- Rutting (small and large device)
- Resistance to water
Construction works

Fot. 1 Podłączenie czujników (EMU) w warstwie podłoża

Fot. 2 Czujniki odkształceń (ASG) na warstwie podbudowy z kruszywa łamanego stabilizowanego mechanicznie

Fot. 3 Prace przy wykonaniu oraz widok warstwy ścieralnej SMA 8 DE80C
## Layer thickness

<table>
<thead>
<tr>
<th></th>
<th>Section A</th>
<th>Section B</th>
<th>Section C</th>
<th>Section D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slabs</td>
<td>15,0</td>
<td>11,7</td>
<td>13,5</td>
<td>14,5</td>
</tr>
<tr>
<td>Cores</td>
<td>15,0</td>
<td>11,8</td>
<td>13,4</td>
<td>14,3</td>
</tr>
<tr>
<td>Wearing course</td>
<td>2,4</td>
<td>1,8</td>
<td>4,8</td>
<td>2,2</td>
</tr>
<tr>
<td>Base course</td>
<td>12,6</td>
<td>10,0</td>
<td>8,6</td>
<td>7,5</td>
</tr>
<tr>
<td>AP AF Layer</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4,6</td>
</tr>
</tbody>
</table>
Testing conditions HVS

- Single wheel
- Wheel Load: 60 kN (80 kN)*
- Tire pressure: 800 kPa
- Speed: 10-12 km/h
- Temperature: +10 °C
- Number of loads 300 000 cycles
Measurements done by VTI

The type and frequency of the measurements are listed below:

- **Transverse profile**
  - daily
- **Vertical displacement of the subgrade**
  - daily
- **Vertical permanent deformation of the subgrade**
  - daily
- **Transverse horizontal strain in the bottom of asphalt layers**
  - daily

**Measurements frequency for subsequent loading levels:**

- **Transverse horizontal strain in the bottom of asphalt layers (second and the last day of the testing)**
- **Vertical displacement of the subgrade (second and the last day of the testing)**
- Wheel loading: 30, 40, 50 and 60 kN
- **Central position of the wheel in transverse direction**
Complementary testing programm

- FWD
- Thickness: cores + GPR
- Coring
- Composition and compaction
- Stiffness ITCY, 4PB
- Fatigue 4PB

* Tests on loaded and not loaded areas
Profile deformation of wearing course

Average Profile Deformation

Structures A and B
1 - 187,000 passes: Load = 60 kN
187,000 - 317,000 passes: Load = 60 kN

Structures C and D
1 - 180,000 repetitions: Load = 60 kN
190,000 - 210,000 repetitions: Load = 80 kN
Tensile strains at the bottom of asphalt layers

Graph showing the relationship between load repetitions and tensile strain for different asphalt structures under different loads.

- **Single wheel, 80 kN, 800 kPa**
- **Single wheel, 60 kN, 800 kPa**

Graph lines indicate:
- **Structure A**
- **Structure B**
- **Structure C**
- **Structure D**
Strain in the top of subgrade

- Single wheel, 60 kN, 800 kPa
- Single wheel, 80 kN, 800 kPa

Graph showing vertical strain (µm/m) vs. load repetitions (0-350,000) for different sections:
- Section A
- Section B
- Section C
- Section D
Permanent strain in the subgrade
Visual inspection

Black path
Good state of wearing course
No cracks
Small deformation
Fatigue damage?

- Bar chart showing strain (μm/m) for sections A, B, C, and D.
- Change in percentage for phases 1 and 2, and start-end 60 kN, for sections A, B, C, and D.
FWD test results
### Modelling

<table>
<thead>
<tr>
<th>Wheel load 60kN</th>
<th>Wheel load 80kN</th>
<th>Fatigue life according to IA (mln)</th>
<th>Fatigue life according to laboratory tests (mln)</th>
<th>Fatigue life taking into account strain in soil base (mln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{asf} ), µm/m</td>
<td>( \varepsilon_{asf} ), µm/m</td>
<td>( \varepsilon_{asf} ), µm/m</td>
<td>60 kN</td>
<td>80 kN</td>
</tr>
<tr>
<td>170</td>
<td>-570</td>
<td>202</td>
<td>-740</td>
<td>1,9</td>
</tr>
<tr>
<td>205</td>
<td>-736</td>
<td>234</td>
<td>-948</td>
<td>0,3</td>
</tr>
<tr>
<td>175</td>
<td>-550</td>
<td>206</td>
<td>-711</td>
<td>0,5</td>
</tr>
<tr>
<td>86*</td>
<td>-626</td>
<td>99</td>
<td>-809</td>
<td>17,5</td>
</tr>
<tr>
<td>213</td>
<td>250</td>
<td>2,2</td>
<td>1,3</td>
<td>4,5</td>
</tr>
</tbody>
</table>
Modelling vs measurements

![Bar chart showing strain at the bottom of asphalt layers for different sections A, B, C, and D, comparing ASG measurements, Modelling method I, and Modelling method II.](image-url)
Damage vs predicted life

- Calculated fatigue life, $10^5$
- Fatigue damage (increase of asphalt strains), %
4PB - test methods and goals

1. **Stiffness 4PB** (PN-EN 12697-26) 10°C, 10Hz
   - Parameters for modelling
   - Damage evaluation (lost of stiffness)

2. **Fatigue 4PB** (PN-EN 12697-24) 10°C, 10Hz
   - Fatigue law (18-20 beams per mix)
   - Damage (lost of fatigue resistance)
Specimens

1. Specimens prepared in laboratory
   HMAC 16 rec
   AC 16 rec
   PA rec

2. Specimens cut from the pavement
   Loaded areas (wheel paths):
   - HMAC 16 A and HMAC 16 D
   - AC 16 B and AC 16 C

   Not loaded areas:
   - HMAC 16 A’ and HMAC 16 D’
   - AC 16 B’ and AC 16 C’
Fatigue life, 4PB.
Stiffness, 4PB
Healing

- **Healing** – it is phenomena of recovery of mechanical properties (stiffness, fatigue resistance) during rest period
- Hot summer days (June/July 2008),
- Pavement HVS test temperature 10°C,
- FWD test – in 2-3 days after HVS removing
- Coring – middle August (5-6 weeks later)
- Rapid increase of temperature could close microcracks and could recover mechanical properties - healing
General assessment of pavements

• Loadings 200 000 (wheel load 60 kN) + 100 000 (wheel load 80 kN) in 14 days
• Equivalent to 700 000 of 100 kN axle loads
• Traffic category KR3 (20 years)
• Structures – thickness for KR2/KR3
• Structures were not destroyed
• Better performance of HMAC structures
• Promising effectiveness of antifatigue layer
• Good performance of HMAC based on limestone aggregates
HMAC – main conclusions

• Modern test methods gives reliable evaluation of properties of HMAC
• Good, controlled performance properties – resistance to rutting, water sensitivity
• Improved resistance to fatigue, higher stiffness
• Higher durability and designed life of the pavement
• Potential reduction of asphalt layer thicknesses
• Lower quality aggregates can be successfully used for HMAC
• Fundamental approach – benefits for investor, contractors and users
• Future – continuation of HMAC development and common use fundamental approach
THANK YOU!