LABORATORY ASSESSMENT OF WARM MIXES BY THE MEANS OF TWO MIX DESIGN METHODS

A. Dony; P. Maillard-Nunes; M. Klincevicius; R. Motta; L. Bernucci; C. Del Priore; Y. Brosseaud; V. Gaudefroy
French-Brazilian partnership

- Escola Politécnica da Universidade de São Paulo USP (LTP - Laboratory of Pavement Technology)
- Ecole Spéciale de Travaux Publics ESTP (GREMACOR Laboratory)
- Central des Ponts et Chaussées LCPC (Division SMIT)
To compare in laboratory WAM – HMA:
  - Two mix design methods:
    - French: performance
      - Gyratory Shear Compactor (NF EN 12 697-31)
      - Water resistance: Duriez test (NF EN 12 697-12)
    - Brazilian: empirical
      - Marshall compaction (AASHTO T 166-93)
      - Moisture damage, ITS ratio (AASHTO T 283-89)
  
  - Estimate the Total Organic Compound emissions (TOCe)
Terminology

- **Semi Warm**: < 100°C
- **Warm**: -30°C
- **Cold asphalt**: asphalt
- **Warm asphalt**: Latent heat vaporization of water
- **Half-warm asphalt**: asphalt
- **Hot asphalt mix**: asphalt

**Legend**

- **HEATING**
- **VAPORIZATION**
- **DRYING**

**Graph**

- **L Fuel /Ton**
- **Temperature (°C)**
  - 0 20 40 60 80 100 120 140 160 180
## Composition of mixes

### Brasilian

<table>
<thead>
<tr>
<th>Material</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone ½ &quot;</td>
<td>25.0</td>
</tr>
<tr>
<td>Chips</td>
<td>30.0</td>
</tr>
<tr>
<td>Stone powder</td>
<td>33.5</td>
</tr>
<tr>
<td>Artificial sand</td>
<td>10.0</td>
</tr>
<tr>
<td>Lime</td>
<td>1.5</td>
</tr>
</tbody>
</table>

- Bitumen 50/70
- Content 4.4%
- Additive 0.3% w/w bitumen

### French

<table>
<thead>
<tr>
<th>Material</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/10</td>
<td>25.0</td>
</tr>
<tr>
<td>2/6</td>
<td>30.0</td>
</tr>
<tr>
<td>0/2</td>
<td>33.5</td>
</tr>
<tr>
<td>Filler</td>
<td>2</td>
</tr>
</tbody>
</table>

- Bitumen 35/50
- Content 5.2%
- Additive 0.3% w/w bitumen

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Composition of mixes

BBSG 0/10 Microdiorite aggregates (La Noubleau Quarry)

CBUQ 0/12.5 Granite aggregates (Sta. Isabel Quarry)
<table>
<thead>
<tr>
<th>Bitumen grade</th>
<th>France</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>BBSG 0/10 with 35/50</strong></td>
<td><strong>CBUQ 12.5mm with 50/70</strong></td>
</tr>
<tr>
<td></td>
<td><strong>BBSG 0/10 with 10/20</strong></td>
<td><strong>CBUQ 12.5mm with 50/70</strong></td>
</tr>
<tr>
<td></td>
<td>HMA</td>
<td>HMA</td>
</tr>
<tr>
<td></td>
<td>WMA *</td>
<td>WMA *</td>
</tr>
<tr>
<td>Bitumen</td>
<td>165</td>
<td>180</td>
</tr>
<tr>
<td>Aggregates</td>
<td>165</td>
<td>180</td>
</tr>
<tr>
<td>Compaction / Test</td>
<td>165</td>
<td>180</td>
</tr>
</tbody>
</table>

* With or without additive
BBSG 0/10 – 35/50 pen grade
Binder content : 5.2 %

BBSG 0/10 – 10/20 pen grade
6.0 %

Exactly the same results: HMA – WAM with or without additive
Even for two different classes of bitumen
Marshall air voids

<table>
<thead>
<tr>
<th>Brazil</th>
<th>Air voids content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>5.1%</td>
</tr>
<tr>
<td>WMA</td>
<td>6.2%</td>
</tr>
</tbody>
</table>

DESIGN AIR VOIDS

Little difference: HMA more dense than WAM
Marshall test other compositions

Brazil

<table>
<thead>
<tr>
<th>Bitumen content</th>
<th>HMA</th>
<th>WMA</th>
<th>WMA</th>
<th>WMA</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.7%</td>
<td>5.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+add.</td>
<td>No add.</td>
<td>+add.</td>
<td>+add.</td>
</tr>
</tbody>
</table>

Air voids (average) [%]

- HMA: 5.0% (sd=0.3%)
- WMA with additive: 6.0% (sd=0.1%)
- WMA: 6.4% (sd=0.1%)
- WMA with additive: 5.8% (sd=0.3%)
- WMA with additive: 5.6% (sd=0.4%)

Little difference: HMA more dense than WAM, confirmed with others compositions, even by increasing binder content.
Duriez results

