Performance Evaluation Of Composite Mixes Containing Rap Aggregates & Hydraulic Binder For Heavy Traffic Pavement
The RECYROUTE Project

IFSTTAR
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EIFFAGE Travaux Publics

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OUTLINE

• Introduction

• Materials: RCC mixes with fibers and RAP

• Laboratory characterisation & full scale test

• Calibration for pavement design & examples

• Conclusions

RCC: Roller Compacted Concrete
RAP: Reclaimed Asphalt Pavement
Introduction

• Traditional technique RCC is recently taken in consideration:
  – Use of RAP as aggregates
  – Improving mechanical properties by adding steel fibres

• French National Research Agency (ANR) project RECYROUTE
  Development of an innovative material FRCC® (Fiber reinforced Rolled Compacted Concrete) mixed with RAP as long lasting composite material for heavy traffic pavements (*continuous structure without joints*)

• 7 Partners: 4 publics
  3 privates

• Budget: 2.3 million €

RCC: Roller Compacted Concrete
RAP: Reclaimed Asphalt Pavement
## Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>FRCC Haut-Lieu (hard limestone)</th>
<th>FRCC Crain (soft limestone)</th>
<th>FRCC RAP</th>
<th>ERTALH (ref.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand 0/4</td>
<td>23%</td>
<td>23%</td>
<td>18%</td>
<td>-</td>
</tr>
<tr>
<td>Crushed Sand 0/6.3</td>
<td>35%</td>
<td>35%</td>
<td>-</td>
<td>25%</td>
</tr>
<tr>
<td>Gravel 6.3/14</td>
<td>30%</td>
<td>30%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAP 0/14</td>
<td>-</td>
<td>-</td>
<td>70%</td>
<td>70%</td>
</tr>
<tr>
<td>Hyd. binder</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>5%</td>
</tr>
<tr>
<td>Additive (Sika)</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>-</td>
</tr>
<tr>
<td>Water content</td>
<td>6.1%</td>
<td>6.1%</td>
<td>6.2%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Steel fibers</td>
<td>30kg/m³</td>
<td>30kg/m³</td>
<td>20kg/m³</td>
<td>-</td>
</tr>
</tbody>
</table>

ERTALH: RAP aggregate treated with hydraulic binder, 70% RAP and without fibers

Dramix RC-80/60-BN steel fibres

before/after compaction
Laboratory characterisation

<table>
<thead>
<tr>
<th>Tests</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength ($R_c$)</td>
<td>Classical mechanical properties for <strong>concrete materials</strong></td>
</tr>
<tr>
<td>Compressive Modulus ($E_c$)</td>
<td></td>
</tr>
<tr>
<td>Tensile Splitting Strength ($R_{it}$)</td>
<td></td>
</tr>
<tr>
<td>Complex stiffness modulus ($E'$)</td>
<td>Thermo-mechanical properties for <strong>materials containing RAP</strong></td>
</tr>
<tr>
<td>Fatigue resistance ($\sigma_6 &amp; b$)</td>
<td></td>
</tr>
</tbody>
</table>
Example of laboratory tests

- **Compressive Strength (MPa)**
  - Mixes: F0% (30), F40% (20), F80% (30), ERTALH
  - Standard deviation

- **Tensile Splitting Strength (MPa)**
  - Curing Time (days)

**FRCC mix:** \textbf{F}x\%\((yy)\)

\%RAP Fibres content \((kg/m^3)\)
Example of laboratory tests

**Fatigue test**

- Controlled force @ $f = 50$ Hz
- Controlled $T = 10^\circ$C

<table>
<thead>
<tr>
<th>Materials</th>
<th>$-1/b$</th>
<th>$\sigma_6$ (MPa)</th>
<th>$\sigma_6$ for design (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRCC RAP</td>
<td>12.4</td>
<td>2.50</td>
<td>1.75</td>
</tr>
<tr>
<td>ERTALH</td>
<td>12.4</td>
<td>1.17</td>
<td>0.82</td>
</tr>
</tbody>
</table>
Example of laboratory tests

\[ E^* = \frac{\sigma_0}{\varepsilon_{0ax}} e^{i\phi_{ax}} = |E^*| e^{i\phi_E} \]

\[ \sigma = F/S = \sigma_0 \cdot e^{i\phi_{ot}} \]
\[ \varepsilon_{ax} = \delta H/H = \varepsilon_{0ax} \cdot e^{i(\phi_{ot} + \phi_{ax})} \]
APT facility of the IFSTTAR

