8th Rilem International Conference on Mechanisms of Cracking and Debonding in Pavements (MCD2016)

Workshop: **Recent progress in Digital Image Correlation: towards integrated identification?**

Practical Experiences with DIC in Asphalt Technology

Moisés BUENO (Empa, Switzerland)
Swiss Federal Laboratories for Materials Science and Technology
Road Engineering and Sealing Components Laboratory

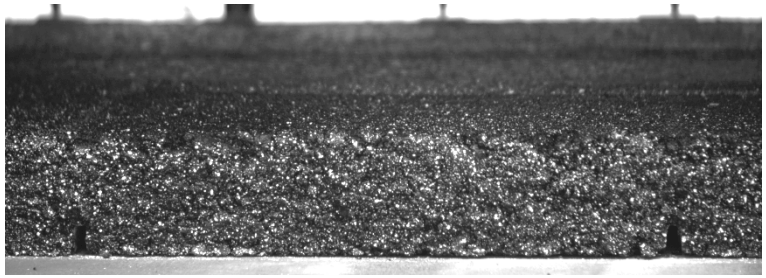
Nantes, June, 9 - 2016

Outline

1. **Digital Image Correlation System**
   - Technical Data
2. **Applications at Empa**
   - Asphalt Mixtures
   - Bridge Expansion Joints
   - Waterproofing Bituminous Membranes
3. **Crack Detection and Induction Healing**
   - Induction Healing of Asphalt Roads
   - 1:3 scale: Model Mobile Load Simulator (MMLS3)
4. **Conclusions**
5. **Future Challenges**

DIC – Technical Data

LIMESS Messtechnik & Software GmbH



- ✓ 2 x 5.0 Mega Pixel CCD Cameras, monochrome
- ✓ Field of view (**FOV**): 2500 x 2000 Pixel
- ✓ 15Hz with full resolution, higher framerate possible with FOV reduction
- ✓ Minimum exposure time: 25ms
- ✓ Precision lenses with focal distance of 8mm and 35mm
- ✓ Timing Hub for synchronisation of the cameras
- ✓ Software **ISTRA 4D**
- ✓ Range of measurement: 10mm^2 to 10m^2
- ✓ **Displacement resolution** approximately 0.01 pixel
- ✓ Measurement **accuracy** in the range of 1/100'000 of the FOV

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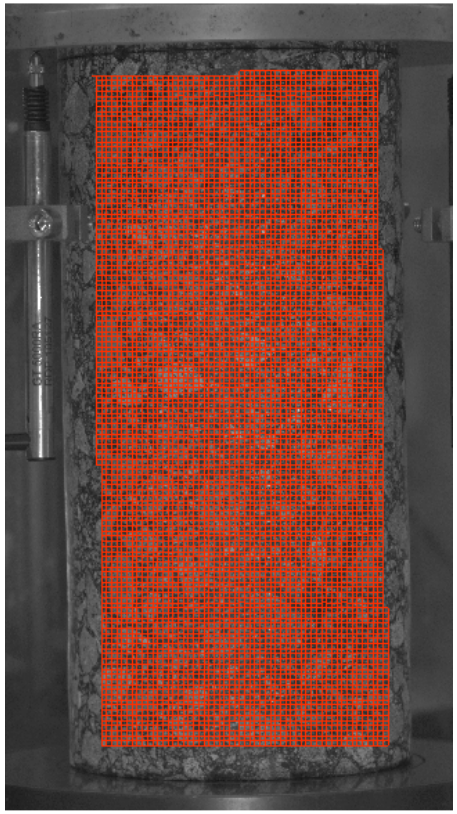
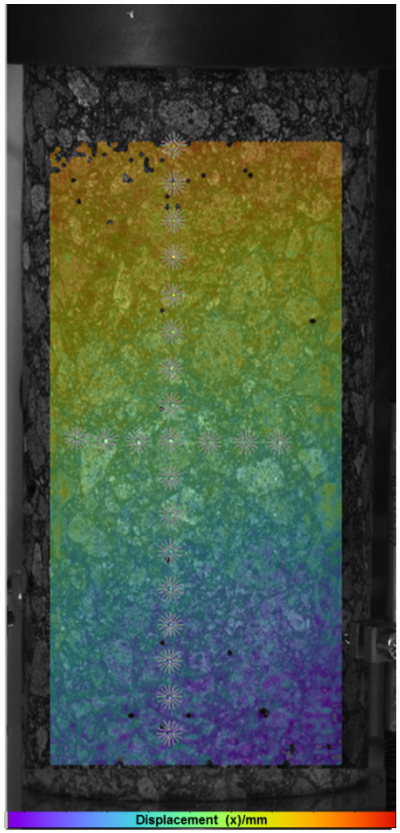
Asphalt Mixtures

Cyclic Load Triaxial Test

Measurement Grid



Parameters 1 Hz // 3.0 MPa
Axial Displacement (step480)



3Dim experimental investigation of linear viscoelastic properties of bituminous mixtures.
Materials and Structures (DOI 10.1617/s11527-016-0827-3) RILEM TC 237-SIB, TG3 (Lily Poulikakos - Empa)

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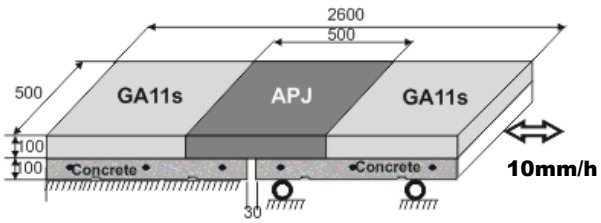
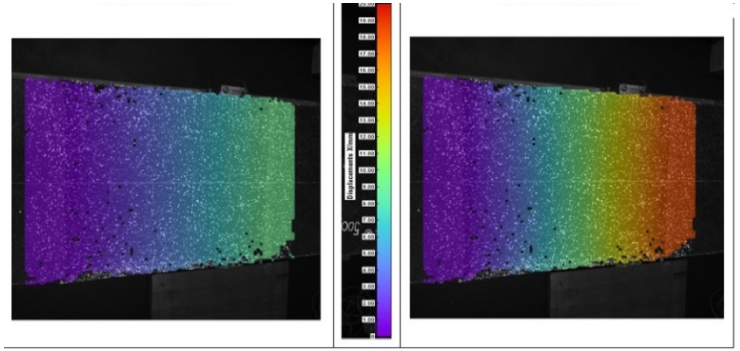
Materials Science and Technology

Bridge Expansion Joints

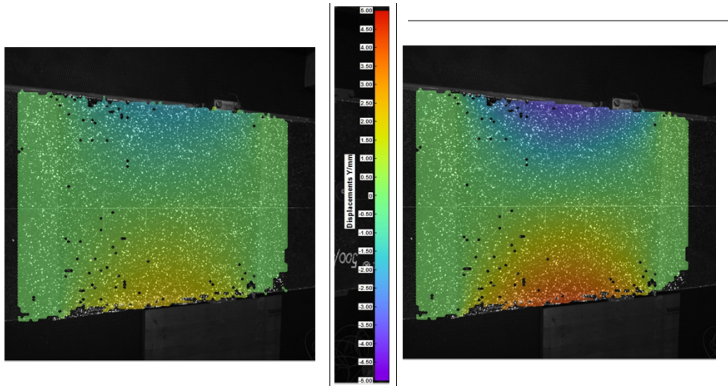
Bituminous Flexible Plug Expansion Joint



