French methodology for hot bituminous mix design

Yves BROSSEAUD
Senior researcher
IFSTTAR – ex LCPC
FRANCE

www.ifsttar.fr

Framework

✓ Mix design presentation
✓ Method
✓ Tests and devices
✓ Performances - specifications
✓ Pertinence of method : comparison lab/field
✓ Conclusion

Method and overview

✓ One material type for each need
✓ Optimized with performance based criteria
✓ In relation with its use on the road
✓ Method used in France since more than 25 years old, so with a very long experience
✓ One laboratory test for One performance

Summarise of French mix design - different steps
Mix design and specifications: level 2
PCG + Water + Rutting RESISTANCE
[Fabrication-preparation sample-checking]

Marshall test

Preparation of samples in laboratory
Good control quality of mix: composition, voids, homogeneity, ...
Accurate and Relevant Tests
Relevant comparison with in situ materials
Plate compactor:
400*600*150
180*500*25 à 100
EN 12697-33

Design steps
Selection and identification of components
Choice: gradation & binder content
Compactability test (gyratory)

Level 1
Compaction
Water sensitivity

Level 2
Rutting test
Rutting

Level 3
Modulus test
Stiffness

Level 4
Fatigue test
Formulation selected

Mix design and Composition

Compactability characterisation

Gyratory Shear compactor
Standard (NF EN 12697-31)
Characterisation of void % reduction under axial force + gyratory shear
Mix design by adjustment of void content according to product standards
Estimation of site void content
Vsite = V(Ne)
N_e: nbr of cycle as thickness (mm)
Correlation coefficient: r = 0.95

Interpretation of gyratory compaction test
Conformity study of a mix in relation to product standard specification for each material type (NF EN 13 108-1/2/7)
Void content versus layer thickness
In site compaction process

Main difference with Superpave interpretation:
N initial, N design 4%, N max

Water sensitivity : Duriez test

- Standard EN 12697-12 exNFP 98-251-1
- Two compaction processes
  D< 14 mm H 190 mm, 60 kN, 5 min
  D>14 mm H 270 mm, 180 kN, 5 min
- Stored at 18 °C, 7 days
- in-air (50% moisture)
- in-water
- Vertical compression (1 mm/s)
- Ratio r/R (and % voids)
- Repeatability and reproducibility
  r = 0.08
  R = 0.13 (ratio of 0.73)

⇒ Decision to use of an adhesion agent
⇒ European standard used also indirect tensile test (EN 12697-12)

Level 2 : rutting resistance test

- Standard (EN 12697-22 ex NFP 98-253-1)
- Influence of heavy, slow, channelled traffic under high temperature
- Relevant correlation with site,
  repeatability (r = 1.2 et R = 1.3)
- Test conditions:
  - Smooth tire, pressure 0.6 MPa
  - Load 5 kN, speed 1 cycle/s
  - Controlled temperature 60°C

LPC Wheel tracking test

- Wheel rut depth measurement
Typical results with LPC Wheel tracking test

Influence of binder type

Influence of sand nature

Influence of void content

Comparaison Résultats d’orniérage (EME)

Surface stability under loads at 60°C, for BBTM

Heavy compaction
Void content : 5%
Rutting resistance - specifications

- Test @ 60 °C

Level 3 and 4

Mechanical tests:
- stiffness measurement (direct tensile test or 2 points bending on trapezoidal samples)
- Fatigue resistance test

Determination of bituminous mixes mechanical characteristics for pavement structural design

- Wearing course
- Base (tensile)
- Sub-base
- Non treated
- Natural soil

Need for stiffness characteristics and fatigue resistance: admissible strain for 1 million cycles

Mechanical tests

- Linear domain (modulus test)
  - Frequencies Domain - dynamic test
    - complex modulus in flexion
  - temporal Domain - quasi-static test
    - secant modulus in traction

- Damage domain (fatigue, test in flexion with imposed constant displacement)

Complex modulus test (NF EN 12697-26)

Test conditions: Frequencies F [1, 3, 10, 25, 30, 40 Hz]
- Temperature 15 °C
- Linear domain low deformation 50*10^-6

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>1</th>
<th>3</th>
<th>10</th>
<th>25</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ε*</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>E*</td>
<td></td>
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</tbody>
</table>