• Moving load in fatigue configuration: dual-wheel 65 kN
• Speed: up to 100 km/h (15 rounds/min.)
• Loading rate: up to 50 000 cycles/day

APT experiment

on selected formulations of FRCC & ERTALH

2.15 million heavy loads (mainly at 65 kN)

EME2: high modulus asphalt (French reference material for heavy traffic)
Calibration of design model based on fatigue criterion

For a hydraulic material:

\[ \sigma_{t,\text{max}} \leq \sigma_{t,\text{adm}} = \sigma_6 K_c K_d K_r K_s \times \left( \frac{\text{NE}}{10^6} \right) \]

- \( \sigma_{t,\text{max}} \): tensile stress (Alizé-LCPC)
- \( \sigma_{t,\text{adm}} \): admissible value
- \( \sigma_6 \): fatigue resistance (laboratory fatigue tests)
- \( K_c \): fatigue slope (laboratory fatigue tests)
- \( K_d \): traffic at considered time « t »
- \( K_r \): fatigue slope (laboratory fatigue tests)
- \( K_s \): coefficient of safety for low bearing capacity of subgrade (good bearing capacity \( \rightarrow K_s = 1 \))
- \( b \): coefficient of risk of failure, representing level of structural degradation of pavement at the considered time "t"
- \( \text{NE} \): coefficient of discontinuity
- \( \text{NE} \): coefficient of calibration: adjustment of model vs. real pavement performance, for rigid pavement \( K_c = 1.5 \)
- \( \frac{\text{NE}}{10^6} \): fatigue resistance (laboratory fatigue tests)

Two additional factors:
- Harmonization between APT results & Real Pavement \( \rightarrow K_{\text{harmonization}} \)
- Effect of hypothetic wide transverse cracking on FRCC pavement \( \rightarrow K_{\text{fiss}} \)
Examples of pavement design

Comparison FRCC & ERTALH with traditional solutions

For traffic of class TC5 (9.2 million in 30 years), on platform PF3 (E≥120 MPa)

<table>
<thead>
<tr>
<th>Traditional solutions</th>
<th>Thickness (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 BB / 21 GB3</td>
<td>29</td>
</tr>
<tr>
<td>2.5 BBTM / 19 EME2</td>
<td>21.5</td>
</tr>
<tr>
<td>19 BC5g / 15 BC2</td>
<td>26.5</td>
</tr>
<tr>
<td>2.5 BBTM / 15 BAC / 9 GB3</td>
<td>18</td>
</tr>
<tr>
<td>4 BB / 14 FRCC Ht-Lieu</td>
<td>20</td>
</tr>
<tr>
<td>4 BB / 16 FRCC Ht-Lieu</td>
<td>21</td>
</tr>
<tr>
<td>4 BB / 17 FRCC RAP</td>
<td>22</td>
</tr>
<tr>
<td>4 BB / 29 ERTALH</td>
<td>33</td>
</tr>
</tbody>
</table>

FRCC new
aggregates

FRCC RAP

**French Pavement Catalogue**

- BBTM: very thin bituminous surface layer and the normal one
- BB: dowelled concrete slabs
- BC5g: foundation lean concrete
- BC2: continuously reinforced concrete pavement (CRCP)
- BAC: base asphalt concrete
- GB3: composite structures
- EME2: FRCC new aggregates
- FRCC Ht-Lieu
- FRCC RAP
- ERTALH

For traffic of class TC5 (9.2 million in 30 years), on platform PF3 (E≥120 MPa)
Conclusions

• Lab tests showed that the mechanical properties of both FRCC and ERTALH decrease (Rc, Rt, E*, σ₆) with high RAP content. Viscous properties are observed as well.

• Full-scale pavement structures were constructed and tested under heavy loads of the IFSTTAR traffic simulator. This APT test showed encouraging behavior of FRCC™ structures, despite low thicknesses of materials used in the base layer (12-15cm) and good behavior for the ref. ERTALH® in 20cm.

• Pavement design of FRCC structures shows similar thickness to high modulus asphalt pavement (EME2) used in France, but significant reduction of thickness compared to classical bituminous pavement (GB3) and concrete pavement structures as well.

• Perspectives: heavy duty pavements (harbors or industrial platforms)
Thank you for your attention!

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