8TH RILEM INTERNATIONAL CONFERENCE ON MECHANISMS OF CRACKING AND DEBONDING IN PAVEMENTS

June 7 - 9, 2016 – Nantes, FRANCE

Characterization and Detection of Debonding Phenomena in Asphalt Pavements and on Concrete Bridge Decks

Manfred N. Partl

Prof. KTH Stockholm, Carleton Ottawa

Empa, Swiss Federal Laboratories for Materials Science and Technology,
Laboratory Road Engineering/Sealing Components, www.empa.ch/Abt301

Empa
Materials Science and Technology

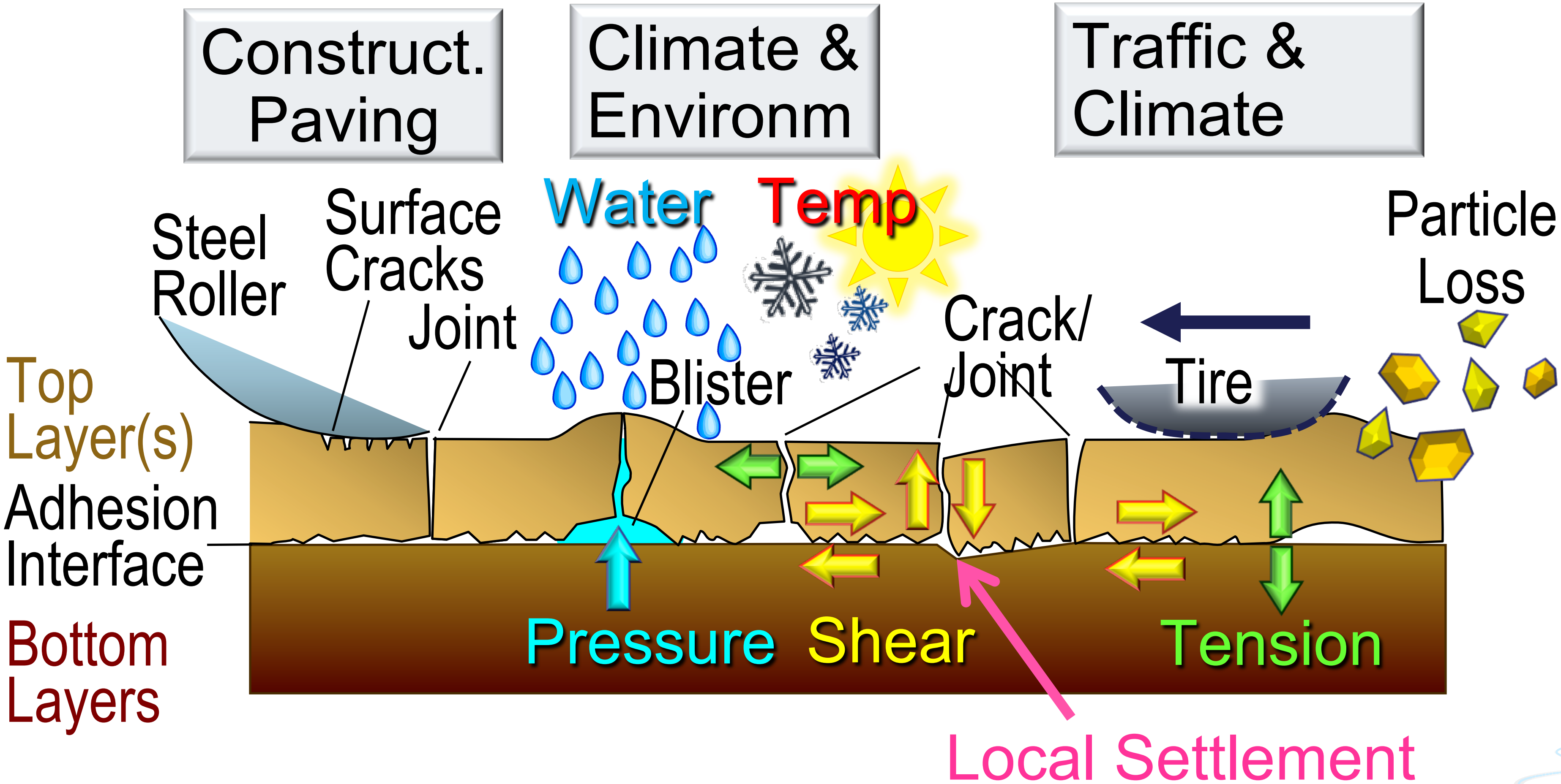
Paper N°: xxxxx

Outline

- Introduction
- Aggregate Debonding
- Interlayer Bond
- APT & Interlayer Bond
- Blisters
- Joints
- Reinforcements
- Crack Healing

Empa
Materials Science and Technology

Debonding Mechanisms



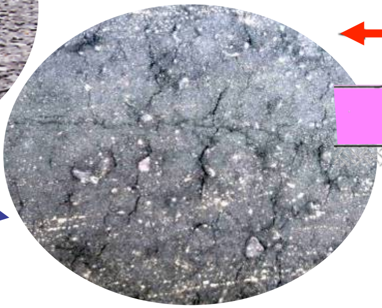
Debonding Types & Examples (1)

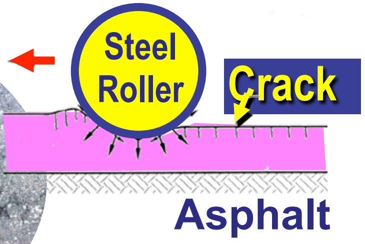
Design/Construction/Compaction:

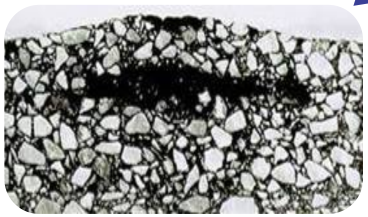
- **Interlayer Debonding/Aggregate Debonding**
  - Insufficient Compaction Pressure
  - Wrong Temperature
  - Construction during Wet Condition
  - Dirt
- **Bad joints**
- **Surface Cracks from Steel Rollers**
- **Blisters**

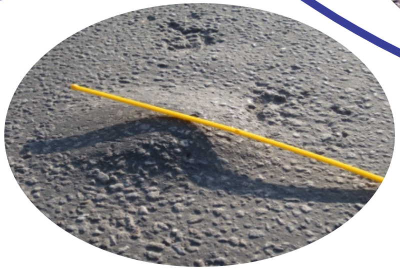
PA

HRA









Empa
Materials Science and Technology

Debonding Types & Examples (2)

Temperature:

- **Temp. Cycles** (Fatigue)
- **Extreme Cooling-Shocks** (Thermal Contraction)

Traffic (Fatigue):

- **Top-Down Cracks** (e.g. Tire-Surface Contact)
- **Bottom-Up Cracks** (e.g. Reflective Cracking)

Settlement & Sliding:

- **Transversal**
- **Longitudinal**
- **Curbstone Foundation**
- **Manholes**

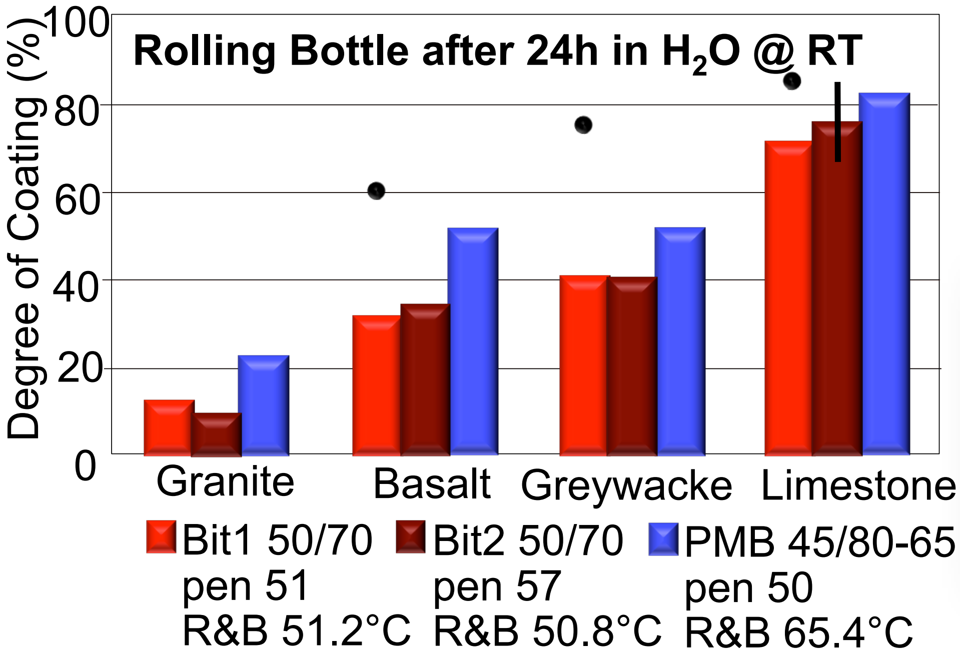
Empa
Materials Science and Technology

June 7-9, 2016 – Nantes, FRANCE
8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements

Stripping: Rilem TC 237-SIB, TG1

Darius Sybilski, IBDiM, PL; Hilde Soenen, Nynas, BE; James Grenfell & Alex Apeagyei, NTEC, Univ. Nottingham, UK; Francisco Barcelo Repsol, ES; Laurent Porot, Arizona Chem., NL; Stefan Vansteenkiste, BRRC, BE; Fransceco Canestrari, Univ Polit. d. Marche, IT; Andrew Hanz, Univ.Wisconsin, US; Safwat Said from VTI, SE; Elisabeth Hauser, Univ Braunschweig ISBM, DE; Antonio D'Andrea, La Sapienza Roma, IT; Ignacio Artamendi, Aggregate Indust., UK; Jeroen Besamusca, Q8, NL

- Rolling Bottle test EN 12697-11
- RTT with **8** Labs
- 2 pure bitumen + 1 polymer bitumen
- 4 aggregate types



Findings:

- Less sensitive to binder than to aggregates
- Results more descriminant after 24h than 6h testing
- Same pen = same results
- Granite <Basalt/Greyw.<Limest.
- High variability of results

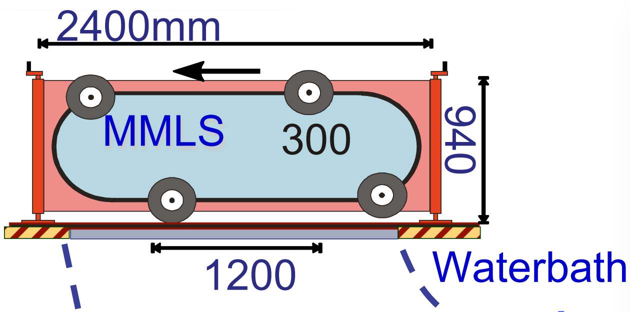
e.g. same aggregate & bitumen:

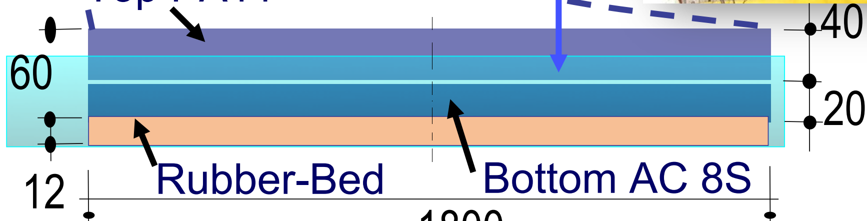
Lab 1: 5%   Lab 4: 20%

Moisture Induced Particle Debonding of PA with MMLS

Lab-Slabs

Kim, H., Sokolov, K., Poulikakos, L.D., Partl, M.N.: *Fatigue Eval. of Carbon FRP-Reinf. Porous Asphalt Composite System Using a Model Mobile Load Simul.* TRR Vol.2116, pp.108-117 (2009).

