Promoting induction heating asphalt mixes
HEALROAD

Part: 1-1 – HEALROAD laboratory research
Part: 1-2 – Full-scale demonstrator
Part: 2 – Onsite visit to duraBASt and HEALROAD demonstration
## Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 9:15</td>
<td>Introduction</td>
</tr>
<tr>
<td>9:15 – 10:00</td>
<td>HEALROAD laboratory research (mixes and induction energy) - UC and UoN</td>
</tr>
<tr>
<td>10:00 – 10:30</td>
<td>Full scale demonstrator (asphalt production, construction and accelerated pavement testing) - SGS, HEIJMANS and BASt</td>
</tr>
<tr>
<td>10:30 – 12:00</td>
<td>Onsite visit to duraBASSt facility and HEALROAD demonstration*</td>
</tr>
</tbody>
</table>
Background / Concept of self-healing

- Asphalt mixture is a natural self-healing material. When a crack is open in the road structure, it can close (heal) when enough temperature and time without traffic are provided.

- However, this process requires days for a complete healing, which in practice is impossible due to continual traffic flow.

- Self-healing of asphalt mixes can be accelerated by means of induction heating, a technique used to increase the temperature of electrically conductive and magnetic susceptible materials.

Source: A.García (UoN)
**Aggregates or bitumen do not directly heat via induction heating.**

Induction heating

- Coil
- Alternating electric field
- Induced currents
- Asphalt concrete
- Road surface

Bitumen
Conductive material

Opening of microcracks

Melted bitumen

Aggregates
Micro-crack
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HEALROAD: Problems addressed

• Temperature at which optimal self-healing is obtained.
• When to apply self-healing?
• Quantification of service life extension
• Adequate use of the induction healing device (parameters).
• Impact of aging in healing performance
• Quantification of the energy needed.
• Solve the clusters when upscaling.
The overall objective of the project is the further development and the technical, economic and environmental validation of healable asphalt mixes via induction heating to overcome the technical barriers for the future industrialization and market uptake.
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Consortium / partners

- PROJECT COORDINATOR
  UNIVERSIDAD DE CANTABRIA (UC)

- EUROPEAN UNION ROAD FEDERATION (ERF)

- UNIVERSITY OF NOTTINGHAM (UoN)

- HEUMANS INFRA B.V. (HEIJMANS)

- BUNDESANSTALT FÜR STRAẞENWESEN (BAST)

- SGS INTRON B.V. (SGS)

October 26th 2017
Scientific & Technical Objectives

1. **Understand** the main **chemical and rheological factors** influencing the movement of bitumen through cracks in order to identify the most suitable bitumen for this application.

2. **Optimize** from the technical, economic and environmental point of view the parameters that most influence the induction heating of the asphalt mixture: **magnetic material and air voids**.

3. **Optimal design of asphalt mixes** from the healing capacity and durability point of view.

4. **Ensure the recyclability** of the HEALROAD mixes by defining the amount of virgin material needed to restore the asphalt mixture properties, including its healing capacity.

5. **Scaling up the production** of HEALROAD mixes in a real asphalt plant.
6. **Demonstration** of the solution proposed:
   - Demonstrating the healing capacity of a real scale test section through and **Accelerated Pavement Testing**.
   - Economic and environmental feasibility through a **LCA and LCC analysis**.
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Expected **results and impacts**

- INCREASED DURABILITY
- LESS INTRUSIVE MAINTENANCE
- RECYCLABLE
- SAME PRODUCTION PROCESS
- 100% APPLICABILITY
- Cost efficiency
- Resource efficiency
- Accessibility and reliability
- Reduction of GHG emissions
- Competitiveness

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Part: 1-1 – HEALROAD laboratory research
Induction heating technique to increase road durability and reduce maintenance costs and disruptions.