HMA, WMA with or without additive, 35/50 or 10/20 bitumen

France

<table>
<thead>
<tr>
<th>Compressive strength (MPa)</th>
<th>Bitumen 35/50 (165°C - 329°F)</th>
<th>Bitumen 35/50 (110°C - 230°F with additive)</th>
<th>Bitumen 35/50 (110°C - 230°F)</th>
<th>Bitumen 10/20 (180°C - 356°F)</th>
<th>Bitumen 10/20 (110°C - 230°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.87</td>
<td>0.85</td>
<td>0.83</td>
<td>0.95</td>
<td>0.83</td>
</tr>
<tr>
<td>Water</td>
<td>13.9</td>
<td>12.1</td>
<td>12.6</td>
<td>15.0</td>
<td>16.1</td>
</tr>
</tbody>
</table>

Water temperature 25°C during 7 days

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Indirect tensile strength

<table>
<thead>
<tr>
<th>Indirect Tensile Strength [MPa]</th>
<th>Air voids [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.01 MPa (sd=0.01 MPa)</td>
<td>5.0% (sd=0.3%)</td>
</tr>
<tr>
<td>1.43 MPa (sd=0.01 MPa)</td>
<td>6.0% (sd=0.1%)</td>
</tr>
</tbody>
</table>

Brazil

HMA 4.4%

WMA 4.4% + 0.3% additive

Low dispersion of individual results

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Water resistance test

Brazil

Tensile strength ratio from moisture-induced damage

⇒ specification from DNIT: up to 0.70

<table>
<thead>
<tr>
<th>Tensile Strength Ratio</th>
<th>HMA</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.62</td>
<td>0.69</td>
</tr>
</tbody>
</table>

HMA 4.4% bitumen
WMA 4.4% bitumen + 0.3% additive

Slightly difference: WMA > HMA, but limit

Water temperature 60°C during 1 day

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Objective

Environmental Assessment and ranking of *bituminous mixes* in lab
Efficient laboratory tool to study and **forecast** asphalt fumes

**Functions**
- Generate fumes
- Collect / Sample
- Analyse

**Parameters studied**
- Mix design
- Binder
- Process
- Manufacturing temperature
Analytical systems to measure asphalt emissions

Evaluation and separation of TOC by a Flame Ionization Detector (FID)

- Evolution of Total Organic Compounds TOC(e) emissions according to time at a stirring velocity of 20 rpm

One studied indicator = Emission Potential

TOC(e) (mg/m³/kg of bitumen)

Emission Potential (mg.s/m³/kg of bitumen)

The emission Potential (EP) is calculated by integrating the area under TOC(E) curve according to time.

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Emissions of fumes

- Emissions of fumes in kg of bitumen:
  - 80
  - 100
  - 120
  - 140

- Mixing time (s):
  - 0
  - 200
  - 400
  - 600
  - 800
  - 1000
  - 1200
  - 1400
  - 1600
  - 1800

- TOC (mg/m³/kg of bitumen):
  - 0
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120

Graph showing emissions of fumes over mixing time for HMA, WMA with additive, and WMA without additive.
## TOCe results

<table>
<thead>
<tr>
<th></th>
<th>Manufacturing temperature °C/[°F]</th>
<th>Additive content (% w/w binder)</th>
<th>TOC(e) max (mg/m³/kg)</th>
<th>Emission Potential (mg.s/m³/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAM without</td>
<td>110/ [230]</td>
<td>0.0</td>
<td>85.0</td>
<td>44.0 $10^3$</td>
</tr>
<tr>
<td>WAM + additive</td>
<td>110/ [230]</td>
<td>0.3</td>
<td>85.2</td>
<td>50.3 $10^3$</td>
</tr>
<tr>
<td>HMA</td>
<td>160/ [320]</td>
<td>0.0</td>
<td>121.6</td>
<td>58.3 $10^3$</td>
</tr>
</tbody>
</table>
Temperature and mix design influence (others results)

Ref Gaudefroy ISAP 2008 paper 110

Increase of Temperature = Increase of TOC(e) emission
Increase of Bitumen content = Decrease of TOC(e) emission
Conclusions

• Workability
  – GSC: no link with temperature
    => no relevant to test WAM / HMA
  – Marshall: some little differences
• Water resistance:
  – Duriez test: no difference (but with a good aggregate)
  – Marshall + ITS: no difference (limit in specifications)
• Emission TOC
  – Better result (low emission) with WAM,
    • no significant difference with or without additive
Conclusions

- WMA durable trend in France
  - Increasing use with promising results
- Still research needs
  - Need specific test to assess workability, and water resistance with sufficient reliability at low temperatures
  - Need of a global environmental assessment tool (like for other techniques)
  - Existing tool for fume assessment in lab to correlate to field
  - Need for job sites surveys
    - To assess durability under traffic
    - To check and/or improve performance based specifications
Thank you for your attention!

contacts:
2ad-fc@wanadoo.fr
liedi@usp.br
yves.brosseaud@lcpc.fr

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