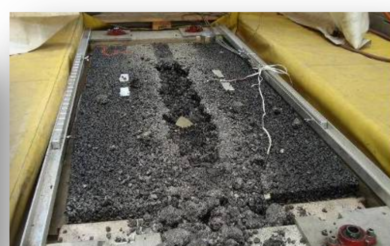




Passings to Failure

Dry	Wet
ca. 320'000	ca. 230'000

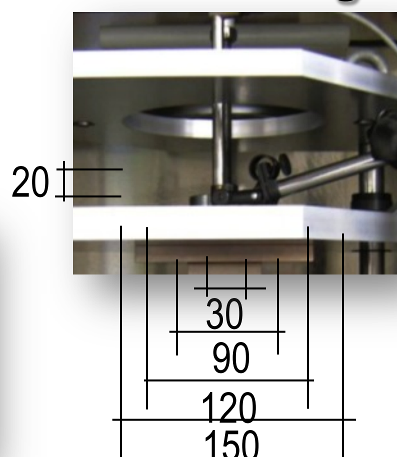
Stripping

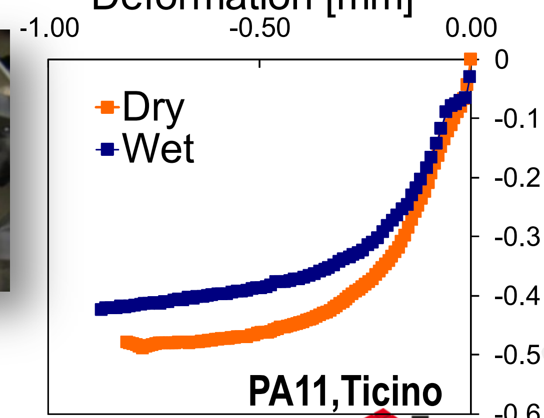


Field Cores

Raab, C., Abd El Halim A.O., Partl, M.N.: *Experimental Investigation of Moisture Damage in Asphalt.* Int. J. of Pav. Research and Technology, Vol5, No3, p133…141, (2012)

4P Bending



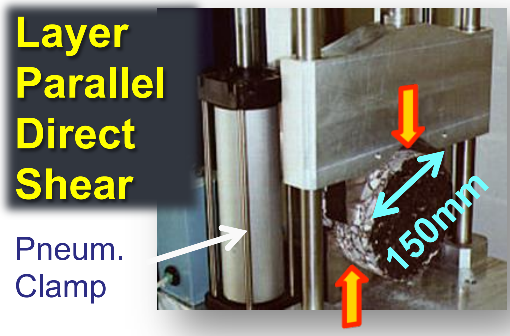


Empa
Materials Science and Technology

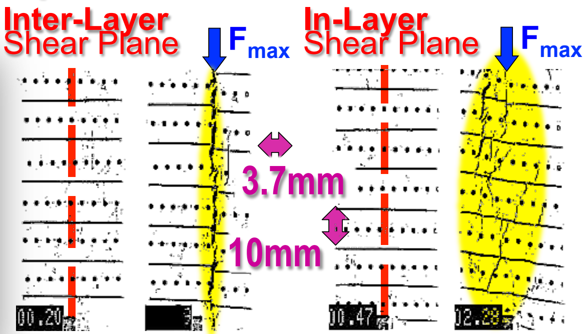
Interlayer Bond

Raab, C, Partl M.N.: *Investigation on Long-Term Interlayer Bonding of Asphalt Pavements*. Baltic Journal of Road and Bridge Engineering. Vol 3 No 2, p65…70, (2008)

LPDS

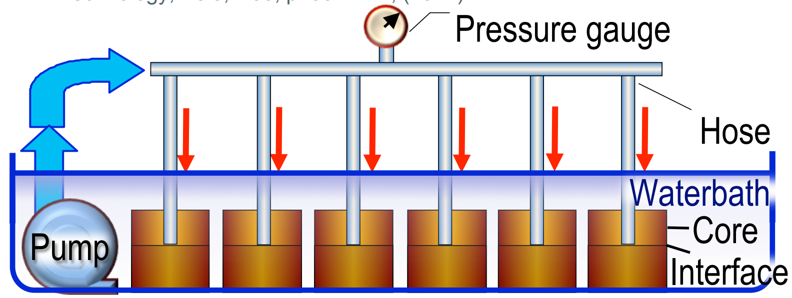


Optical Measurem. SMA

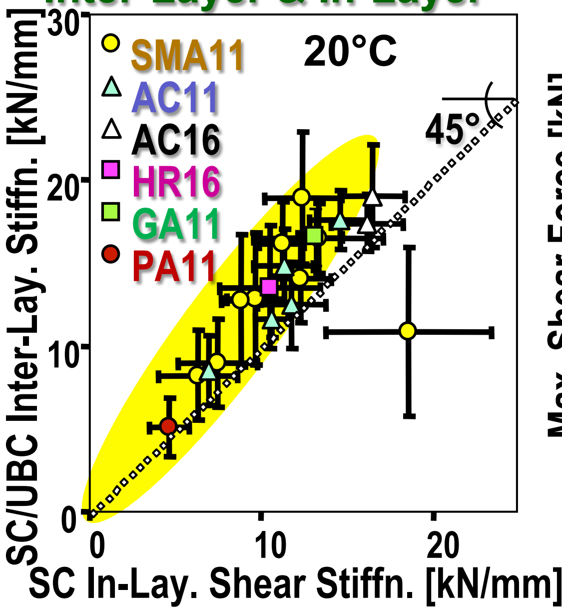


Water Pressure Conditioning LPDS

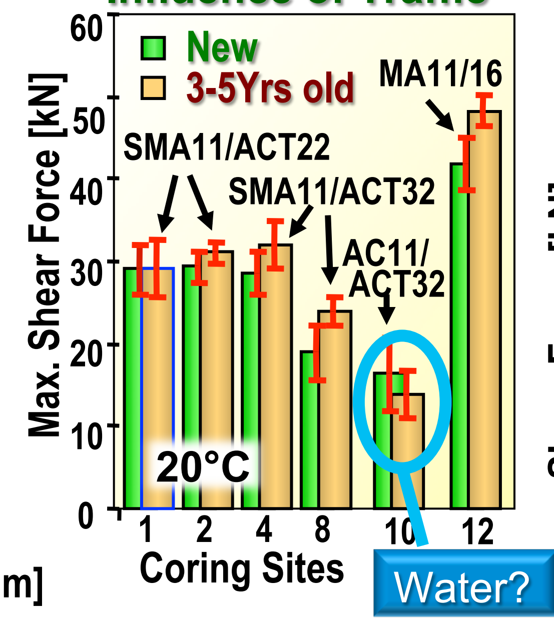
Raab, C., Abd El Halim A.O., Partl, M.N.: *Experimental Investigation of Moisture Damage in Asphalt*. International J. of Pavement Research and Technology, Vol5, No3, p133…141, (2012)