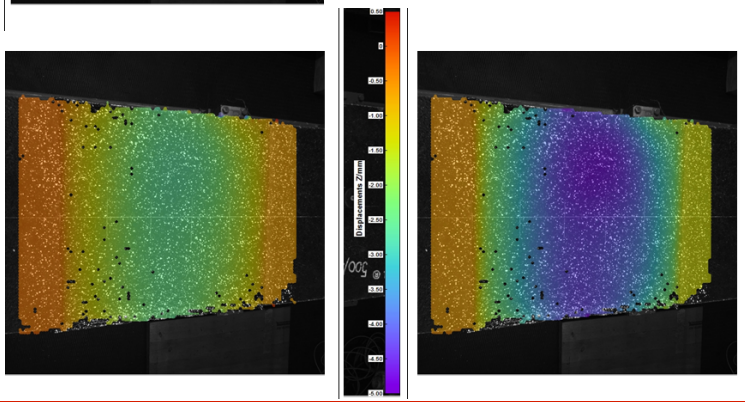
Displacement x
@ 10 mm and 19.5 mm



Displacement y
@ 10 mm and 19.5 mm



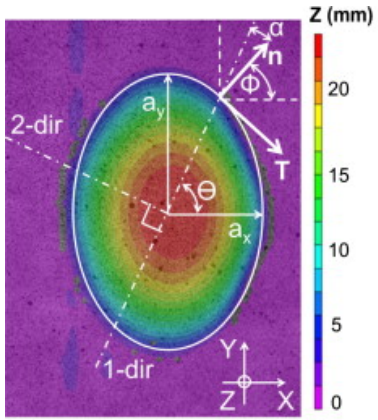
Displacement z
@ 10 mm and 19.5 mm

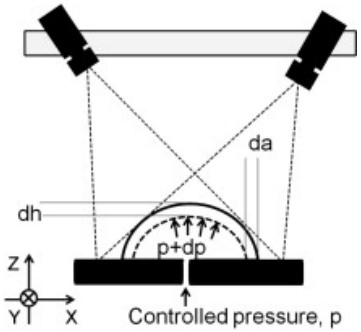


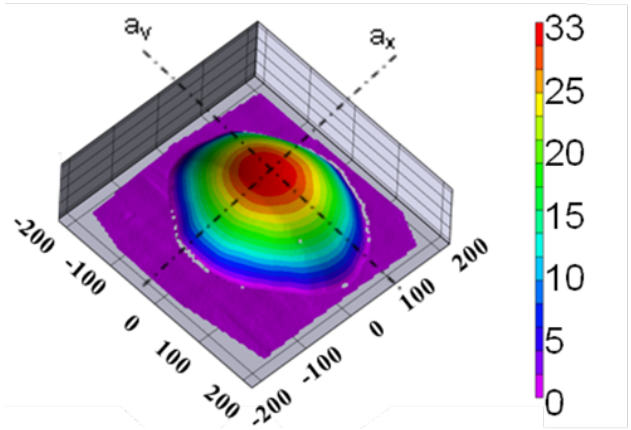
KTI Projekt: *Entwicklung einer neuen Generation von flexiblen Fahrbahnübergängenfür Brücken*
Sivotha Hean (Empa)

Blisters formation on Concrete Bridge Decks with Waterproofing Asphalt Pavement Systems

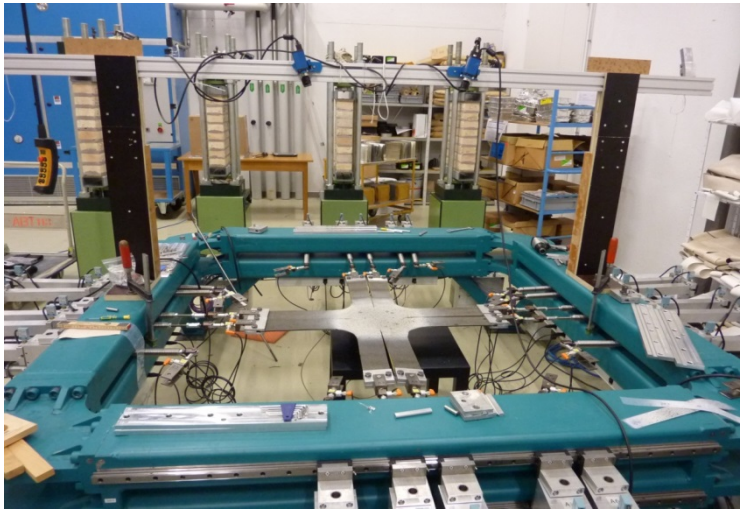
Determination of blister propagation

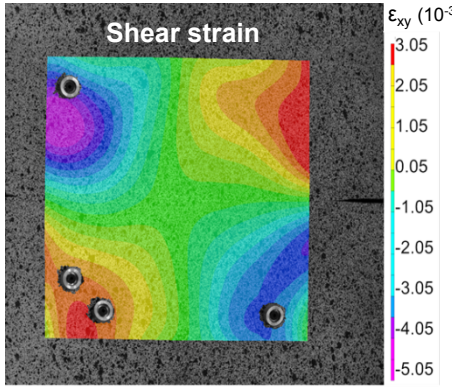




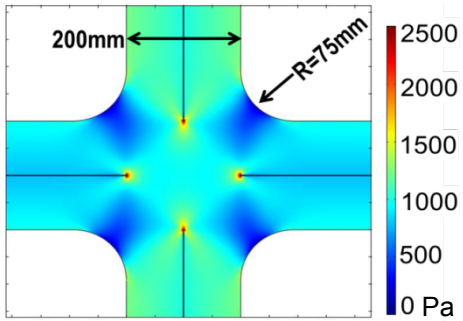


Biaxial tension test





***Von Mises* stress distribution (FEM)**



Adhesive blister propagation under an orthotropic bituminous waterproofing membrane
Construction and Building Materials,48 (2013),1171–1178; B.W. Hailesilassie and M.N. Partl

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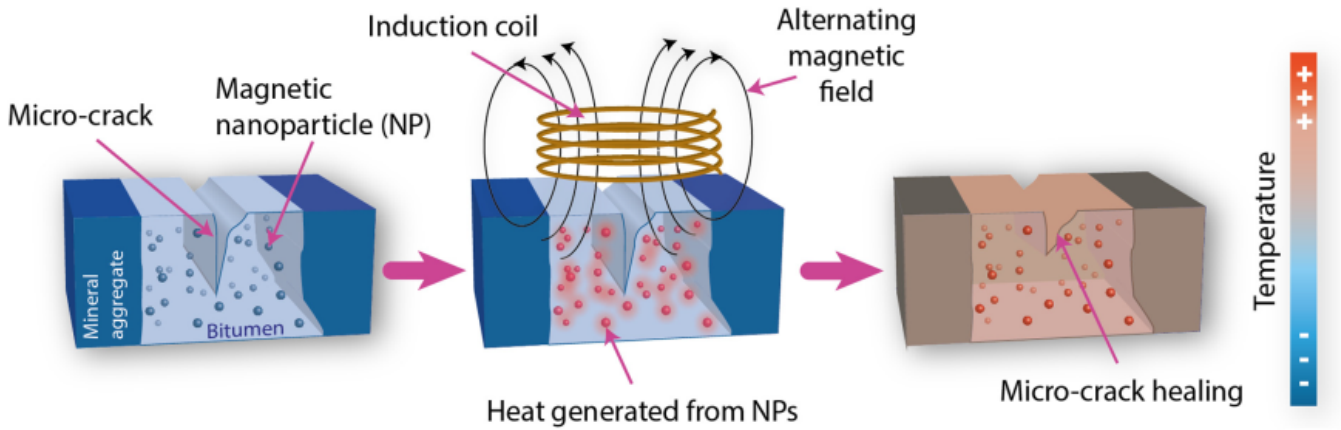
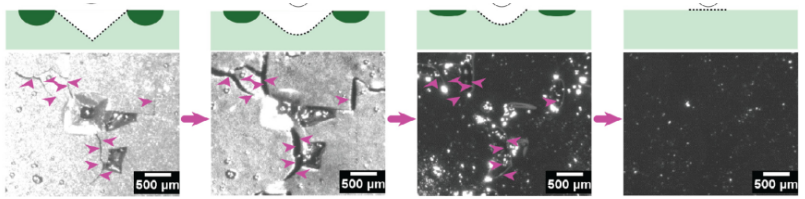
Induction Healing



1. **Magnetic field** generated by **electrical current** in the coil
2. Induction of **electrical current** by **magnetic field** (***Faraday's law***)
3. Heating of the conductive material (***Joule's principle***)
4. **Heat transference** from particles to bitumen
5. Viscosity decrease – **Flow behaviour**
6. **Crack Closure and Recovery of the Adhesion Bonds**