Complex modulus test

EN 12697-26 ex NFP 98 260-2
- 2 points bending on trapezoidal samples, 4 repetitions
- E pavement design 15°C, 10 Hz
- Master curve (rheological behavior)
1 parallelepiped sample from cut of plate or PCG sample
- Control temperature (climate chamber)
- Frequencies imposed (vibrator system)
- Solicitations in linear domain ($\varepsilon < 50 \times 10^{-6}$)
- Modulus at fixed conditions: 15°C, 10 Hz
- Machine « compact » and easy to use

Device to measure modulus with simple system

- 1 parallelepiped sample from cut of plate or PCG sample
- Control temperature (climate chamber)
- Frequencies imposed (vibrator system)
- Solicitations in linear domain ($\varepsilon < 50 \times 10^{-6}$)
- Modulus at fixed conditions: 15°C, 10 Hz
- Machine « compact » and easy to use

Stiffness

Modulus @ 15°C: complex (10 Hz)

- Machine « compact » and easy to use

Principle of fatigue test

Fatigue according to NF EN 12697-24 - annex A

- Standard EN 12697-24 ex NF P 98-261-1
- 2 points Bending beam on trapezoidal sample
- 3 strain levels with 6 specimens each, 10°C and 25 Hz
- Strain calculated for 1 million of cycles $\varepsilon_6$
- (better behavior for high $\varepsilon_6$)
- $F = 4.2 \mustrain, R = 8.3 \mustrain$

Fatigue equipment in flexion (M2F)

- Solicitations with imposed displacement
- Test: 2 samples tested simultaneously
- Control temperature (climate chamber)
- Frequencies variables: 5 to 25 Hz (motor with eccentric)
- Optional measurement of complex modulus before test at 15°C, 10 Hz, $\varepsilon = 50 \times 10^{-6}$
- Electronic data capture allows to help for analyze of test
- Tester report with $\varepsilon_6$

Fatigue test

- Admissible strain @ 10°C and 25 Hz [$\mustrain$]

Displacement resp. (x)

Load resp. (P)

Time

$e_6$

Ln (duration of life)

Fatigue law = $k N^p$

Service life N

M 2 F apparatus

Droite de fatigue

Fatigue test

Modulus and fatigue test

- Solicitations with imposed displacement
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Fatigue test

- Admissible strain @ 10°C and 25 Hz [$\mustrain$]
**Base Hot Mix Asphalt: main performances**

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>Volume (Voids %)</th>
<th>Giratory</th>
<th>C80 (D 10mm)</th>
<th>C100 (D 14mm)</th>
<th>C120 (D 20mm)</th>
<th>Water sensitivity</th>
<th>Rut depth (60°C-100 mm)</th>
<th>Stiffness modulus (15°C-10Hz)</th>
<th>Fatigue – admissible strain (@ 1 million de cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB Class 2</td>
<td>≤11</td>
<td>≥0.65</td>
<td>≤10**</td>
<td>≥9.000</td>
<td>≥90.10**</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CB Class 3</td>
<td>≤10</td>
<td>≥0.7</td>
<td>≤10**</td>
<td>≥9.000</td>
<td>≥90.10**</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CB Class 4</td>
<td>≤9</td>
<td>≥0.7</td>
<td>≤10**</td>
<td>≥11.000</td>
<td>≥100.10**</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EME Class 1</td>
<td>≤10</td>
<td>≥0.7</td>
<td>≤7.5**</td>
<td>≥14.000</td>
<td>≥100.10**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EME Class 2</td>
<td>≤8</td>
<td>≥0.75</td>
<td>≤7.5**</td>
<td>≥14.000</td>
<td>≥130.10**</td>
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</tr>
</tbody>
</table>

**Summary of mechanical properties used in pavement design**

- **Modulus E 15°C 10 Hz**
- **Fatigue ε 10°C 25 Hz**

**Volume composition**: voids content %

- **Surface or wearing course**
  - wear resistance in humidity conditions
  - rutting resistance
  - evolution of surface characteristics (texture)

- **Structure or base course** (thickness > 5 cm)
  - modulus properties
  - fatigue resistance
  - rutting behaviour

**Ranking of hot bituminous mixes**

**Properties determined in laboratory and some controls in place**

- **Volume composition**: voids content %
- **Performances**:
  - Surface or wearing course
    - wear resistance in humidity conditions
    - rutting resistance
    - evolution of surface characteristics (texture)
  - Structure or base course (thickness > 5 cm)
    - modulus properties
    - fatigue resistance
    - rutting behaviour

**Need for the study of laboratory**

Starting from components representative of the job site and in conformity with the standards of tests of mix design,

- It can be possible to have a **good control** on:
  - mix design,
  - manufacture,
  - preparation of the sample,

with the **accuracy** of the means of laboratory.