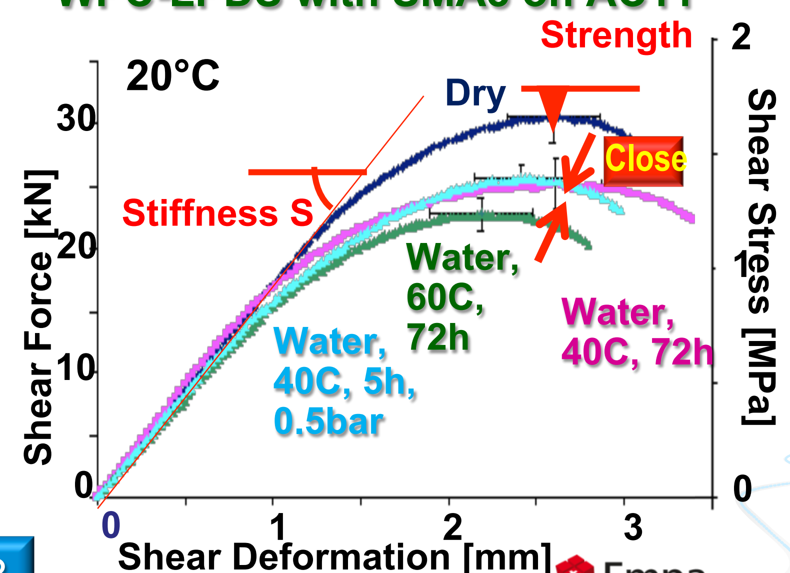
Inter-Layer & In-Layer



Influence of Traffic



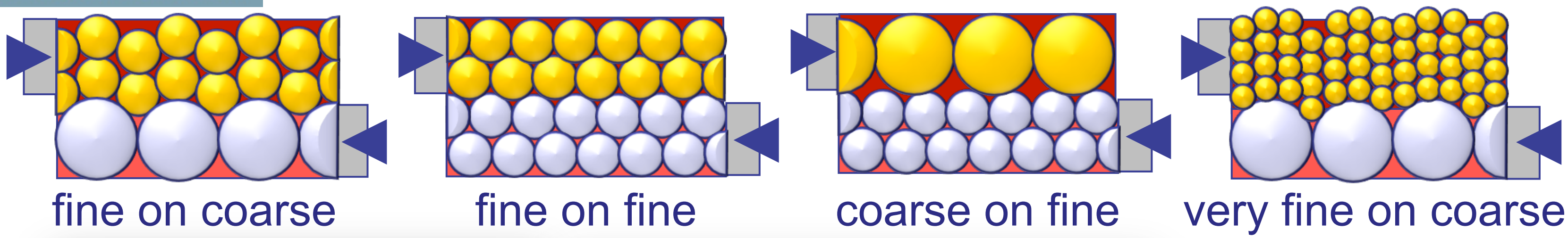
WPC-LPDS with SMA8 on AC11

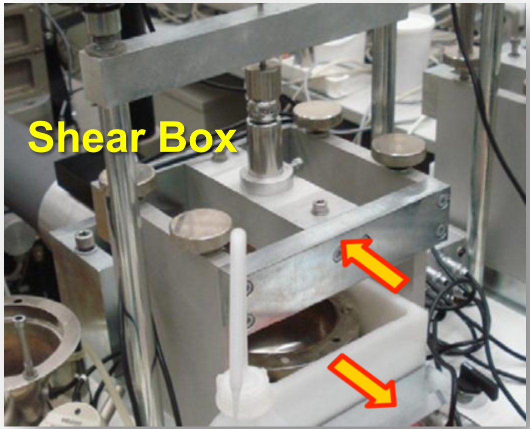


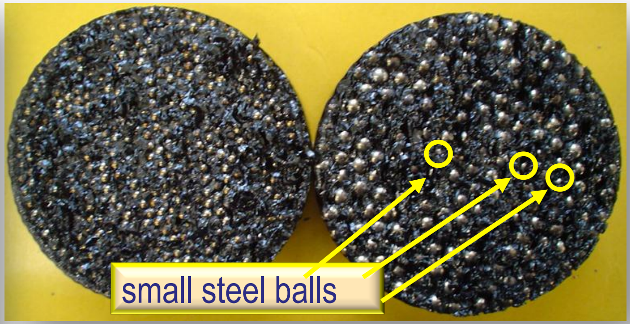
Roughness Aggregate Size

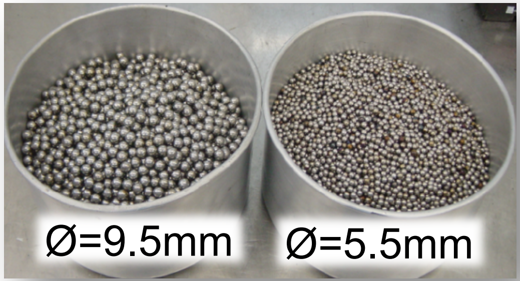
Raab, C., Abd El Halim A. O., Partl, M.N.: *Interlayer Bond Testing using a Model Material*. Construction & Building Materials 26, pp. 190..199 (2011)

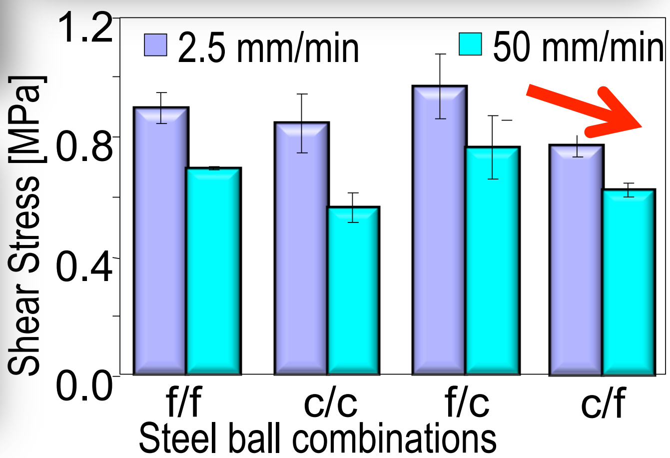
Experimental Modelling





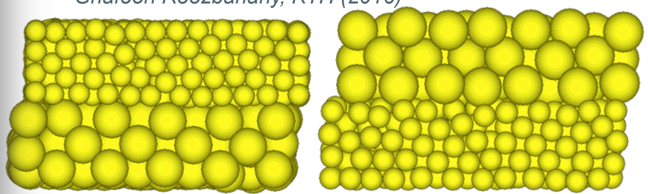


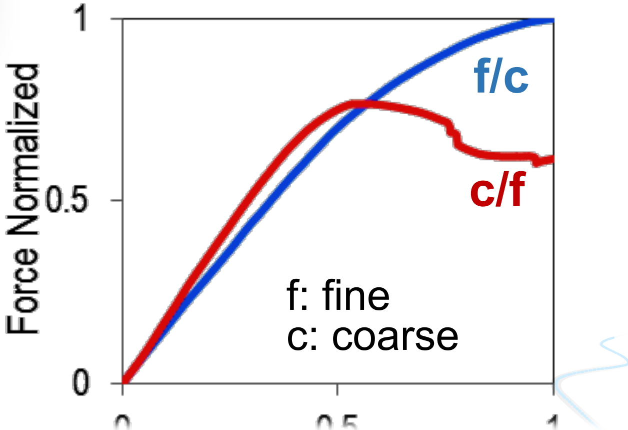




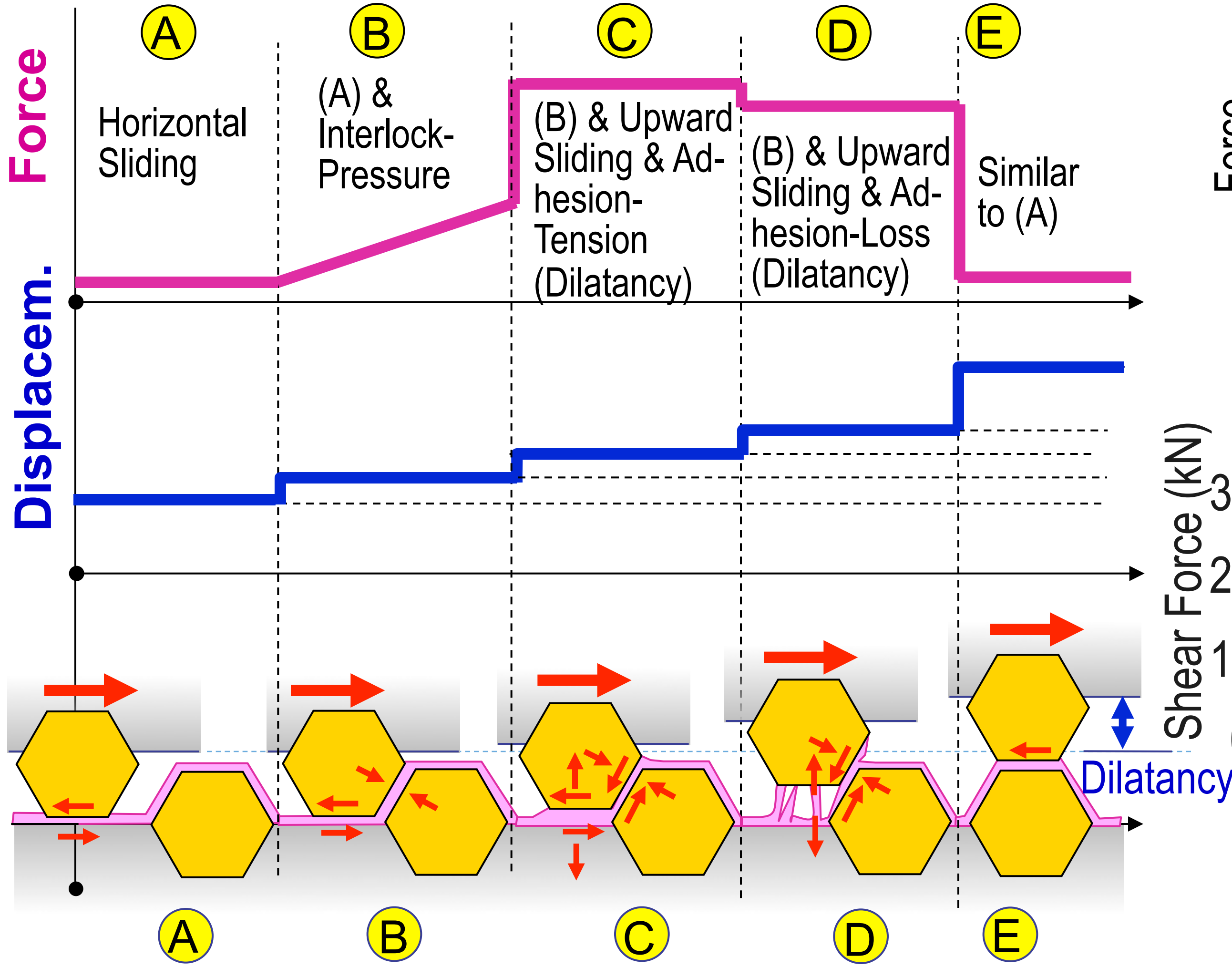
Discrete Element (PFC3D)

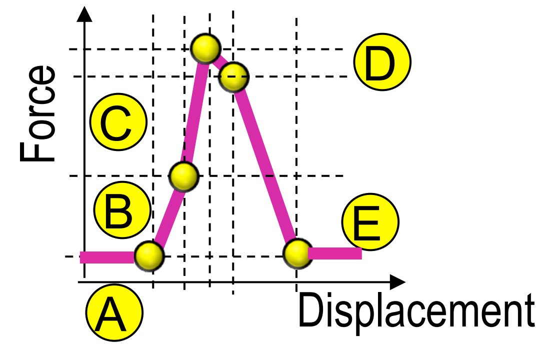
Ghafoori Roozbahany, KTH (2016)