Iron oxide nanoparticles for magnetically-triggered healing of bituminous materials
Construction and Building Materials,112 (2016),497–505; E. Jeoffroy, D. Koulialias, S. Yoon, M.N. Partl, A.R. Studart

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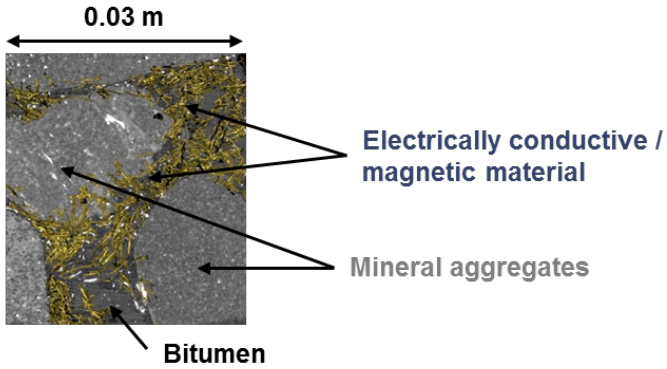
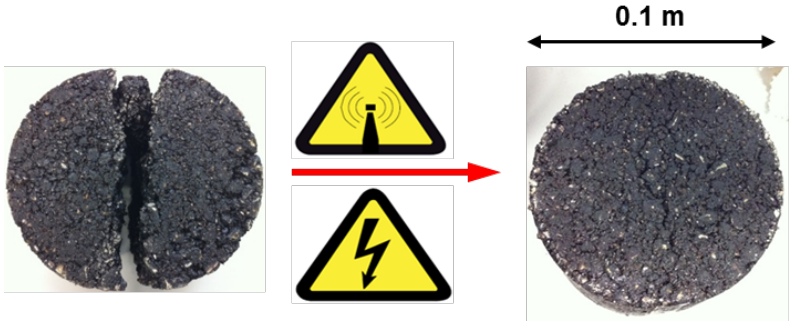
Induction Healing

Phase 1. Mixture Design

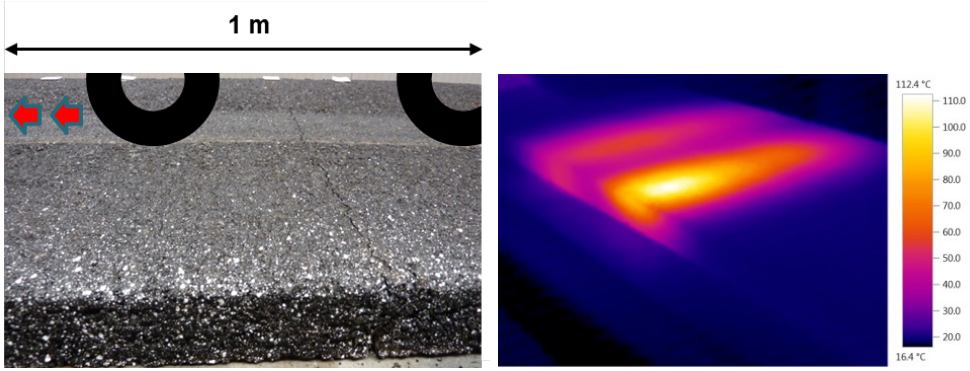


Phase 2. Healing Characterization



- ✓ **Short** Fibers (<2mm) with **large Ø** improve efficiency of induction
- ✓ Healing is only effective in AC above a certain temperature T_{newt}
- ✓ **Overheating** (heating time) can cause **structural damages.**
- ✓ After a certain **number of cycles** (fatigue behaviour), there is **no mechanical recover** by induction heating

Phase 3. Model System (Up-scaling)



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Model Mobile Load Simulator (MMLS3)

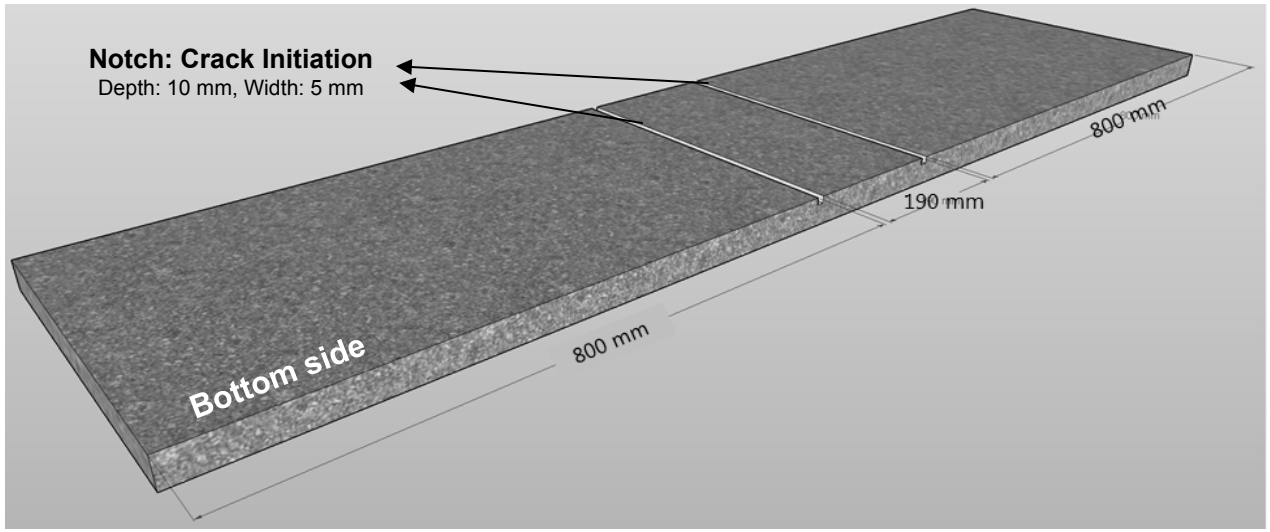
Asphalt Mixture AC8 + 14%wt. iron particles (0.6-1.0 mm)

BAV Volketswil

Bitumen 50/70 (5.9 %wt.)

Softening point: 65 °C

→ **5 Slabs (1800 mm x 435 mm x 40 mm)**



Damage detection and artificial healing of asphalt concrete after trafficking with a load simulator
Mech Time-Depend Mater *(DOI 10.1007/s11043-016-9306-z) M. Bueno, M. Arraigada* and M.N. Partl

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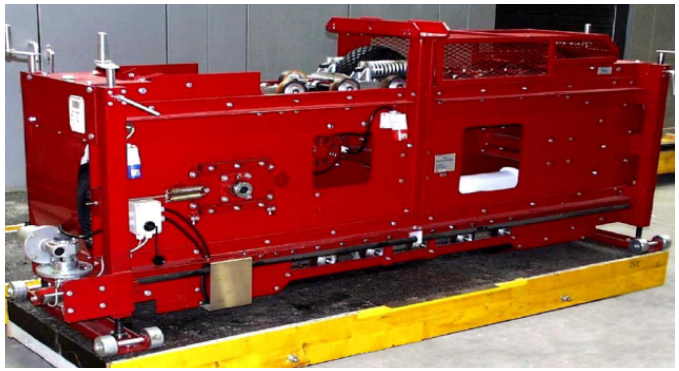
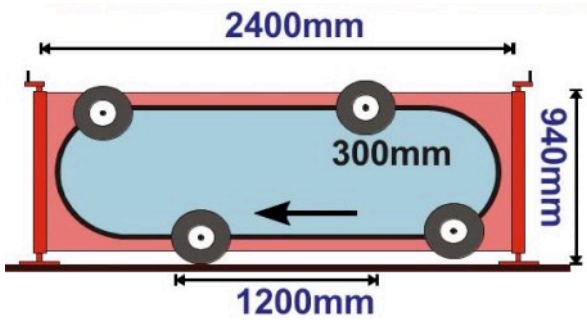
Experimental Procedure