Breixo Gómez Meijide
Type of bitumen
### Fundamental analysis

<table>
<thead>
<tr>
<th>Bitumen type</th>
<th>P49</th>
<th>S46</th>
<th>S70</th>
<th>T44</th>
<th>T73</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface tension [mJ·m⁻²]</strong></td>
<td>25.5</td>
<td>24.5</td>
<td>24.7</td>
<td>23.2</td>
<td>24.5</td>
</tr>
<tr>
<td><strong>Density at 25 °C [kg·m⁻³]</strong></td>
<td>1025</td>
<td>1034</td>
<td>1020</td>
<td>1026</td>
<td>1020</td>
</tr>
<tr>
<td><strong>Volumetric thermal expansion coefficient [10⁻⁴ K⁻¹]</strong></td>
<td>6.12</td>
<td>6.64</td>
<td>6.69</td>
<td>6.14</td>
<td>6.30</td>
</tr>
<tr>
<td><strong>Viscosity at 100 °C [Pa s]</strong></td>
<td>3.93</td>
<td>2.87</td>
<td>2.00</td>
<td>3.90</td>
<td>2.36</td>
</tr>
<tr>
<td><strong>Saturate content [%]</strong></td>
<td>4.9 ± 0.2</td>
<td>4.7 ± 0.2</td>
<td>5.3 ± 0.2</td>
<td>4.9 ± 0.2</td>
<td>4.1 ± 0.2</td>
</tr>
<tr>
<td><strong>Aromatic content [%]</strong></td>
<td>41.8 ± 1.4</td>
<td>43.2 ± 1.5</td>
<td>43.3 ± 1.8</td>
<td>43.3 ± 1.8</td>
<td>51.1 ± 2.1</td>
</tr>
<tr>
<td><strong>Resin content [%]</strong></td>
<td>35.6 ± 1.3</td>
<td>35.9 ± 1.3</td>
<td>37.7 ± 2.0</td>
<td>36.1 ± 1.5</td>
<td>33.1 ± 1.6</td>
</tr>
<tr>
<td><strong>Asphaltene content [%]</strong></td>
<td>15.8 ± 0.4</td>
<td>15.8 ± 0.6</td>
<td>13.7 ± 0.3</td>
<td>15.5 ± 0.6</td>
<td>11.0 ± 0.4</td>
</tr>
<tr>
<td><strong>Wax content [%]</strong></td>
<td>0.5</td>
<td>1.7</td>
<td>3.6</td>
<td>2.2</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>MMHC [-]</strong></td>
<td>2.203</td>
<td>2.214</td>
<td>2.197</td>
<td>2.203</td>
<td>2.203</td>
</tr>
</tbody>
</table>
Fundamental analysis

\[ \frac{F_f}{F_i} = HR(\%) \]
\[ \tau(t) = \tau_h(t_{\text{heat}}) + \tau_c(t_{\text{heat}}) \]

\[ \tau_h(t) = T_{ss} \cdot t + \frac{T_{ss} - T_{air}}{k_h} (e^{-k_h t} - 1) \quad ; \quad t < t_{\text{heat}} \]

\[ \tau_c(t) = T_{air} \cdot (t - t_{\text{heat}}) + \frac{T_{\text{max}} - T_{air}}{k_c} (1 - e^{-k_c(t-t_{\text{heat}})}) \quad ; \quad t > t_{\text{heat}} \]
Fundamental analysis

Healing rate \( (C_1) \)

\[ S(\tau) = \frac{C_1}{F_0} \cdot e^{-D\tau} \left( -1 + e^{\frac{D\tau}{\tau_c}} \right)^2 \]

- Real data infrared

Critical energy \( (\tau_c) \) that triggers healing process
Type of bitumen

- Penetration grade
- Viscosity
- Density
- Thermal expansion
- Fractional distribution (SARA)
- Attenuated Total Reflection Fourier Transformed Infrared Spectroscopy
- Capillary tests

No significant correlation with any of these factors for the studied types of bitumen
Type of bitumen

- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

Healing Ratio (%)

- Israel 40/60
- Total 40/60
- Shell 50/70
- Total 70/100
- Shell 70/100

Healing Energy (K·S)
Heating method
Heating method

**Critical energy ($\tau_c$) that triggers healing process**

Induction method faster and more energy efficient
Heating method

There is a minimum temperature required for an effective and efficient healing

Critical energy ($\tau_c$) that triggers healing process

Heating ratio (%) vs $\tau$ (K-s)

- Induction
- Inf-70cm
- Inf-30cm
- Inf-110cm
Heating method

- **Steady-state temperature**
- **Decreasing healing**
Heating method

There is an optimum heating time
Types of conductive particles
Type of conductive particles

Reductions in economic and environmental impact through the use of metal waste
Type of conductive particles