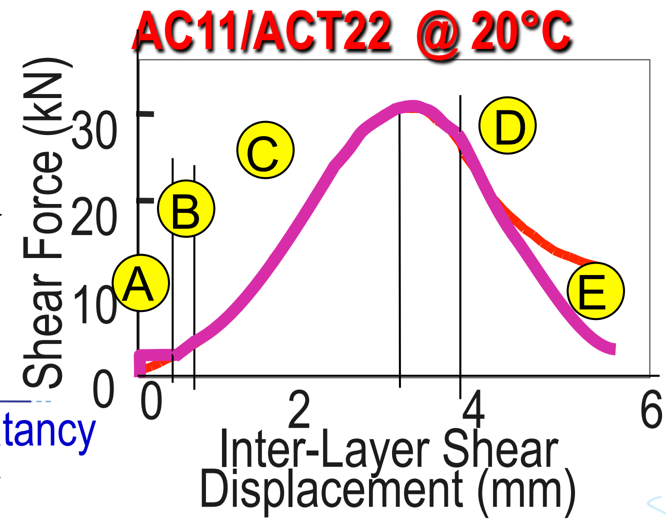




Shear Dilatation Mechanism



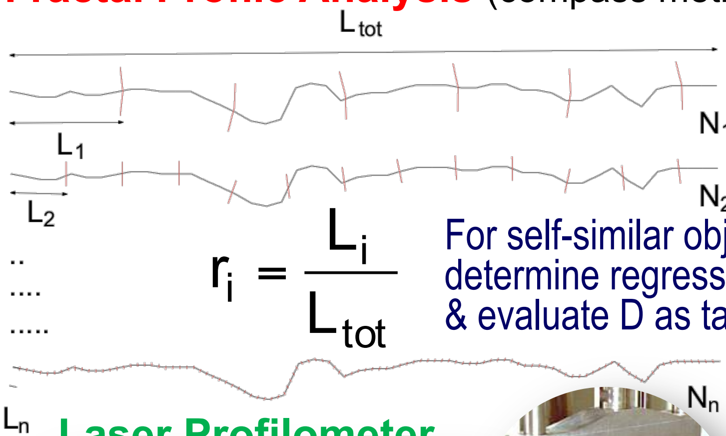




Empa
Materials Science and Technology

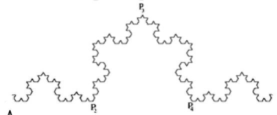
Contact Surface Roughness vs. Interlayer Shear Resistance

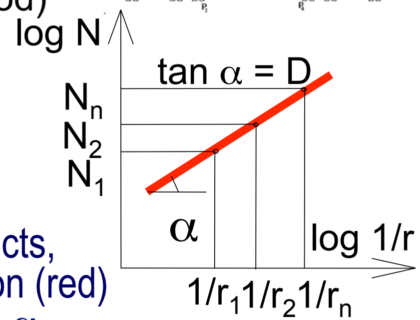
Fractal Profile Analysis (compass method)



$$r_i = \frac{L_i}{L_{tot}}$$

For self-similar objects, determine regression (red) & evaluate D as $\tan \alpha$.

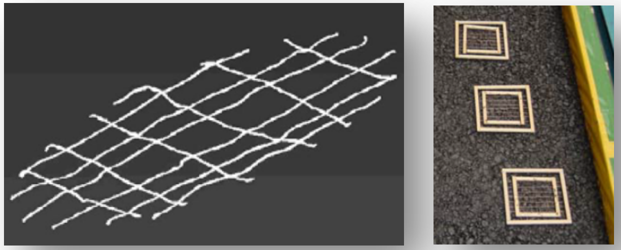




$$D_i = \frac{\log(N_i)}{\log(1/r_i)}$$

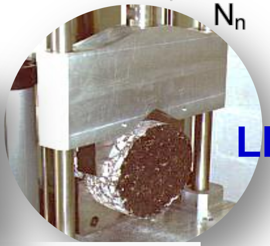
CT of Interlayer Roughness

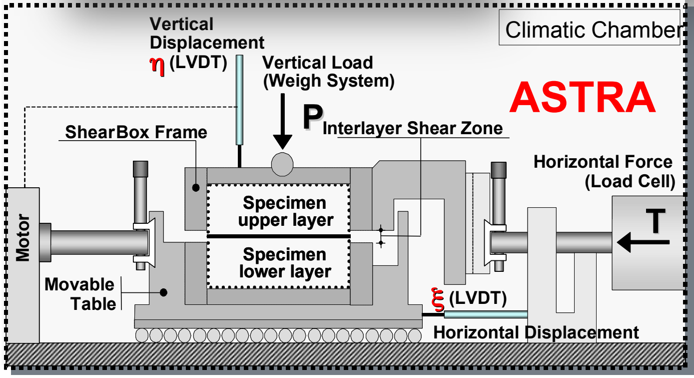
Using a copper wire mesh

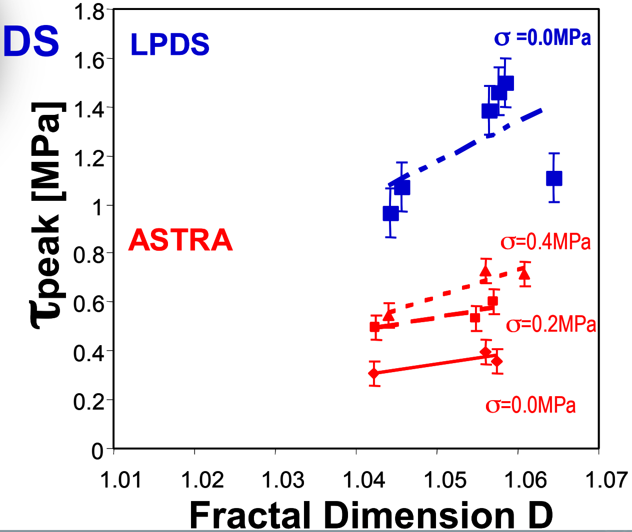


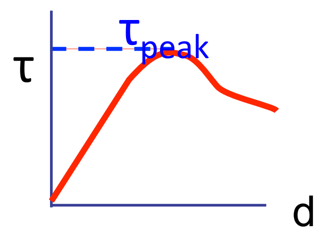
D = Fractal dimension
N = Number of portions similar to object
r = Reduction factor of the single portion

Laser Profilometer





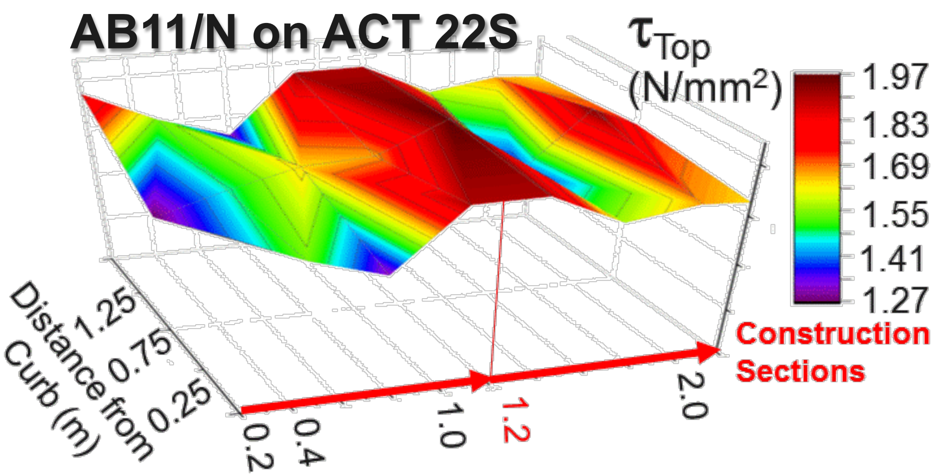




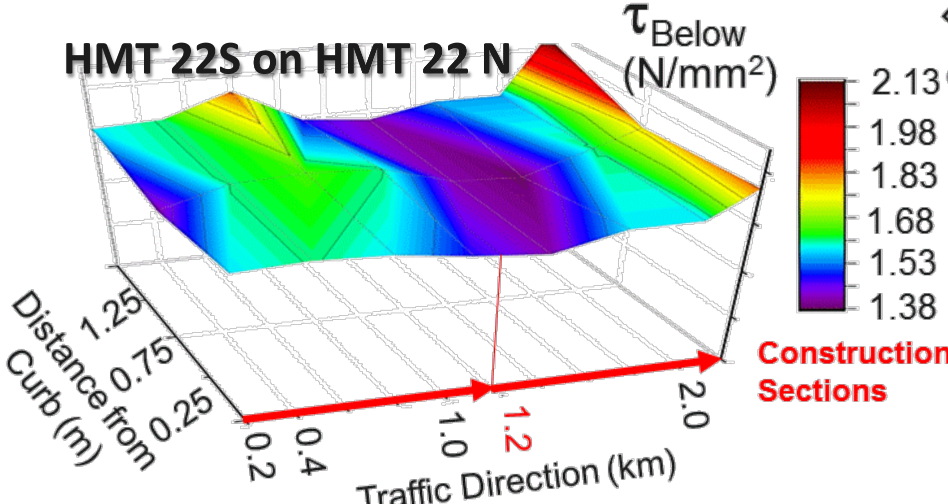
Partl, M. N. , Canestrari, F., Ferrotti, G., Santagata, F.A.: *Influence of Contact Surface Roughness on Interlayer Shear Resistance*. ISAP 10th Int. Conf. on Asphalt Pav., 12-17 Aug., Quebec, (2006)

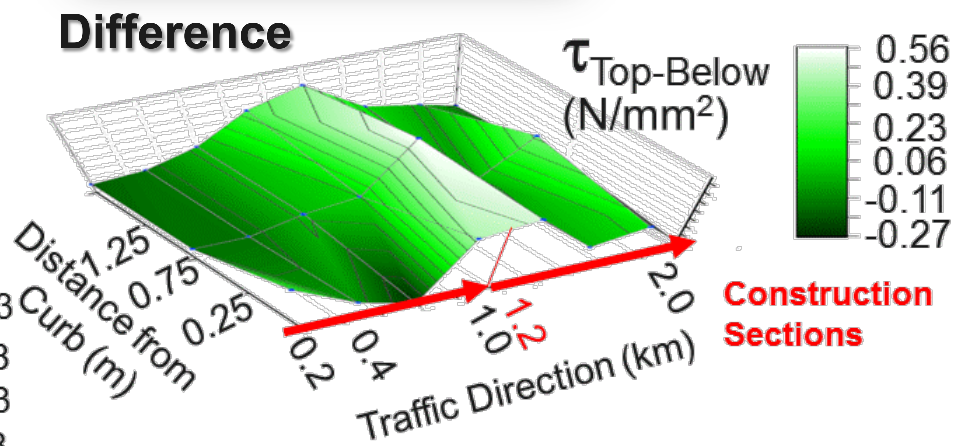
Empa
Materials Science and Technology

Compaction & Interlayer Shear: Emergency Lane A2 Egerkingen CH



Raab, C.: *Schichtenverbund: Ein wichtiger Faktor im Belagsbau*. Strasse und Verkehr, Nr4,p167-175,(1995)