- method optimization of the mixture authorizes, with controlled parameter, it is thus **selective**.
- method is moreover **repeatable**,
- the given properties are **relevant** compared to those obtained on average on a well led job site,
- the specifications of the products taken as reference for the study are **realistic** compared to the behaviors awaited in place.

**Path lab to field?**

Assessment of link between lab to field:
- PCG
- Rutting test
- Modulus test
- Fatigue test

**Accuracy, Selectivity, Pertinence**

- **Classification in lab / Behavior in place**
- **Comparison between different lab**
  - Round robin test: repeatability, reproducibility
  - Tests in different labs
- **How can we determined specifications?**
GSC: dispersion in field (N7 Base)

- Preliminary study
- Correspondence: checking and average of field
- Low dispersion of workability: range max 5 to 9%

GSC: prediction voids % on field

- PCG 100 giration
- Field density (nuclear) GDF 6 cm
- Some order of magnitude GSC Field
- Dispersion field = 2 * GSC

GSC: lab – field - specifications

- PCG mobile
- Average density

Specific studies with LPC rutting test

- Correspondence lab-field (Dot Colorado -USA)
- Previous standardization tests studies
- Comparison rutting tester english-french
- Behaviour of different asphalt mixes in europe with LPC rutting tester
- Researches : correspondences lab-field
- Studies on fatigue test track in Nantes (Seattle)
- Research experience (mix design guide)

DOT Colorado study

- 33 job sites: crossing traffic, ambiance temperature

Results on sites

- With high temperature

Results on sites

- At moderated temperature
Results on sites
With low temperature

DOT Colorado study
ranging: behaviour site / LPC criteria

Rutting Prediction
Excellent correlation between rutting prevision with LPC equipment
and on job site, if taking into account: heavy traffic and temperature

Conclusion of Dot Colorado study

GSC-plate compactor
rutting: comparison field - lab

Influence of nature of bitumen
Comparison AC with or without Polymers

% de vides
% d'ornière

Sample from field
low relation
G SC-PC (high)
Rut : field < Lab
no significative
Rut: prediction with BB with bad rutting resistance.

Field more stable than in lab.
Range does not change.

Dispersion of complex modulus: example of results in place on motorway.

Low variability on each sample:
- Maximum 1300 MPa
- Minimum 80 MPa

Significant difference between each point.

Conclusions modulus lab/field:

- Average in field same order of magnitude as in lab.
- High dispersions of mechanical performances on field (20 to 30%)
  - Many determinations on field (20) to validate study.
- Lab study ESSENTIAL.
- Factors of influence: % voids and properties of bitumen reclaimed, explain the field dispersions.
Characterisation of AC polymers
Behaviour in fatigue with continue or discontinue constant deformation

<table>
<thead>
<tr>
<th></th>
<th>BB B</th>
<th>BB M</th>
<th>Dur</th>
<th>EMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>V %</td>
<td>5,2</td>
<td>2,9</td>
<td>3,8</td>
<td>5,1</td>
</tr>
<tr>
<td>Module (MPa)</td>
<td>8300</td>
<td>6800</td>
<td>13500</td>
<td>8200</td>
</tr>
</tbody>
</table>

Discontinue
pente x/y
147 ± 7
-5,3
237 ± 13
-7,5
133 ± 4
-5,3
130 ± 6
-5,3

Continue
pente
6,6
0,615
217 ± 6
-7,5
0,499
123 ± 4
-5,8
0,443
130 ± 6
-5,3

Field properties dispersion

✓ Range of dispersion:
  - GSC
  - Base mixes ± 2 à 2,5 points
  - Surface mixes ± 1 à 1,5 points
  - Modulus ± 20 à 30 %
  - Fatigue ± 10 à 15 %
✓ Rut : around 2 points with BB presented a good rutting resistance (< 5% 30000 cycles)

On job sites where the rules of fabrication and placement were corrected apply.

Conclusion

✓ Well-known well used by road technicians
✓ Free method to improve the quality in term of performances requirements, even for
  ✓ Road materials (innovative efforts, quality system,...)
  ✓ Road structures (allowable for private free variant, but same rules for all...)
✓ A good feed back with the job site
  ✓ Specifications : realistic, relevant,
  ✓ Statistical method : take into account variation due to construction, and dispersion of material, adjustment coefficient
✓ Method admitting by European standardization :
  ✓ road material mix design, laboratory characterization tests,
  ✓ in future : pavement design procedure (harmonization to do)

Thanks a lot for your attention