- Grit
- Wool
- Tyre
- Shavings
<table>
<thead>
<tr>
<th>Volumetric properties</th>
<th>Type of fibre</th>
<th>Grit</th>
<th>Wool</th>
<th>Tyre</th>
<th>Shavings</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Density</td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>- Air voids</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>- Homogeneity of mix</td>
<td></td>
<td>●</td>
<td>●</td>
<td>▼</td>
<td>●</td>
</tr>
<tr>
<td>- Indirect tensile strength</td>
<td></td>
<td>▲▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>- Resistance to water damage</td>
<td></td>
<td>▼▼</td>
<td>▼</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Stiffness modulus</td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>- Particle loss resistance</td>
<td></td>
<td>▼</td>
<td>●</td>
<td>▼</td>
<td>●</td>
</tr>
<tr>
<td>- Skid resistance</td>
<td></td>
<td>▲▲</td>
<td>▲</td>
<td>▲▲</td>
<td>▲</td>
</tr>
<tr>
<td>Healing properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Induction heating capacity</td>
<td></td>
<td>▲▲</td>
<td>▲▲</td>
<td>▲▲</td>
<td>▲</td>
</tr>
<tr>
<td>- Self-healing properties</td>
<td></td>
<td>▲▲▲</td>
<td>▲▲</td>
<td>▲▲</td>
<td>▲</td>
</tr>
</tbody>
</table>

▲ Increase ▼ Decrease ● No significant effect (x1 – Slight effect; x2 – Moderate effect; x3 – Strong effect)

*Due to test configuration, results in real roads are expected to be better than those observed in the present investigation.
Aging and RAP content
## Aging and RAP content

<table>
<thead>
<tr>
<th>Mix</th>
<th>RAP content in mix (%)</th>
<th>Ageing after compaction (days)</th>
<th>New road (control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>New road (control)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>3</td>
<td>Effect of ageing process during the service life of the road</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>0</td>
<td>Effect of mixing aged material</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>0</td>
<td>(RAP) with new material for a new road</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Aging and RAP content

Great effect first days
Aging and RAP content

Days in oven at 85°C

Density (t/m³)

0  3  6  9  12  15

RAP effect
Aging effect

RAP content (%)

Healing Ratio (%)

Healing energy (K·s)

- 26.5%
- 20.4%
- 13.2%
- 4.5%
- 0.5%
Aging and RAP content
Fatigue life
Fatigue life

![Fatigue life diagram]

- **Induction**
- **Infrared-30cm**
- **Infrared-70cm**
- **Infrared-110cm**
### Fatigue life

| Size (mm) | 31.5 | 20 | 16 | 14 | 10 | 8 | 6.3 | 4 | 2.8 | 2 | 1 | 0.5 | 0.25 | 0.125 | 0.063 |
|----------|------|----|----|----|----|---|-----|---|-----|---|---|----|------|-------|-------|------|
| % Passin| 100  | 99.1| 91.3| 83.3| 62 | 54.1| 47.8| 34.3| 28.7| 23.7|17 | 12.9| 10.2 | 8.1 | 6.5 |
| % Passin| 100  | 99.1| 91.2| 82.9| 58.8| 48.7| 40.7| 29.5| 25  | 20.8|15 | 11.3| 9.1  | 7.2 | 5.7 |
| % Passin| 100  | 99.1| 91.2| 82.9| 58.8| 48.7| 40.7| 29.5| 25  | 20.8|15 | 11.3| 9.1  | 7.2 | 5.7 |
| % Passin| 100  | 99.1| 99.1| 99.1| 88.1| 88.1| 88.1| 81.4| 81.4| 81.4|78 | 53.4| 25.4 | 5.1 | 4.1 |
| % Passin| 100  | 100 | 100 | 100 | 78.2| 78.2| 78.2| 74  | 74  | 74  |68 | 27.6| 13.5 | 3.5 | 2.9 |

#### Weibull Distribution
- **Number of cycles with 50% probability of breaking**
- **Cumulative deformation**

#### Bitumen
- 4.7% 4.5% 4.2% 3.3% 2.7%

#### Air voids
- 5% 10% 13% 21% 26%

### Weibull Distribution
- **Number of cycles (N)**
- **Reference sample**
- **Heated sample**

### Cumulative deformation
- **Thermal treatment**
- **Extrusion of service life**

### HI

\[ HI = \frac{N_f - N_{0.5}}{N_{0.5}} \]
Fatigue life

- Healing index vs. Number of cycles (N)
- Optimum cracks size (Maximum HI)
- Cracks too small vs. Cracks too wide
- \( N_{opt} \)
Fatigue life

\[ y = 6118.2e^{-0.144x} \]

\[ R^2 = 0.8922 \]