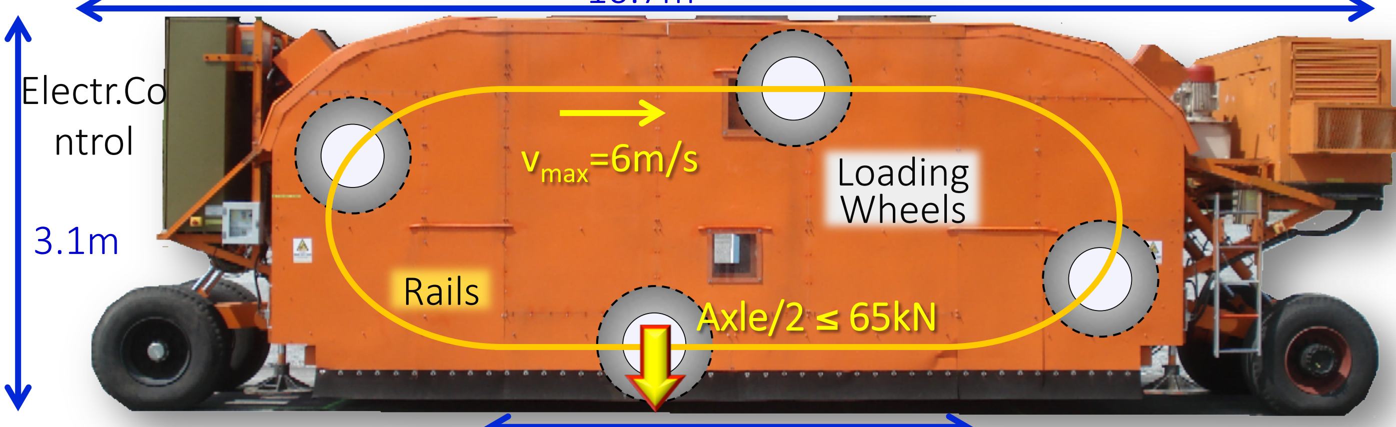
- Large Differences at Section Ends
- Surface Layer Bond Higher

Empa
Materials Science and Technology

June 7-9, 2016 – Nantes, FRANCE
8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements

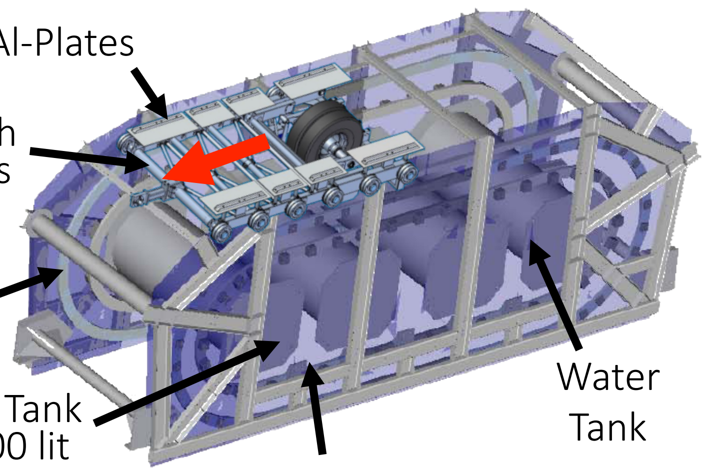
MLS10 Function, Tech. Data

Partl, M.N., Raab, C., Arraigada, M.: *Innovative Asphalt Research using Accelerated Pavement Testing.* Journal of Marine Science and Technology JMST, Vol. 23, No. 3, pp 269-280, (2015)



Generator

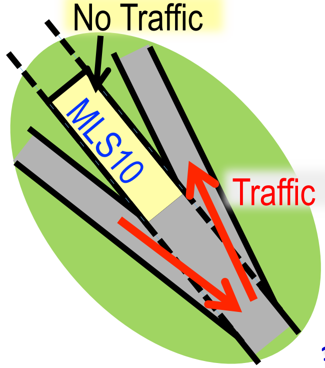
Max.Load	**65 kN**
Dual Tires	**285/70** R19.5
Sup.Single	495/45 R22.5
Test Track	**4.2 m**
Max.Speed	**6000 Pass/h;22 km/h**
Weight ca.	**34 t**

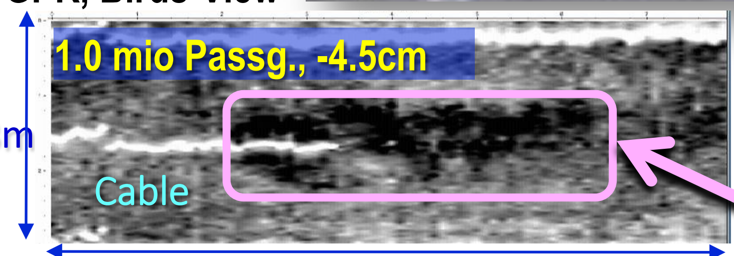


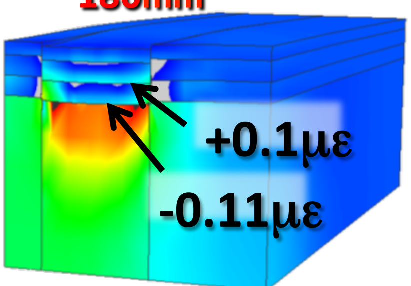
Empa
Materials Science and Technology

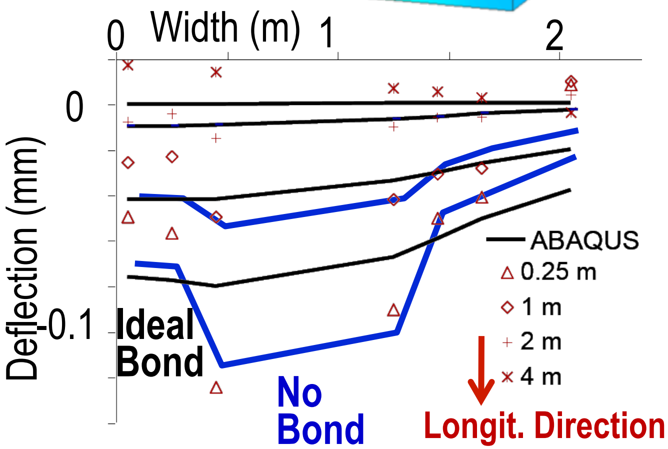
Test-Field Hinwil (A53)

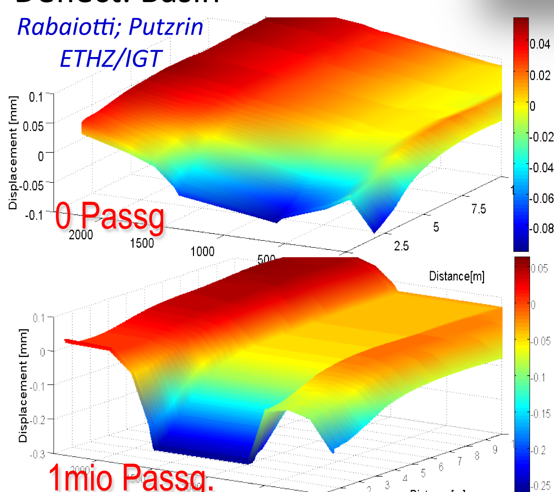
Partl, M.N., Arraigada, M.: *Der neue Mobile Load Simulator MLS10.* Strasse und Autobahn, 62, Nr 4, p252…257 April (2011)

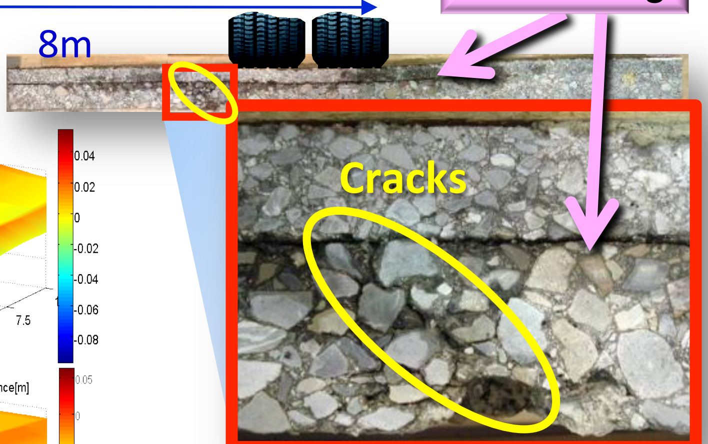








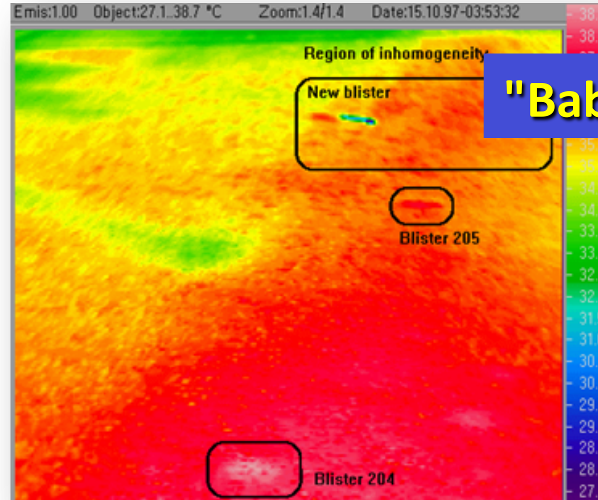




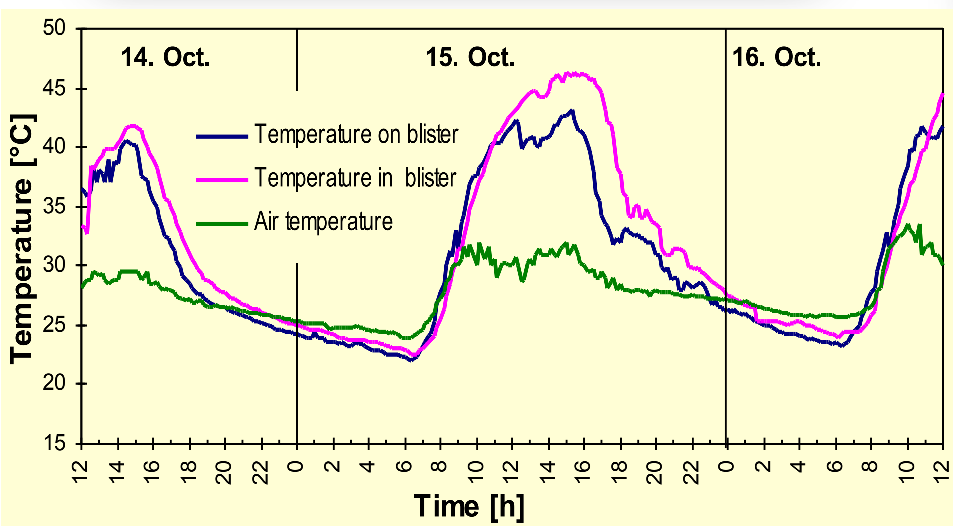
Empa
Materials Science and Technology

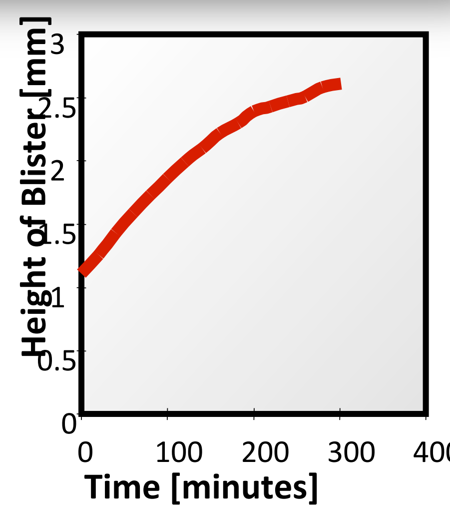
Blister Growth on Suspension Bridge with MA

