Evaluation of WMA key performances with regards to curing time and conditioning method

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Presentation outline

- Introduction
- Research objectives and organization
- Laboratory evaluation of WMA performances
  - WMA selection
  - Testing methodology
  - Mix design and compaction temperature
  - Tests results on binders and mastics
  - Analysis of the curing time
  - Analysis of the conditioning method
- Conclusions and recommendations

  Multiple attribute decision model for asphalt mixture choice
Introduction

- Continuous increases of energy consumption and emissions

![Graph showing emissions over time](image)

- Numerous methods and tools developed in order to decrease the environmental load
- Asphalt pavements require a lot of energy and the domain has to contribute to the sustainable development concerns
Research motivations and objectives

- **Research motivations**
  - Apparition of “green” asphalt mixtures
  - Asphalt pavement modulus is a key parameter (design, lifetime calculation)
  - Need for a global evaluation tool, that help in the choice of the asphalt mixture

- **Research objectives**
  - Identify the WMA critical and/or unverified mechanical performances
  - Extended laboratory analysis of the abovementioned performances
  - Setup and critical analysis of an indirect tensile test (IT-CY) for WMA secant modulus evaluation
  - Develop a methodology for a global evaluation method of asphalt mixtures → assist in the decision making process
Situation and objectives

Knowledge update

Base parameters definition and WMA selection

- Performance-based approach (laboratory)
  - Performances/characteristics evaluation in laboratory (critical/unverified)
  - Setup and validation of indirect tensile test

- Energy (LCI)
- Emissions (LCI)
- Costs (LCI)
- Performances

- Databases
- Calculations
- Measure & survey

Asphalt mixture global evaluation tool
- Detailed methodology
- Example and sensitivity analysis

Conclusions & Recommendations
### Warm-Mix Asphalt selection

#### WMA selection for laboratory analysis

<table>
<thead>
<tr>
<th>Type of asphalt mixture</th>
<th>Moisture control</th>
<th>Wax (FT)</th>
<th>Chemical additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and environmental savings (estimation)</td>
<td>+++</td>
<td>+</td>
<td>++/++++</td>
</tr>
<tr>
<td>Production easiness (plant)</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Experience (Europe)</td>
<td>++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Product name</td>
<td>LEA®</td>
<td>Sasobit®</td>
<td>Cecabase RT 945®</td>
</tr>
<tr>
<td>Research code</td>
<td>EST</td>
<td>ET-C</td>
<td>ET-P</td>
</tr>
</tbody>
</table>

+ Low  
++ Medium  
+++ High
## Testing methodology

### I – BASE COMPONENTS CHARACTERISATION

<table>
<thead>
<tr>
<th>Component</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>Consistency, deformation, viscosity, low temperature behavior, thermal susceptibility, rutting susceptibility</td>
</tr>
<tr>
<td>Filler</td>
<td>Gradation, voids content, density</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Gradation, density, angularity, petrography</td>
</tr>
<tr>
<td>Sand</td>
<td>Gradation, density, angularity, voids content</td>
</tr>
</tbody>
</table>

### II – VOLUMETRIC MIX DESIGN (EQUI-MANIABILITY)

- Marshall compacity
- Gyratory compactor

### III – EXTENDED CHARACTERISATION TESTS AND PERFORMANCE TESTS

<table>
<thead>
<tr>
<th>Component</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
<td>Viscosity virgin/additivated, consistency, deformation</td>
</tr>
<tr>
<td>Mastic</td>
<td>Viscosity</td>
</tr>
<tr>
<td>Asphalt mix</td>
<td>Flow and stability, resistance to permanent deformation, mechanical resistance, water sensitivity, complex modulus, fatigue behavior</td>
</tr>
</tbody>
</table>

### IV – SPECIFIC ANALYSIS

- Curing time analysis (performance increases)
- Analysis of the conditioning method
Testing methodology

- **Controlled parameters**
  - Layer: Base course (Swiss AC T 22S)
  - Bitumen: pen 50-70 (PG 64-22)
  - Same aggregates
  - No reclaimed asphalt pavement (RAP)

- **WMA additive content:**
  - Wax (ET-C) 3%/mass of bitumen
  - Chemical additive (ET-P) 0.4%/mass of bitumen
  - Vegetal flux (EST) 0.4%/mass of bitumen
Mix design