Model Mobile Load Simulator (MMLS3)





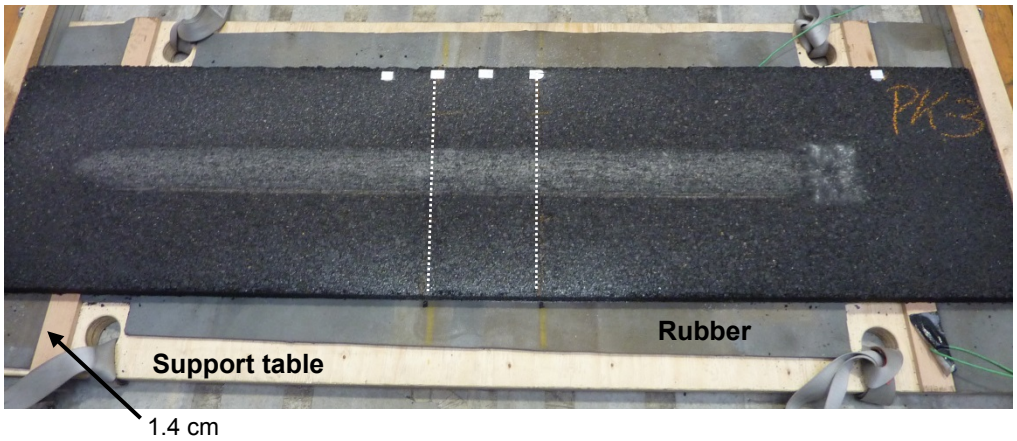
Test Temperature: 18°C

ca. 7000 cycles/hour

Tire Pressure: 600 kPa

Load: 2.1 kN

5 Slabs (1800 mm x 435 mm x 40 mm)



Experimental Procedure (3 phases):

1. **Damage phase**
2. **Healing process**
3. **Validation phase (until failure)**

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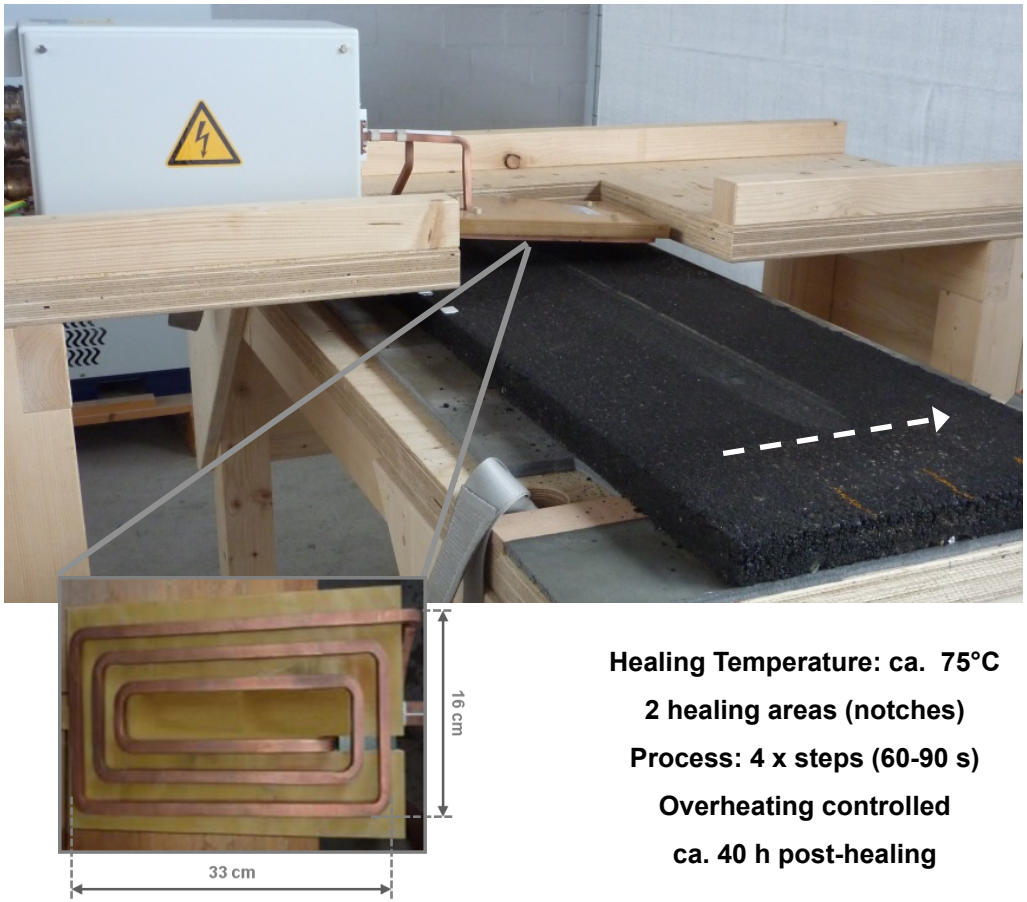
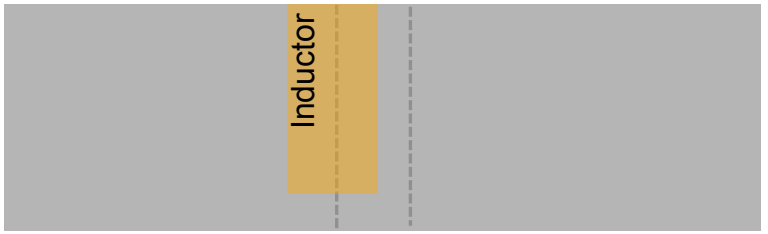
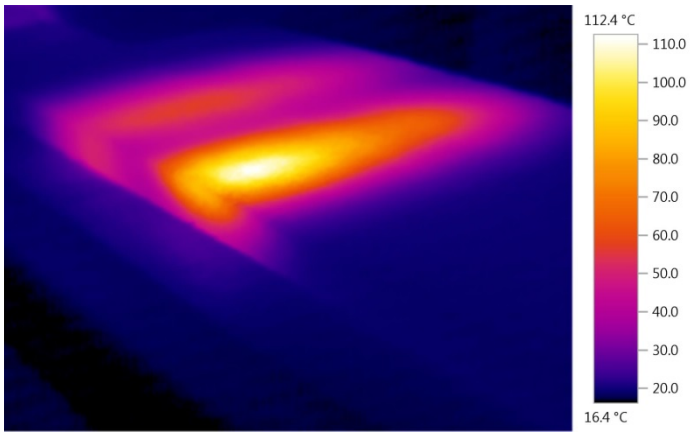
Experimental Procedure

Model Mobile Load Simulator (MMLS3)

Healing process







Healing Temperature: ca. 75°C

2 healing areas (notches)

Process: 4 x steps (60-90 s)