Partl, M. N., Gubler, R., Hean, S.: *Belagsschäden infolge Blasenbildung auf einer neuen Hängebrücke in Hongkong.* In "Nachhaltige Material- und Systemtechnik" (W. Muster und K. Schläpfer Herausgeber), EMPA Dübendorf, ISBN 3-905594-21-8, pp337-343, (2001)



"Baby" Blister

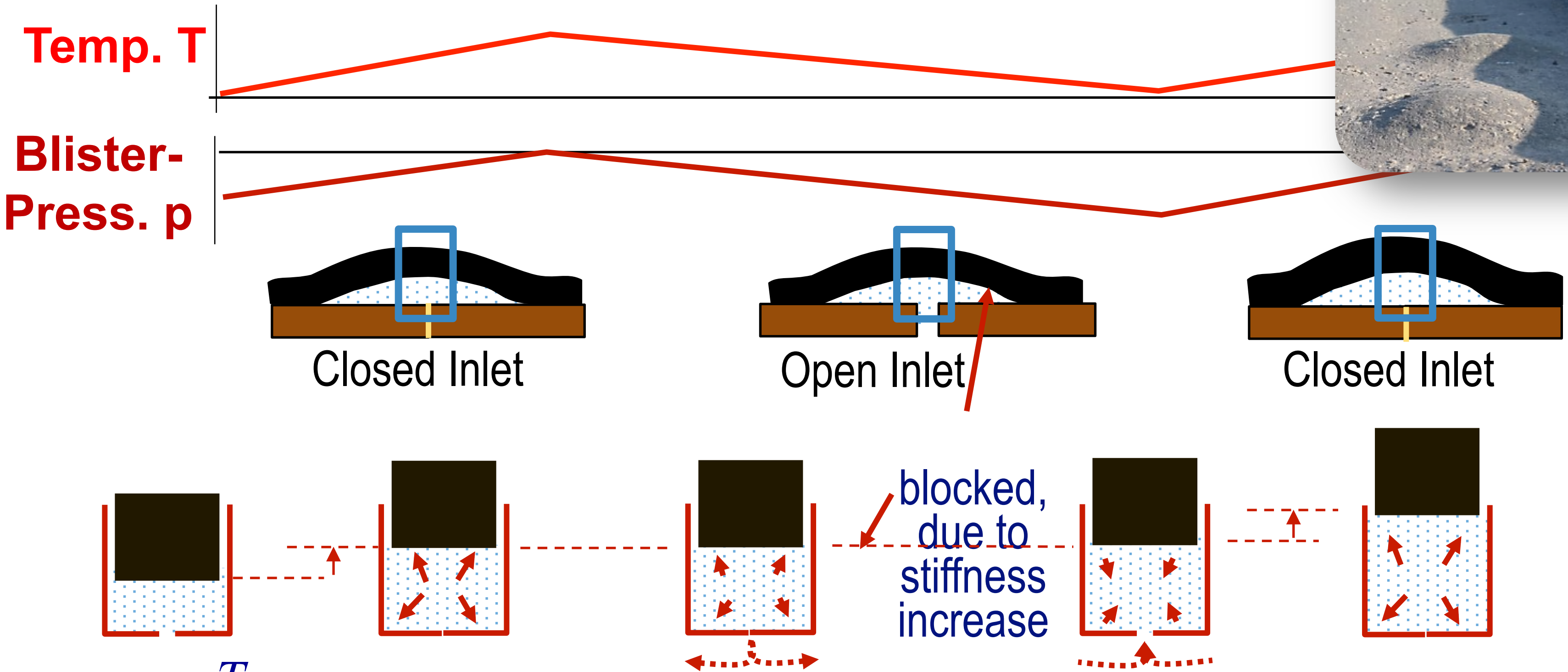




Empa
Materials Science and Technology

Mechanism of Blister Growth in MA

Pumping Effect



$$p = R\frac{T}{V}$$

Pressure growth and closing of inlet (dilatation)

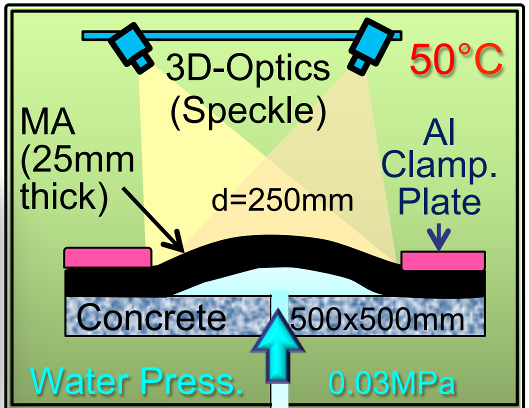
Pressure reduction & loosing some gas through inlet. (dilatation)

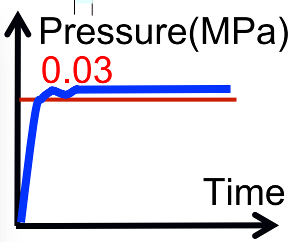
Opening of inlet (dilatation) & sucking gas due to under pressure

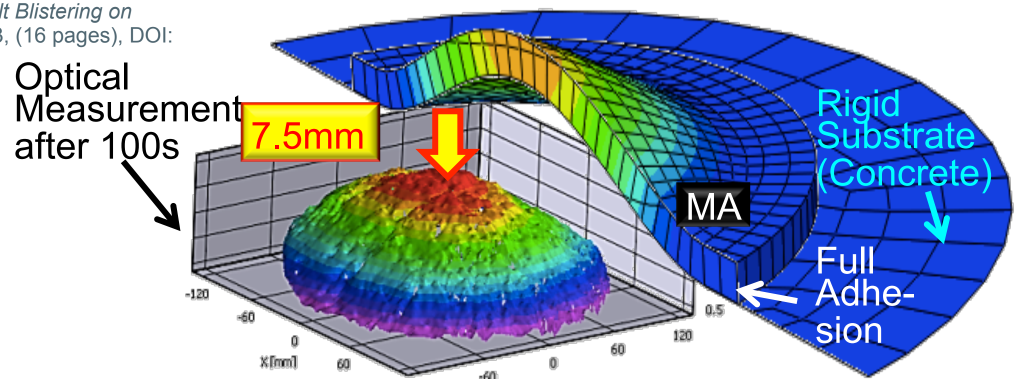
Next cycle

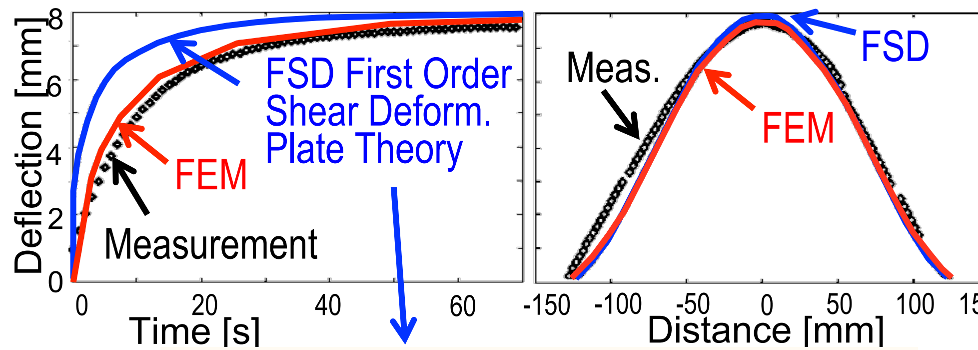
Blister Growth under MA

Hailesilassie, B. W., Partl, M.N.: *Mechanisms of Asphalt Blistering on Concrete Bridges*, J. of ASTM International, Vol 9, No 3, (16 pages), DOI: 10.1520/JAI104135 (2012)

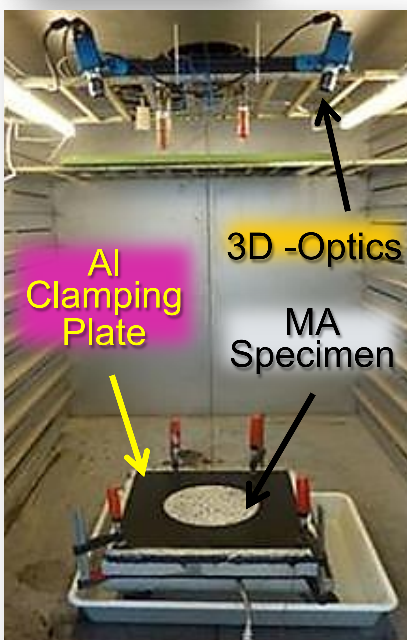




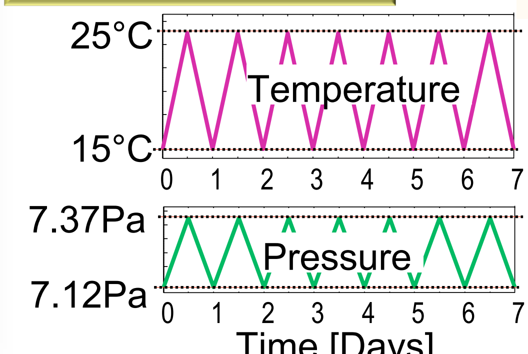


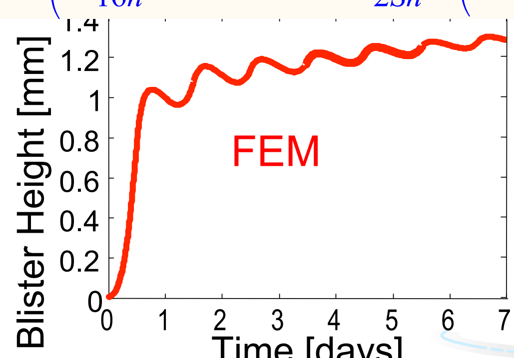


$$w_o(t) = \left(\frac{(3(1-\nu^2)}{16h^3}(R^2-r^2)^2 + \frac{R^2(1+\nu)}{2Sh}\left(1-(\frac{r}{R})^2\right)\right) p_0 D(t)$$