<table>
<thead>
<tr>
<th>Air void content (%)</th>
<th>Fatigue life without thermal heating ( N_{0.5} )</th>
<th>Longest fatigue life with thermal treatment</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>21160</td>
<td>30218</td>
<td>42.8%</td>
</tr>
<tr>
<td>10%</td>
<td>11440</td>
<td>15419</td>
<td>34.8%</td>
</tr>
<tr>
<td>13%</td>
<td>2120</td>
<td>4657</td>
<td>119.7%</td>
</tr>
<tr>
<td>21%</td>
<td>1200</td>
<td>3333</td>
<td>177.8%</td>
</tr>
<tr>
<td>26%</td>
<td>227</td>
<td>721</td>
<td>217%</td>
</tr>
</tbody>
</table>
Fatigue life

![Graph showing healing index vs. number of cycles and deformation vs. temperature](https://via.placeholder.com/150)

- 110 cm - 51°C
- 70 cm - 71°C
- 30 cm - 93°C
Fatigue life

Dense

Porous
Fatigue life

Increasing air voids content

Low air voids content $\chi >> 0$

Air voids close to percolation $\chi > 0$

Percolated air voids $\chi < 0$

Percolation threshold

Euler number
**Fatigue life**

**Dense asphalt**
- Aggregate
- Crack
- Heating
- Healed crack

Dense sample damaged

When sample is heated, bitumen flows through cracks

If sample is overheated, bitumen expands increasing interstitial space

**Porous asphalt**
- Air
- Crack
- Heating
- Healed crack

Porous sample damaged

When sample is heated, bitumen flows through cracks

If sample is overheated, bitumen expands filling air voids
Thank you

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Part: 1-2 – Full-scale demonstrator

October 26th 2017
Part 1-2 - **Agenda**

- full-scale Asphalt production (Task 5.1)

- test-section on duraBASSt (Task 5.2)
  - construction
  - testing
  - healing

- evaluation process and LCA/LCCA are not presented during this event
Part 1-2 - **Mix design and testing**

1. The Healroad mixtures, developed by Cantabria University UC, are translated by Heijmans to Dutch raw materials
   - volumetric approach / high density of steel particles
   - results showed the required Type Test properties
2. Ravelling test at the PA variant: Rotating Surface Abrasion test (RSAT)
Part 1-2 - **Full-scale Asphalt production (Task 5.1)**

- Determining the correct mixing procedure in a asphalt production plant

Several mixing-variants, produced in an asphalt plant → mechanical tests

→ No special and exceptional procedures are needed to produce the Healroad mixtures
→ Standard production plant is suitable with the usual way of adding additives
→ Positive factor for the introduction of Healroad mixes in the European asphalt market
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Part 1-2 - **test section** on duraBASSt
Part 1-2 - **Construction test-section on duraBASSt** (Task 5.2)

- Transport to duraBASSt, laying and compaction

→ Special attention to temperature (no segregation) / compaction in the correct window
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Part 1-2 - **test section** on duraBASt

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**October 26th 2017**

**Slide 53**
Part 1-2 - **test section** on duraBAST

- failure criteria = stone loss

- HEIJMANS laboratory test with RSAT
  - 5 samples – laboratory production
  - 5 samples – duraBAST production

- BASSt will use two loading points
  - first loading point = reference track
    - no healing at all six samples
    - surface observation (pictures)
  - second loading point
    - no healing at two samples
    - healing on four samples different moments
Part 1-2 - test section on duraBASSt

- Accelerated Pavement Testing (APT)
  - Mobile Load Simulator MLS30
    - Super-Single (9.0 bar)
      - 4 loading wheels in closed chain
    - load = 75 kN
      - speed = 7 km/h = 2000 Ü/h
    - lateral unite
      - ±350 mm left and right
        (one whole program need approx. 12min)
Part 1-2 - **test section** on duraBASSt

- loading cycles and healing actions

**HR1: 150000 loading cycles =100%**
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Part 1-2 - **test section** on duraBAS
t

- Details to Induction machine
  - 1400 Volt
  - 312 kHz
  - 33 Ampere
  - Energy 7-7.5 kW
  - 40 cm Coil (2 pieces)
  - Condensators:
    - 4 x 0.33 µF
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Part 1 - 2 - **test section** on duraBASt
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Part: 2 – Onsite visit to duraBASt and HEALROAD demonstration

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Part 2 - **Onsite visit** to duraBASt and HEALROAD demonstration

duraBASt – outdoor test area
demonstration, investigation (**Untersuchung**), reference **areal**

investigation areal
APT (MLS30) and non-destructive test methods

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