Overheating controlled

ca. 40 h post-healing

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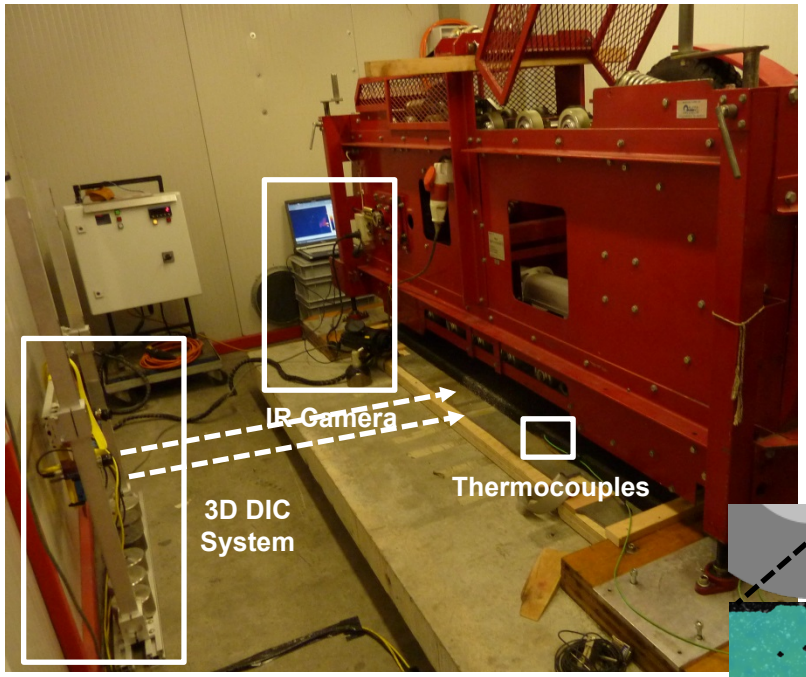
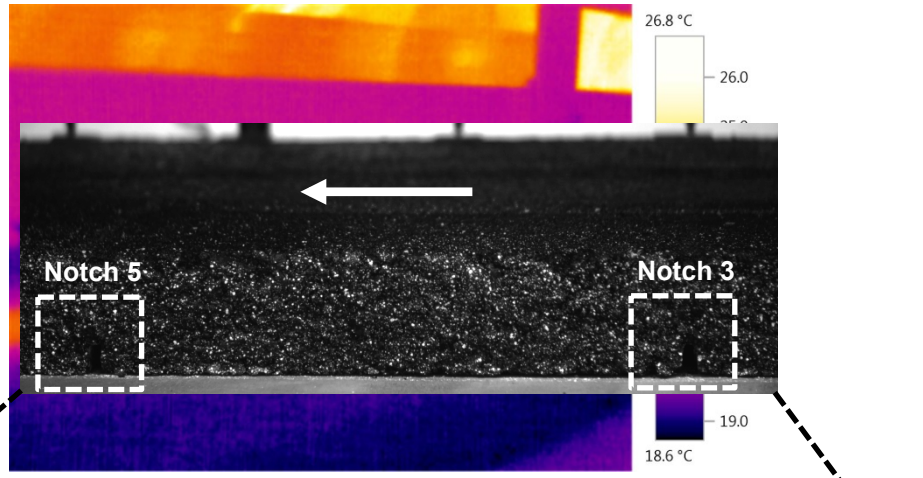
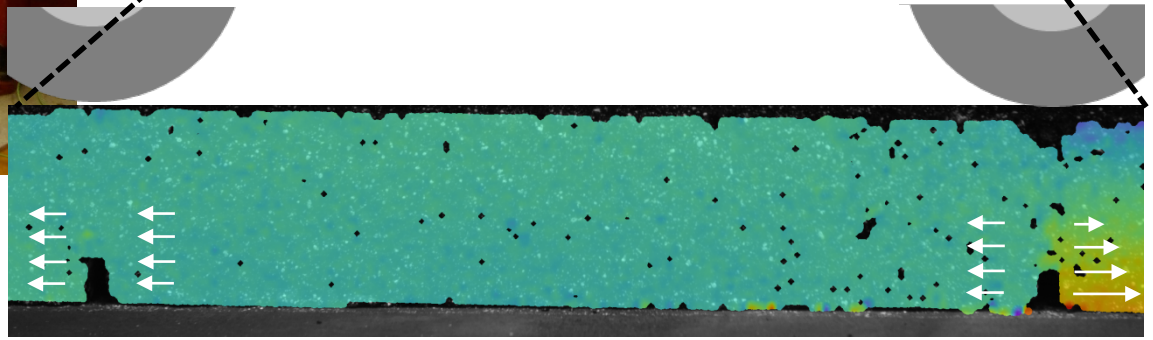
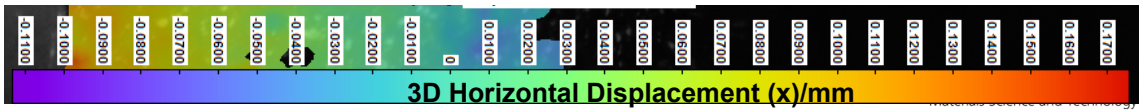
Experimental Procedure

Model Mobile Load Simulator (MMLS3)









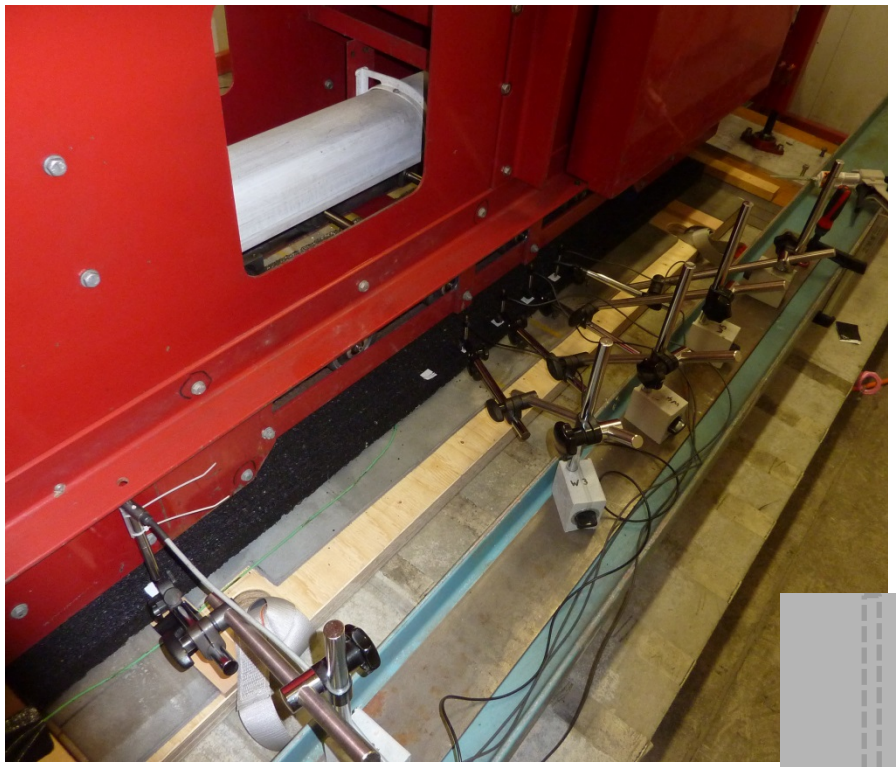
Accuracy: 200 μstrains

20 images/s

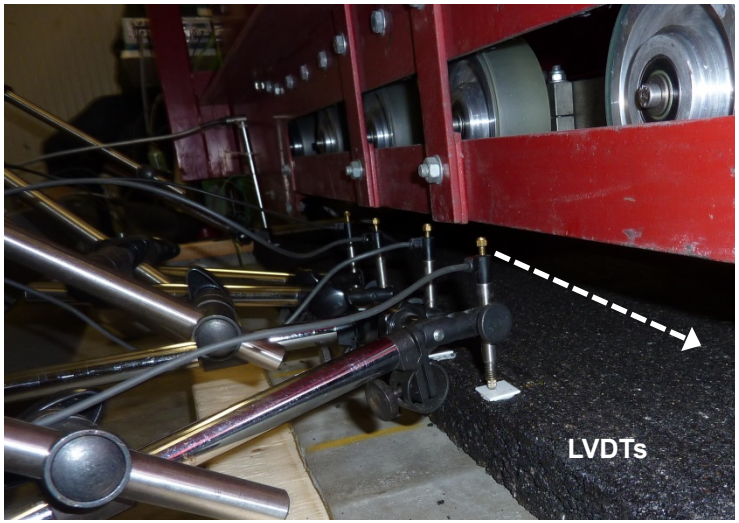
Sequences of 124 images every 1000 loading cycles