- Similar grading curve for the different mixes (no mix design optimization)
- Binder content: 4.4%/asphalt mix
Compaction temperature

Determination of optimal compaction temperature

![Graph showing compaction temperature vs. compacity PCG (%)](image)
Binder characterization

- Penetration tests on base and recovered binder
Binder characterization

- Performance Grade (PG)

- Temperature [°C]

- Binder characteristics:
  - PG 64-22
  - PG 70-16

- Temperature range:
  - -40 to 80 °C

- Performance Grade:
  - PG 64-22
  - PG 70-16

- Performance characteristics:
  - EST
  - ET-P
  - ET-C
  - REF

- Performance values:
  - -24.6 °C (EST) 66.4
  - -24.2 °C (ET-P) 68.8
  - -20.7 °C (ET-C) 75
  - -24.2 °C (REF) 69.4

- Reference temperature:
  - -3.5 °C

- Performance grade:
  - PG 64-22
  - PG 70-16

- Temperature range:
  - -40 to 80 °C

- Performance characteristics:
  - EST
  - ET-P
  - ET-C
  - REF

- Performance values:
  - -24.6 °C (EST) 66.4
  - -24.2 °C (ET-P) 68.8
  - -20.7 °C (ET-C) 75
  - -24.2 °C (REF) 69.4

- Reference temperature:
  - -3.5 °C
Viscosity measurement

- Plate diameter: 25 mm
- Dynamic loading: 0.5 Hz (3.14 rad/s)
- Strain amplitude: 0.1%
- Initial gap: 0.8 mm to 1 mm
- Temperature screening: 155 °C to 15 °C
- Temperature variation: 5 °C/min
Viscosity measurement

- Dynamic viscosity and phase angle of binder

![Graph showing dynamic viscosity and phase angle of binder](image)
Viscosity measurement

Dynamic viscosity and phase angle of mastic
### Analysis of the curing time

Tests at different time after mix production: 0, 1, 2, 4 and 12 weeks

<table>
<thead>
<tr>
<th>Standards</th>
<th>Test conditions</th>
</tr>
</thead>
</table>
| EN 12697-23 (modified for LT) | • Marshall samples (50/50)  
  • Temperature: -10 °C, 15 °C, 40°C  
  • Speed: 18 mm/min, 48 mm/min |
| EN 12697-22 | • Samples: 18 cm x 50 cm x 10 cm  
  • Temperature: 60 °C |
| EN 12697-12 | • Marshall samples (25/25)  
  • Wet samples: 68-72 h at 40°C |
| EN 12697-26 | • Trapezoidal specimens (h=250 mm)  
  • Temperature: -10 to 30/35 °C  
  • Frequency: 1 to 40 Hz |
Analysis of the curing time

- Indirect tensile strength (-10 °C)
Analysis of the curing time

- Indirect tensile strength (40 °C)

![Bar chart showing indirect tensile strength over weeks for different conditions: REF, ET-C, ET-P, EST.}]
Analysis of the curing time

- Rutting susceptibility

![Bar chart showing calculated rut depth over time for different samples and conditions. The chart includes data points for 10,000 and 30,000 cycles, with various color codes for different samples and time periods.](image)
### Analysis of the curing time

#### Moisture susceptibility

<table>
<thead>
<tr>
<th>Curing [week]</th>
<th>REF</th>
<th>ITSD [kN/m²]</th>
<th>ITSW [kN/m²]</th>
<th>ITSD [%REF] - dry</th>
<th>ITSW [%REF] - water</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>929</td>
<td>745</td>
<td>ET-C 78%</td>
<td>ET-C 89%</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>930</td>
<td>815</td>
<td>ET-P 92%</td>
<td>ET-P 104%</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1109</td>
<td>999</td>
<td>EST 70%</td>
<td>EST 92%</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1022</td>
<td>881</td>
<td>ET-C 88%</td>
<td>ET-C 102%</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>925</td>
<td>804</td>
<td>ET-P 92%</td>
<td>ET-P 102%</td>
</tr>
</tbody>
</table>

- REF: 100%
- > 100%
- 90% ... 100%
- 80% ... 90%
- 70% ... 80%
- < 70%
Analysis of the curing time

- Complex modulus – Master curve ($T_R = 15 \, ^{\circ}\text{C}, 2 \, \text{weeks}$)

![Graph showing complex modulus $E^*$ vs. reduced frequency for different curing times and conditions.]

