Energy Sustainable Bituminous Mixes

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Variables that most influence Energy Consumption during the manufacturing and compacting processes of bituminous mixes

Mixes with the same Mechanical Properties than conventional mixes

- Static test: Sensitivity to water
- Dynamic test: Stiffness modulus
VARIABLES ANALYZED

- **Mix gradation:** AC 22, AC 16, and SMA 8
- **Bitumen type:** B-60/70 and B-13/22
- **Bitumen contents:** 4.6% - 5.5% w/m, in a range of 0.3%
- **Tensoactives at different temperatures:** 160°C, 140°C and 120°C
  - **T1** (pellets): 3.0 % w/b
  - **T2** (viscous liquid): 0.3 % w/b
- **Aggregate nature, form and roughness:** crushed (ophite and limestone) and *rounded aggregates.*
MIX GRADATION

AC22: B-60/70 & B-13/22
AC16: B-60/70

SMA 8: B-60/70 + Cellulose Fibers (0.3% w/m)

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<table>
<thead>
<tr>
<th>N° Mixture</th>
<th>Bitumen</th>
<th>AGGREGATES</th>
<th>Rounded aggregate content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type</td>
<td>Sieve Size (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22-11.5</td>
<td>11.5-8</td>
<td>8-4</td>
</tr>
<tr>
<td>M₁</td>
<td>60/70</td>
<td>Crushed</td>
<td>Crushed</td>
</tr>
<tr>
<td>M₂</td>
<td>13/22</td>
<td>Crushed</td>
<td>Crushed</td>
</tr>
<tr>
<td>M₃</td>
<td>60/70</td>
<td>Rounded</td>
<td>Rounded</td>
</tr>
<tr>
<td>M₄</td>
<td>13/22</td>
<td>Crushed</td>
<td>Crushed</td>
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<td>Crushed</td>
<td>Crushed</td>
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<tr>
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<td>13/22</td>
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</tr>
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<td>M₈</td>
<td>13/22</td>
<td>Crushed</td>
<td>Crushed</td>
</tr>
<tr>
<td>M₉</td>
<td>60/70</td>
<td>Crushed</td>
<td>Crushed</td>
</tr>
<tr>
<td>M₁₀</td>
<td>13/22</td>
<td>Crushed</td>
<td>Crushed</td>
</tr>
</tbody>
</table>
1. Energy consumption during manufacture

2. Analysis of the ease of compaction with the gyratory compactor

3. Mechanical behaviour
   - Sensitivity to water
   - Stiffness modulus
Energy Consumption

1. ENERGY CONSUMPTION DURING MANUFACTURE

\[ E_{\text{manufacture}} = E_{\text{aggregate}} + E_{\text{bitumen}} + E_{\text{water}} + E_{\text{coating}} \]

- **Time:** 180 seconds of mixing
- **3,600 grams of mix**
INFLUENCE OF MIX GRADATION

- Types of gradation: **SMA 8** (6.3% w/m) and **AC16** (4.85% w/m)
- Manufacture temperature: **160°C**

### Influence of gradation

![Graph showing the influence of gradation](image)

**Energy Consumption during Manufacture**

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1. ENERGY CONSUMPTION DURING MANUFACTURE

INFLUENCE OF TEMPERATURE AND ADDITIVES

- Bituminous mix: **AC16 B-60/70** (reference)
- Two tensoactive additives:
  - **T1** (adhesion agent, polymers and resin): 3.0% w/b
  - **T2** (adhesion agents): 0.3% w/b
- Temperatures: 160°C, 140°C and 120°C
1. ENERGY CONSUMPTION DURING MANUFACTURE

INFLUENCE OF TEMPERATURE AND ADDITIVES

- **Reference Mix**: consumption at 160°C was lower than at 140°C and 120°C.
1. ENERGY CONSUMPTION DURING MANUFACTURE

INFLUENCE OF TEMPERATURE AND ADDITIVES

With **both additives**, mixes made at **120°C** consumed less energy during the manufacture process.
1. ENERGY CONSUMPTION DURING MANUFACTURE

INFLUENCE OF AGGREGATE NATURE AND BITUMEN

- Type of mix: AC22
  - Mixes M1-M10
- Manufacture temperature: 160°C
- 4 percentages of bitumen B-60/70 and B-13/22
  - From 4.6% to 5.5 % w/m in range of 0.3%
The use of *rounded aggregates* decrease the energy consumption.
1. ENERGY CONSUMPTION DURING MANUFACTURE

INFLUENCE OF BITUMEN CONTENT

When % bitumen increased the energy consumption is reduced in all mixes.

Mixes with B-60/70 consumed less energy than those with B-13/22.
2. DETERMINATION OF THE EASE OF COMPACTION

**Shear Effort** \((kN/m^2)\) and **Density** \((kg/m^3)\)

EN 12697-31: \(P_{\text{vertical}} = 600\) kPa, \(\alpha = 0.82^\circ\), \(w = 30\) r.p.m.