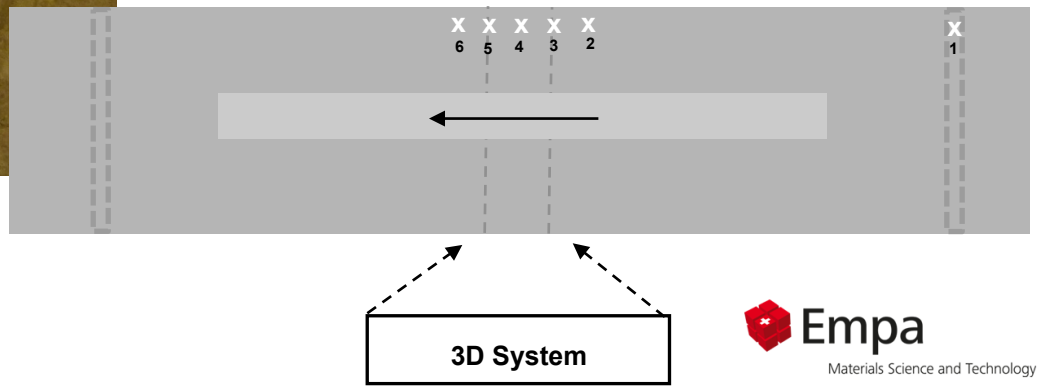
Experimental Procedure

Model Mobile Load Simulator (MMLS3)



Vertical Deformation Sensors
LVDT: Linear Variable Differential Transformer





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Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 1: Preliminary test**

  30000 cycles

  Validation of the 3D DIC system

- **Slab 2:**

  Damage phase: 15000 cycles

- **Slab 3:**

  Damage phase: based on “continuous” 3D image analysis

- **Slab 4:**

  Damage phase: based on “continuous” 3D image analysis

- **Slab 5: Multiple healing analysis**

  20000 cycles (no damage) + 15000 cycles (damage) + 15000 cycles (damage) + 12000 cycles until failure (notch 3)

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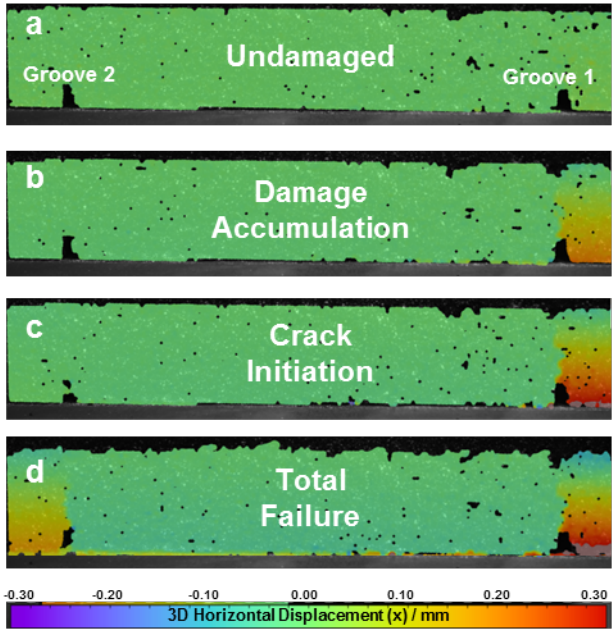
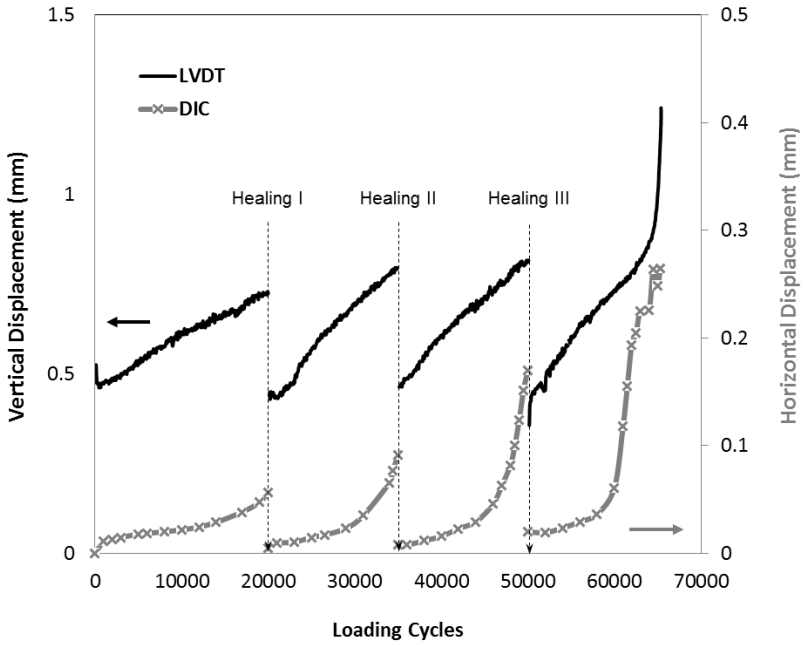
Experimental Results

Model Mobile Load Simulator (MMLS3)





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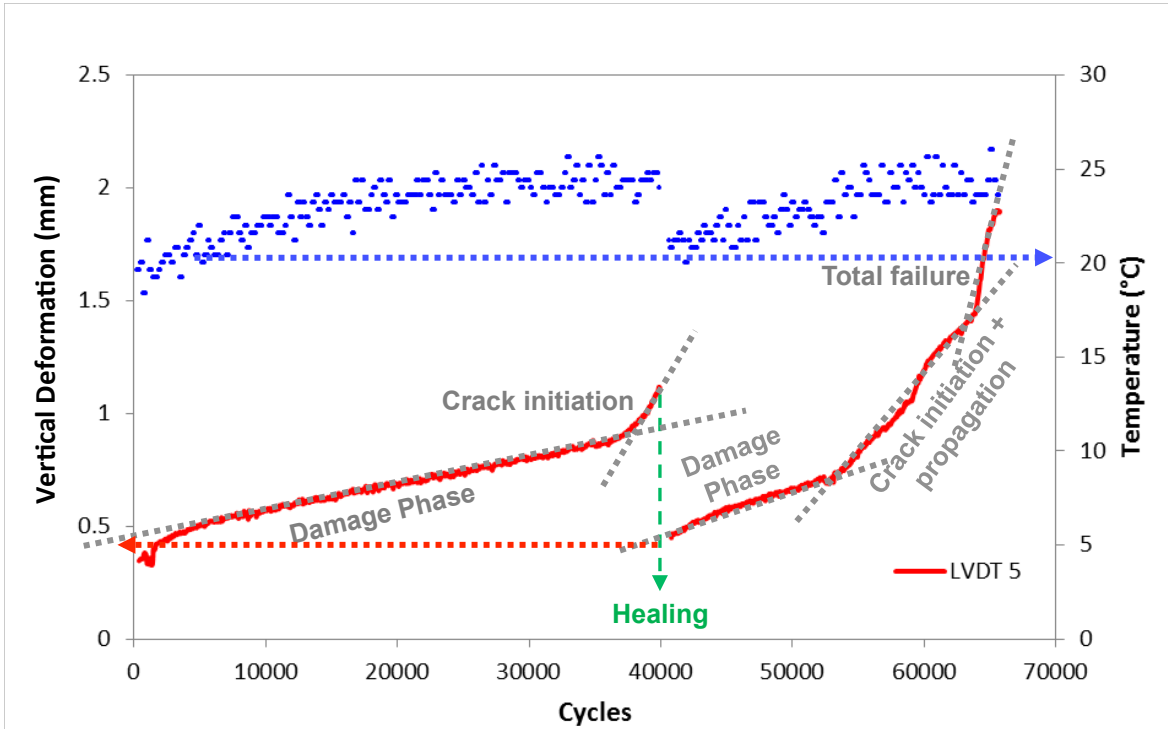
Experimental Results

Model Mobile Load Simulator (MMLS3)