- REF
- ET-C (wax)
- ET-P (chemical add.)
- EST (moist. control)
Analysis of the curing time

- Complex modulus – Master curve ($T_R=15 \, ^\circ\text{C}$, 12 weeks)

![Graph showing complex modulus $E^*$ vs. reduced frequency for different treatments: REF, ET-C (wax), ET-P (chemical add.), EST (moist. control).]
Analysis of the conditioning method

- Tests with and without conditioning in a plastic bag
  - “Reproduction” of in-situ conditions for base course

- Test selection (asphalt mixture)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test selected</th>
<th>Standards</th>
<th>Test conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low, high and intermediate temperature behavior</td>
<td>Indirect tensile strength</td>
<td>EN 12697-23 (modified for LT)</td>
<td>• Marshall samples (50/50)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Temperature: -10 °C, 15 °C, 40°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Speed: 18 mm/min, 48 mm/min</td>
</tr>
</tbody>
</table>
Analysis of the conditioning method

- Indirect tensile test (ET-C)

![Graph showing stress measured at 40 °C over different conditioning periods.

Stress [N/mm²]

- 0.38
- 0.34
- 0.35
- 0.37
- 0.35
- 0.37
- 0.39
- 0.37
- 0.36

Stress measured at 40 °C

- 0 week
- 1 week
- 1 week (cond)
- 2 weeks
- 2 weeks (cond)
- 4 weeks
- 4 weeks (cond)
- 12 weeks
- 12 weeks (cond)
Analysis of the conditioning method

- Indirect tensile test (EST)

![Graph showing stress measured at -10 °C over different time periods and conditioning conditions.](image)

Stress measured at -10 °C
Conclusions and recommendations

- Same mix design and grading curve (no optimization)
- Results are consistent and coherent. The specific behavior of each type of WMA has been highlighted
- WMA with wax: Better rutting resistance, but low temperature performances negatively affected
- WMA with chemical additive: No effect on binder or mastic (surfactant). Characteristics and mechanical behavior comparable to reference HMA
- WMA with moisture control: Lower mechanical performances (moisture sensitivity, high temperature behavior, rutting resistance)
Conclusions and recommendations

- No specific curing time of the tested mixtures. Statistical T-Test confirmed the measurements
- The conditioning method in plastic bags did not highlight significant differences (confirmed by T-Test)
- Further research directions:
  - Mix design and optimization in a WMA perspective
  - Evaluation of residual humidity effect on asphalt mixture mechanical behavior
  - Applicability and meaning of traditional tests on asphalt and binder

→ NATIONAL RESEARCH PROJECT (PLANET) IN PROGRESS
Model for asphalt mixture choice

- **Situation:**
  - Many GHG and energy calculators
  - **Lack of model helping in the decision making between the various asphalt mixture type**

- **Model developed**
  - Various parameters: energy, emissions, costs, performances, production complexity, sustainability, …
  - Model developed in two parts:
    1. Development of indicators
    2. Multiple attribute decision model
Model for asphalt mixture choice

Part 1

1 – Life cycle inventory (LCI) and performance indicators

- Calculation
  - Material heating
  - Burner heating

- Measurements (CH)
  - Aggregates prep.
  - Asphalt plants

- Literature
  - Databases

Laboratory testing (performances)

LCI
- Energy
- Emissions
- Costs
- Performances

Indicators
Model for asphalt mixture choice

Part 2

2 – Global evaluation model

Level 1
Pareto analysis
- Objective: Identify major unitary processes for each attribute and alternative
- Data: Raw and normalized indices (performances)
- Criteria: Energy, emissions, energy costs and performances
- Method: Pareto representation

Level 2
Graphical analysis
- Objective: Identify potential alternative outranking
- Data: Raw and normalized indices (performances)
- Criteria: Energy, emissions, energy costs and performances
- Method: Graphical analysis

Level 3
Partial aggregation
- Objective: Alternatives ranking (fuzzy outranking)
- Data: Raw
- Criteria: Energy, emissions, energy costs, performances and qualitative
- Method: Partial aggregation (Electre III)

Level 4
Complete aggregation
- Objective: Alternatives ranking (uncertainty and unknown part taken into account)
- Data: Raw
- Criteria: Energy, emissions, energy costs, performances and qualitative
- Method: Complete aggregation (Evidential reasoning approach)

DECISION AID (asphalt mixture type)
Thank you for your attention!

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