N = 200 cycles
EN 12697-10: Compactability Factor (K)

Self-compaction ($V_1$)

$V_i = -K \cdot \ln(N) + V_1$

$V_i = -4.09 \ln(N) + 25.00$

$R^2 = 0.994$
2. DETERMINATION OF THE EASE OF COMPACTION

INFLUENCE OF MIX GRADATION

- Types of gradation: SMA 8 (6.3% w/m) and AC16 (4.85% w/m)
- Compaction temperature: 160°C

<table>
<thead>
<tr>
<th>Type of Mix</th>
<th>$V_1$ (real)</th>
<th>Equation</th>
<th>$K$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC16</td>
<td>25.3</td>
<td>$V = -3.01 \ln(N) + 26.1$</td>
<td>3.01</td>
<td>0.997</td>
</tr>
<tr>
<td>SMA 8</td>
<td>24.1</td>
<td>$V = -3.32 \ln(N) + 25.1$</td>
<td>3.32</td>
<td>0.996</td>
</tr>
</tbody>
</table>
**2. DETERMINATION OF THE EASE OF COMPACTION**

**INFLUENCE OF TEMPERATURE AND ADDITIVES**

- **T1** presented **higher values** of **K factor** compared to Reference mix.
- **T2** presented a **similar compactability behaviour** than the Reference mix.

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**K factor-Temperature of compaction**

- **Reference**
- **Additive T1**
- **Additive T2**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Reference</th>
<th>Additive T1</th>
<th>Additive T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>160°C</td>
<td>3.10</td>
<td>3.30</td>
<td>2.90</td>
</tr>
<tr>
<td>140°C</td>
<td>3.00</td>
<td>3.20</td>
<td>2.80</td>
</tr>
<tr>
<td>120°C</td>
<td>2.90</td>
<td>2.70</td>
<td>2.60</td>
</tr>
</tbody>
</table>

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2. DETERMINATION OF THE EASE OF COMPACTION

INFLUENCE OF AGGREGATE NATURE

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\[ V_i = -3.91 \ln(N) + 23.51 \]
\[ R^2 = 0.996 \]

\[ V_i = -3.99 \ln(N) + 23.40 \]
\[ R^2 = 0.997 \]

\[ V_1 = 25.92 \]

\[ V_1 = 14.17 \]
2. DETERMINATION OF THE EASE OF COMPACTION

INFLUENCE OF AGGREGATE NATURE

\[ V_i = -2.81 \ln(N) + 15.80 \]
\[ R^2 = 0.992 \]

\[ V_i = -3.58 \ln(N) + 22.00 \]
\[ R^2 = 0.996 \]

Shear Effort (kN/m²) vs. Nº Cycles (N) for M3 (92.5%) and M1 (0%)
INFLUENCE OF AGGREGATE NATURE

Representation of **shear effort** depending on the number of cycles.

- **Mix M3**
- **Mix M1**

Drop of the shear effort ➔ 98% maximum theoretical density
Representation of **accumulated shear effort** (area accumulated under the curve of the previous curve) opposite to **percentage of compaction** (% Gmm).
Comparison of the ease of compaction of mixes manufactured with different percentages of rounded aggregates.

![Bar graph showing comparison of compaction ease for different mixtures.](chart.png)

- **B-60/70**
- **B-13/22**
Adhesivity between binder and aggregates.

**Spanish Standards (PG-3):**

\[
\text{ITSR (\%)} = \frac{\text{ITSw}}{\text{ITSD}}
\]

- **ITSR (\%)**
  - Surface layer: 85%
  - Bin/Base layers: 80%

Pre-treatment: Vacuum machine (50 mm Hg)

Static Machine
TENSOACTIVE AND TEMPERATURE INFLUENCE (AC16 B-60/70)

- **Reference mix**: 160°C fulfilled the Spanish Standard (85%), but not at 140°C and 120°C (~ 50%)

- **Additivated mixes**: at 160°C and 140°C, with both additives carried out the standard (80%), but at 120°C only the additive T1 fulfilled the norm.

AGGREGATE INFLUENCE (AC22 B-60/70 and B-13/22)

- Satisfied the specifications contained in the article 542 of the PG-3.
3. Mechanical Behaviour

STIFFNESS (EN 12697-26: Annex C. Indirect Traction)

EN 12697-26: Temperature: 20°C; Applied load time = 124ms

\[ S_m = \frac{F \times (v + 0.27)}{(z \times h)} \]

The type of binder has more influence than the nature of aggregates.

[Graph showing influence of aggregate nature and bitumen type]
CONCLUSIONS I

Variables that reduce the Manufacture energy consumption

- MIX GRADATION: **AC16** needed lower energy than SMA

- ADDITIVES: the energy consumption at 120 °C was lower than Reference mix at 160°C.

- AGGREGATE NATURE: mixes manufactured with *rounded aggregates* improves the mixing process in relation to mixes with crushed aggregates.

- TYPE AND PERCENTAGE OF BITUMEN: the use of *soft bitumens (B-60/70)* and high percentages reduce the manufacture energy consumption.
Ease of Compaction

Analyzing the factor K: mixes with similar initial air voids

- **MIX GRADATION:** *Discountinous mixtures* are more easily compacted than continuous.

- **ADDITIVES:** At all the temperatures, the use of additive T1 *eases* the compaction process.

Analyzing the area accumulated under the shear effort curve

- **AGGREGATE NATURE:** mixes manufactured with *rounded aggregates* are more workable and easier to compact than those manufactured with crushed aggregate.

- **TYPE AND PERCENTAGE OF BITUMEN:** the use of *soft bitumen (B-60/70)* and higher percentages reduce the shear effort required to compact the mixtures.
Mechanical behavior of the mixes

**Sensitivity to water**

- All mixes (AC22 and AC16) made at 160°C satisfied the Spanish Standard (80-85%).
- The sensitivity to water is improved using both additives at each temperature.

**Stiffness modulus**

- The type of binder had more influence than the nature of the aggregates. The plastic deformations of mixes with rounded aggregates can be removed using harder bitumens.
- AC22 produced with B-13/22 satisfied the specifications marked on the PG-3 (11,000 MPa).
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THANK YOU FOR YOUR ATTENTION

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