3D DIC: 3D Digital Image Correlation System

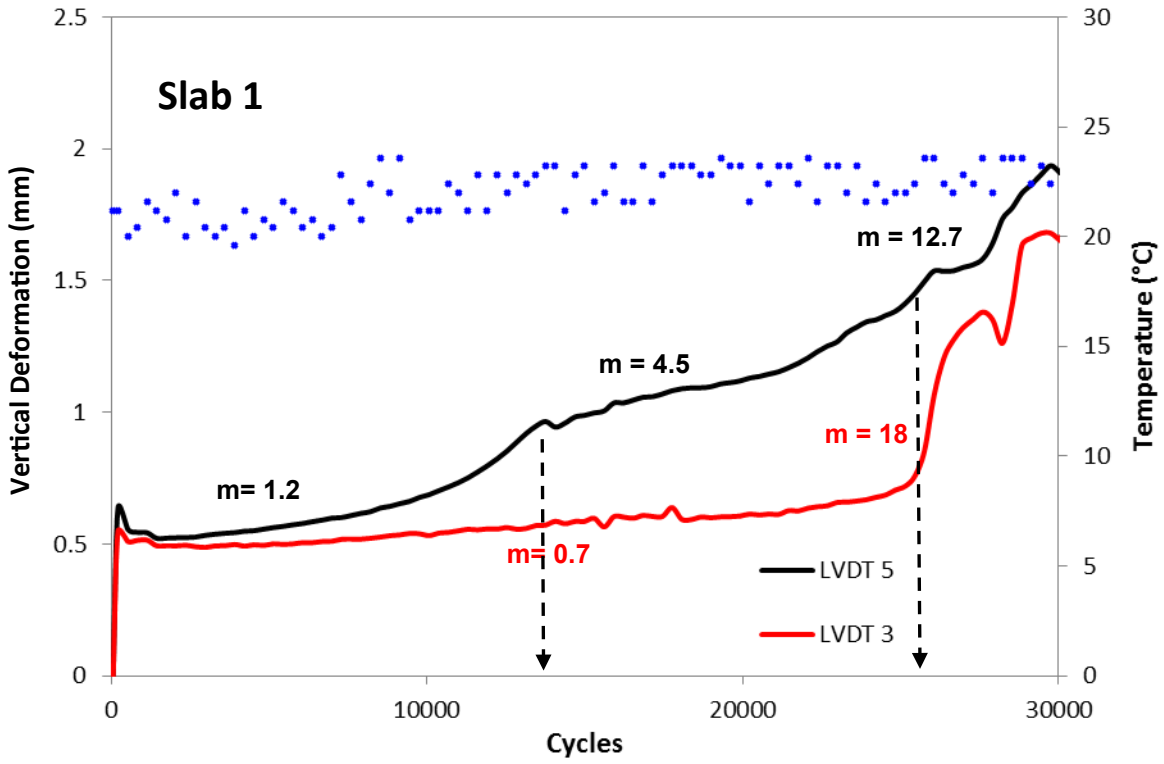
Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 1: Preliminary test**

  30000 cycles

  Validation of the 3D DIC



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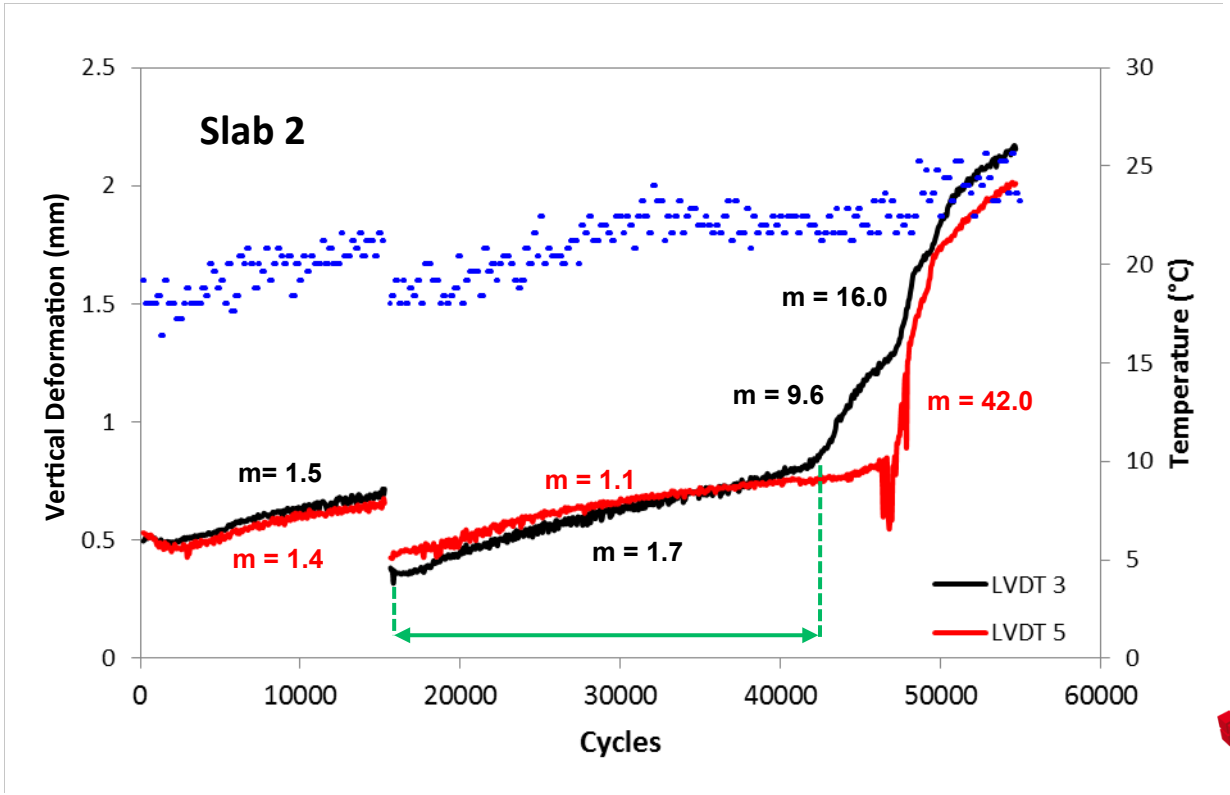
Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 2:**

  Damage phase: 15000 cycles (first test with 3D System)



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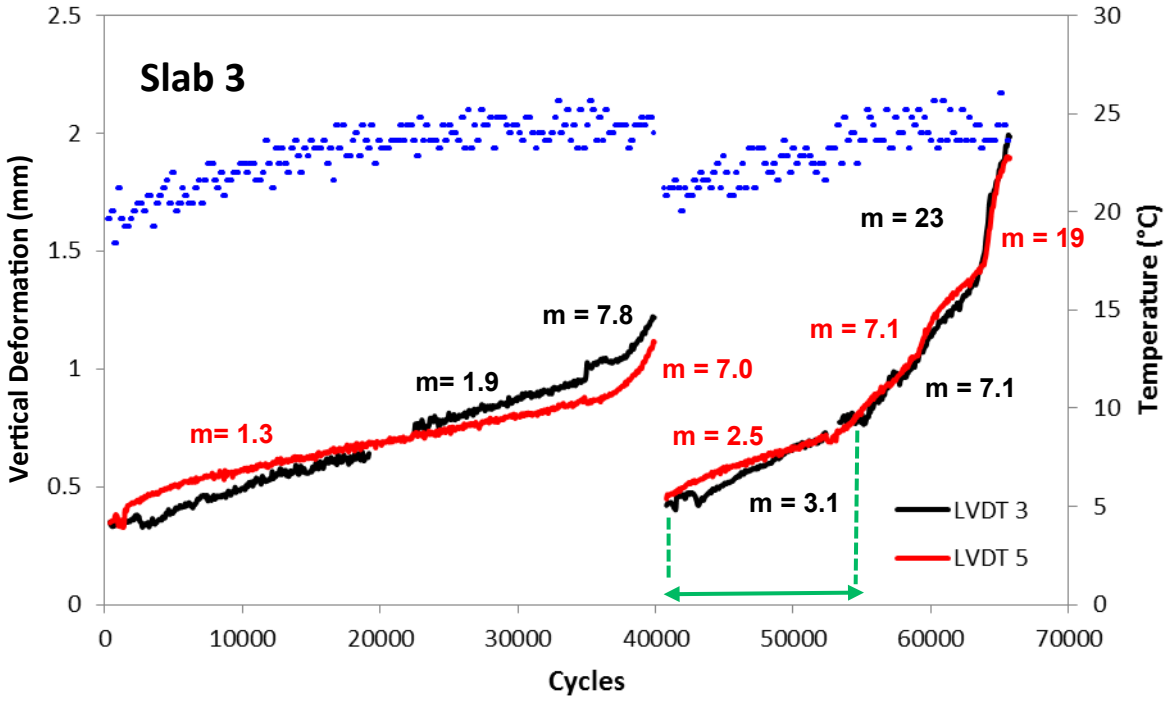
Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 3:**

  Damage phase: based on "continuous" 3D image analysis



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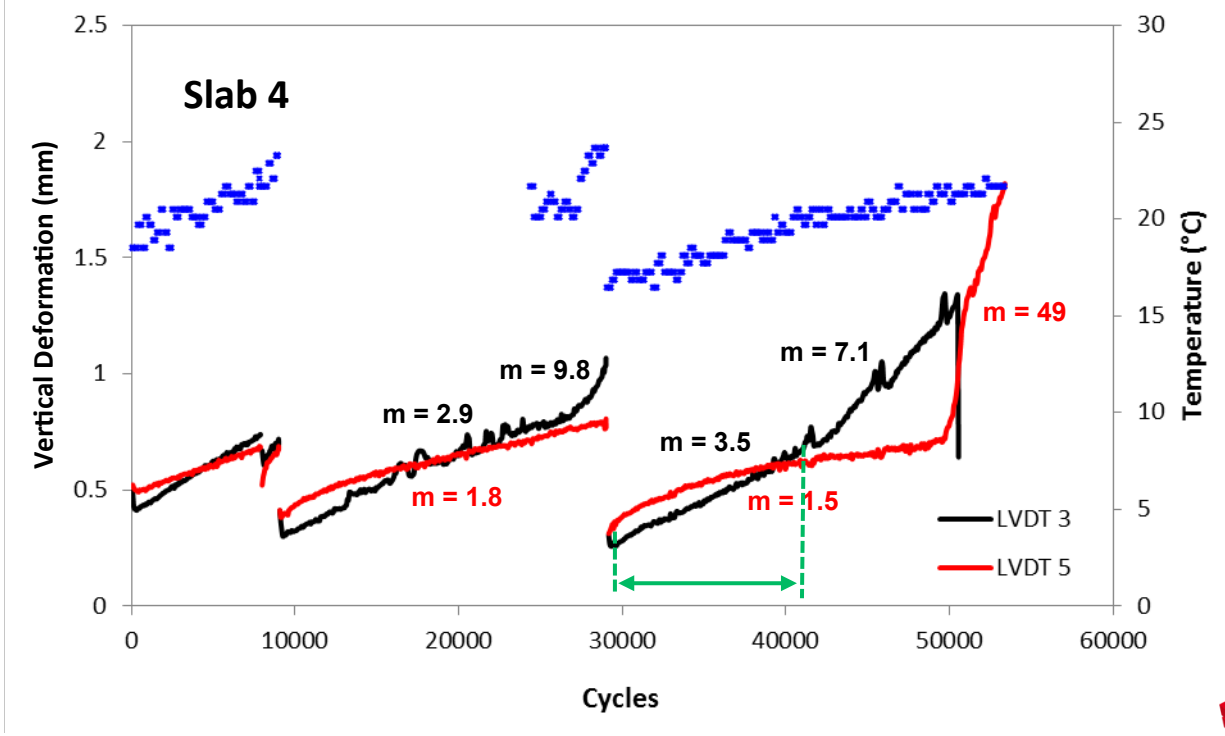
Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 4:**

  Damage phase: based on "continuous" 3D image analysis



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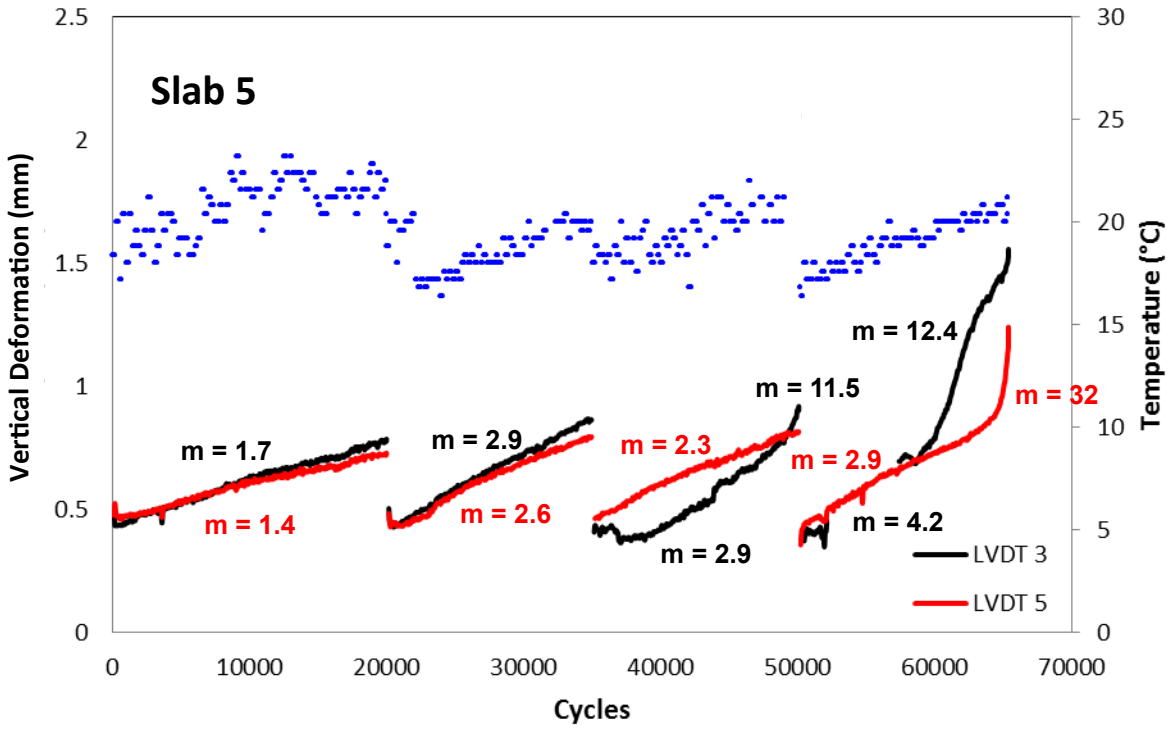
Experimental Results

Model Mobile Load Simulator (MMLS3)

- **Slab 5: Multiple healing analysis**

  20000 cycles (no damage) + 15000 cycles (damage) + 15000 cycles (damage) + 12000 cycles until partial failure (notch 3)



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Conclusions

- ✓ Development and validation of a **new method** for evaluating the healing of asphalt slabs (**up-scaled**) by induction heating.
- ✓ The **enhancement of the life** of the pavement due to the healing process has been confirmed in a **larger scale**.
- ✓ After healing, the initial **performance** is **recovered** (LVDT) and the **damage** is **healed** (3D DIC).
- ✓ The **number of cycles** until total failure is **longer** when the healing process is carried out **before damage** starts.
- ✓ The effect of **multiple healing** process as **maintenance technique** has been proven.

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Future work

- ✓ Definition of the **conditions** the innovative procedure as **maintenance technique** (when and how to accomplish healing treatments).
- ✓ Description of the healable damage (crack size limitations, crack propagation velocity)
- ✓ To isolate the effect of natural healing (bitumen properties)
- ✓ New experimental setup (DIC): External trigger
- ✓ Assessment of the healing process with DIC.
- ✓ To focus the healing concept on a **specific application** (different experimental configurations):
  - Low temperature cracking,
  - Bridge joints,
  - Metallic grid or asphalt interlayer for reflective cracking,
  - Construction induced cracking (e.g. during compaction)
  - ….

8th Rilem International Conference on Mechanisms of Cracking and Debonding in Pavements (MCD2016)

Workshop: **Recent progress in Digital Image Correlation: towards integrated identification?**

Practical Experiences with DIC in Asphalt Technology

Moisés BUENO (Empa, Switzerland)
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Nantes, June, 9 - 2016