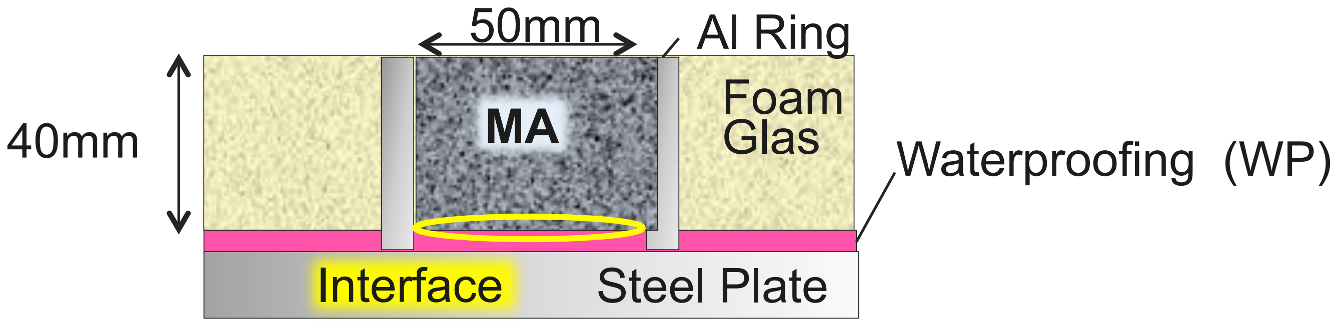
Repeated Loading

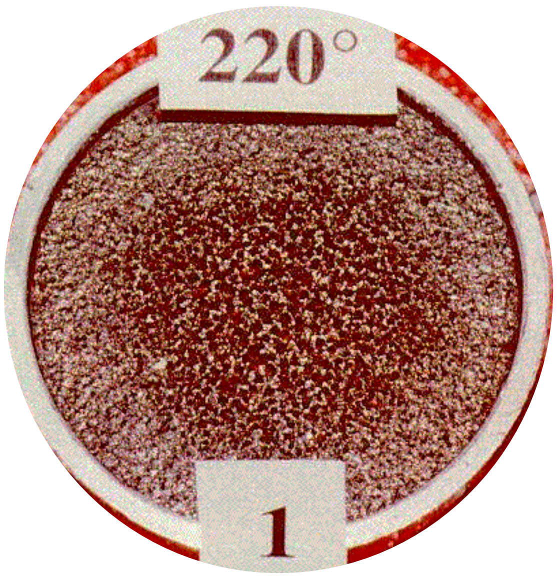


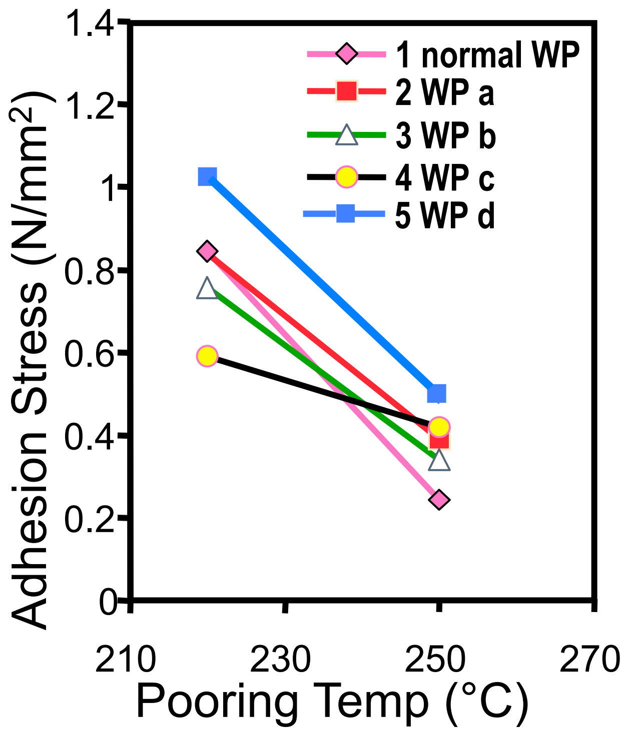


Empa
Materials Science and Technology

Effect of Pooring Temperature on Adhesion of Mastic Asphalt



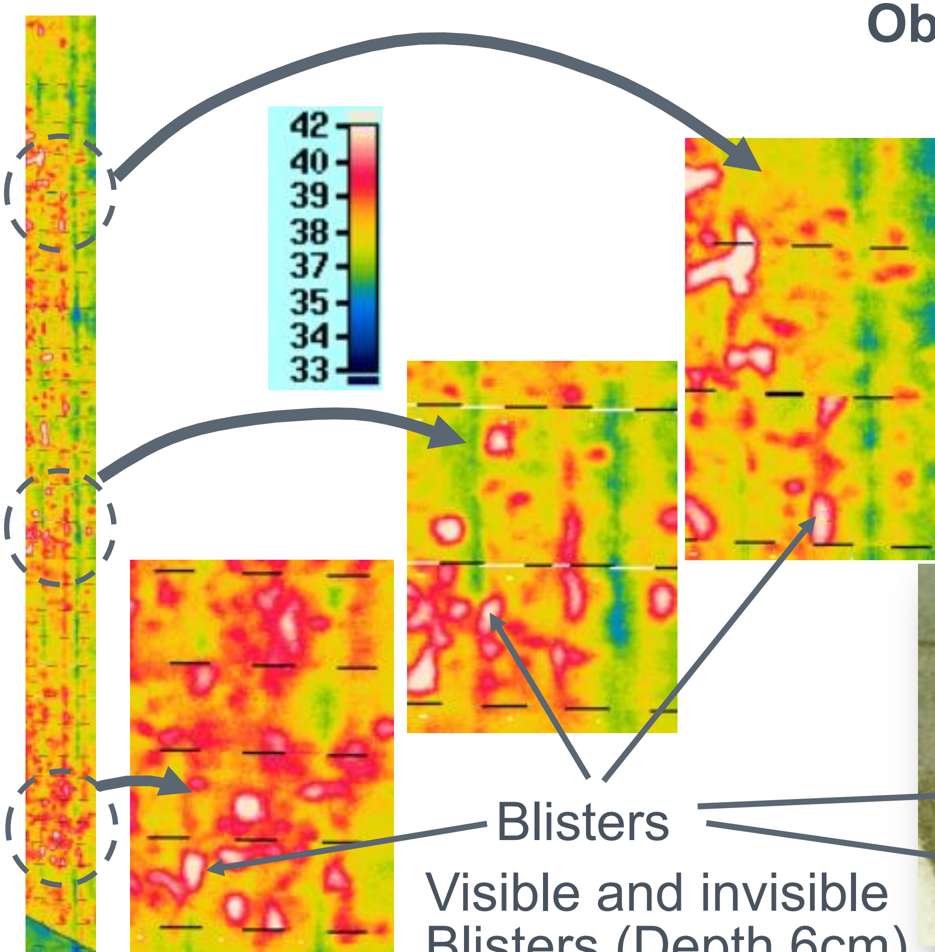




Empa
Materials Science and Technology

IR Thermography Detection of Blisters GA/Sealing Membrane

Object Z28/Canton. SO (45m)

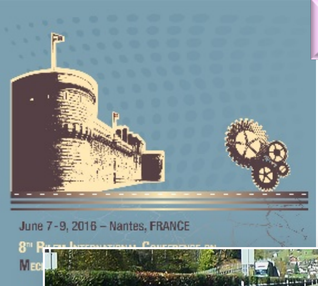


Right Lane

Blisters

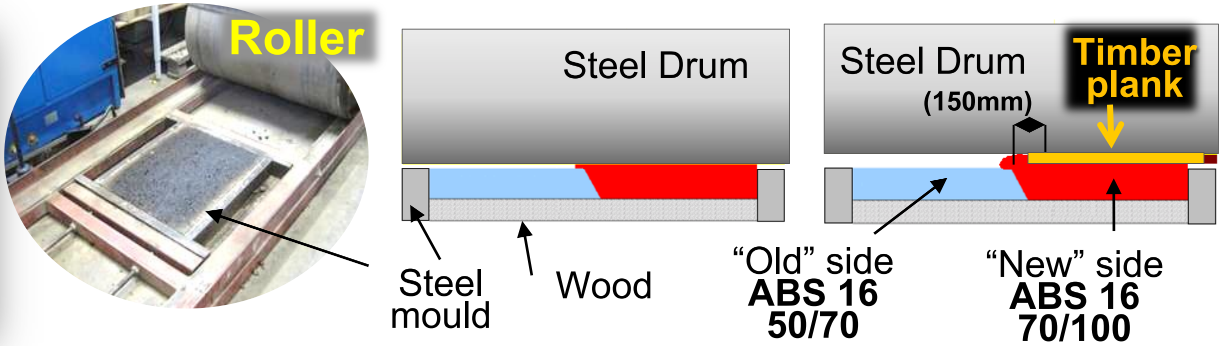
Visible and invisible Blisters (Depth 6cm)

Empa
Materials Science and Technology



Construction Joints

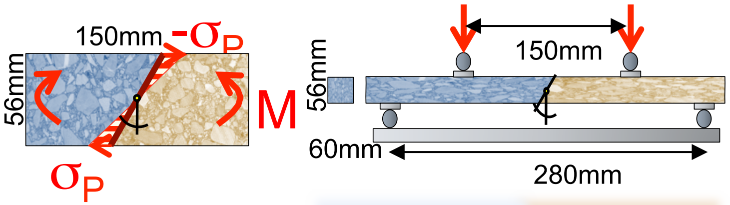
Ghafoori Roozbahany, E., Witkiewicz, P-J., Partl, M.N.: *Fracture Testing for Evaluation of Asphalt Pavement Joints.* RMPD, Vol.14, No4, pp764-791 (2013)



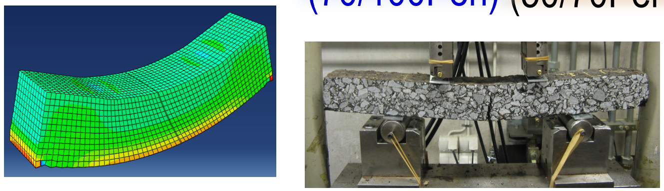
4 Pt. Bending 4PB:

(prism.,0.5; 5; 50mm/min)

→ Bending capacity of system (soft support)



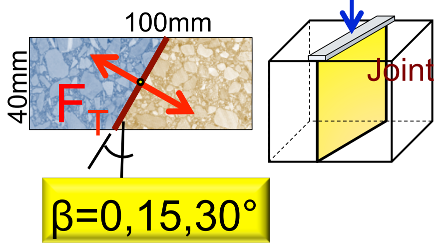
Fresh Side (70/100Pen) | "Old" Side (50/70Pen)

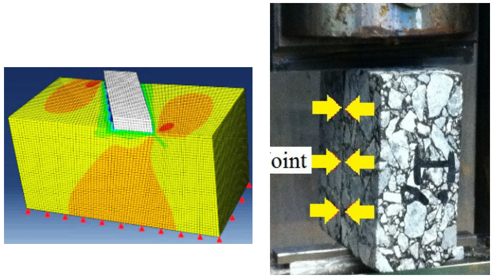


Indirect Tensile IDT:

(cubic spec., 50mm/min)

→Bonding capacity of joint

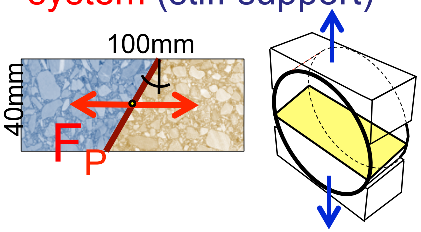


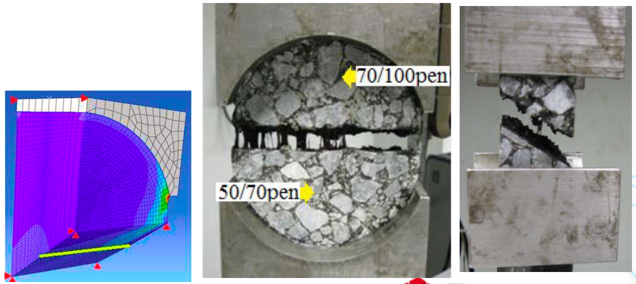


Direct Tensile DTT:

(cylin. spec., 22.3mm/min)

→ Tension capacity of system (stiff support)





Empa Materials Science and Technology

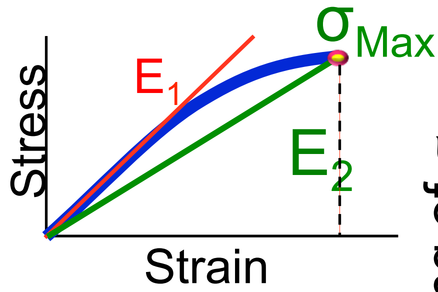
Construction Joints (Results)

Ghafoori Roozbahany, E., Witkiewicz, P-J., Partl, M.N.: *Fracture Testing for Evaluation of Asphalt Pavement Joints.* RMPD, Vol.14, No4, pp764-791 (2013)

Relative Ranking: $Y = Y_i - Y_{min} / Y_{max} - Y_{min}$

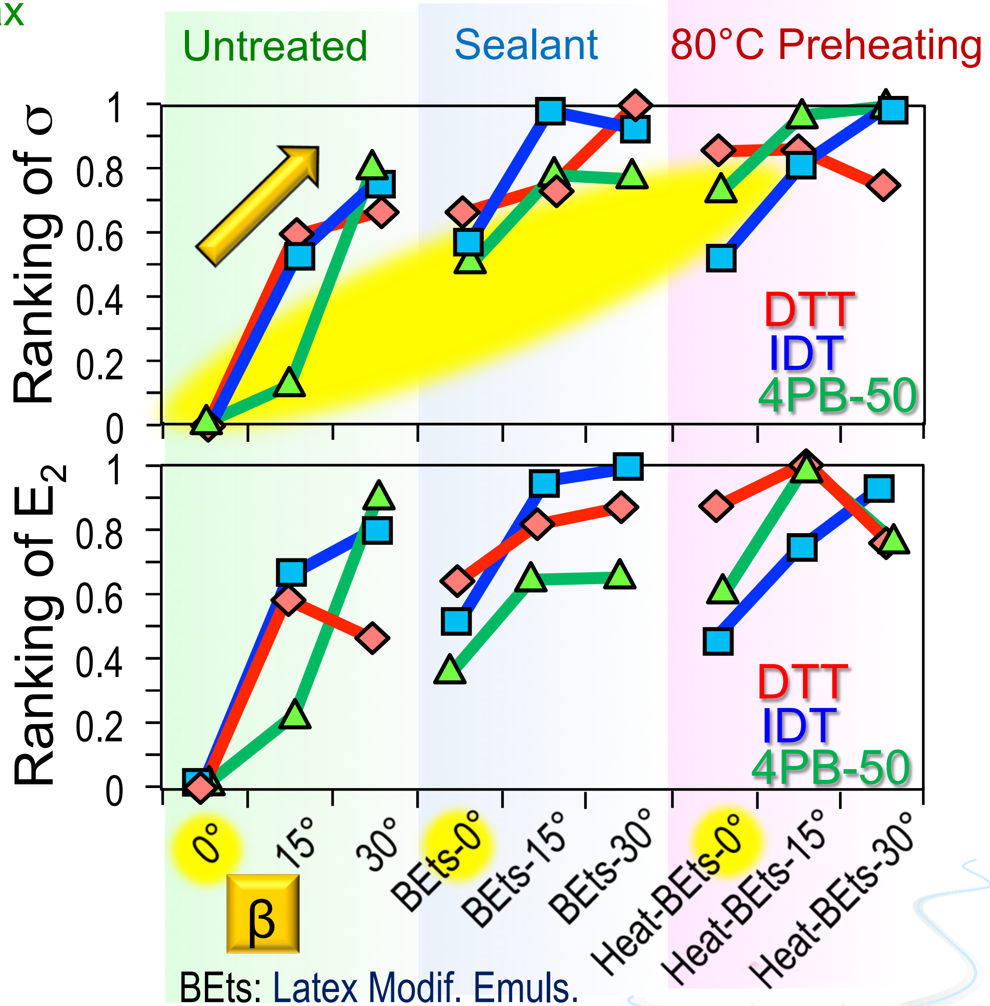
Measurement:

Max. Stress & Secant Modulus E_2



β=0,15,30°

	without plank			w. plank
Treatment	**0°**	**15°**	**30°**	**0°**
Untreated	⊛	⊛	⊛	⊛
Sealing	⊛	⊛	⊛	⊛
Preheating	⊛			
Preheating + Sealing	⊛	⊛	⊛	⊛
Bets (polymer mod.)	⊛			

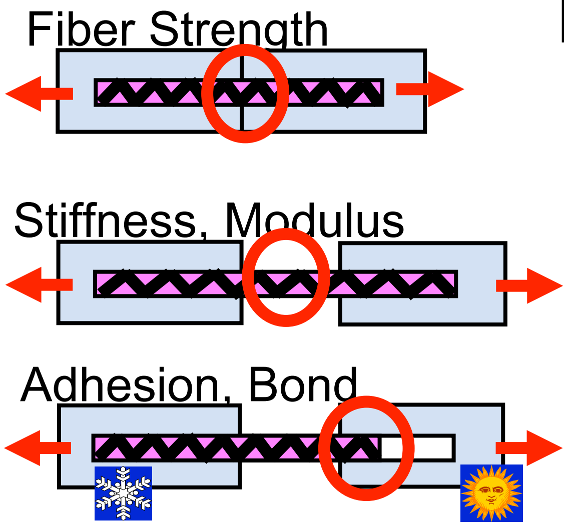


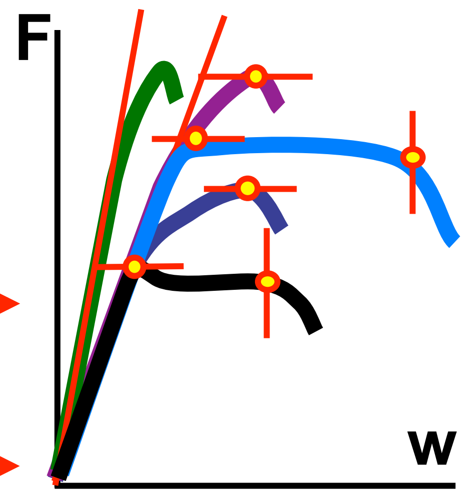
Findings:

- P+S superior to untreated joints
- Joints w. slope surface better properties
- Compaction hot to cold better (w plank)
- Lab tests assessment promising
  cubic IDT, DTT, 4PB

Reinforcement of Asphalt

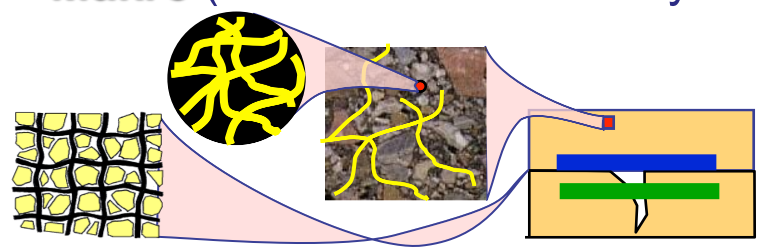
Mechanical Principles:





Reinforcement Scales:

- **Nano** (Binder…Molecules…PmB)
- **Mikro** (Mastic…Fibers…Filler)
- **Meso** (Asphalt…Fibers…Skeleton)
- **Makro** (Pavem...Reinforc. Layers)

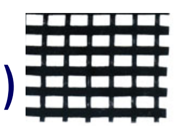


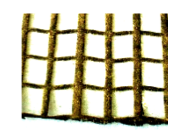
Role of Crack Reinforcement:

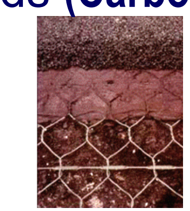
- Crack Bridging **(= Passive Role)**
- Crack Prevention **(= Active Role)**

Types

- Fibers **(pre-coat..)**
- Grids **(Carbon..)**



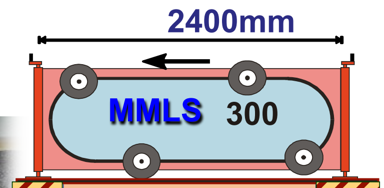


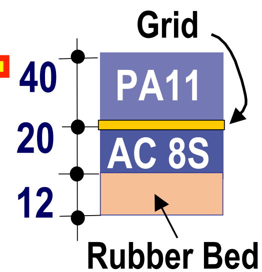


MMLS Fatigue Tests:

ca **320‘000**

ca **380‘000**



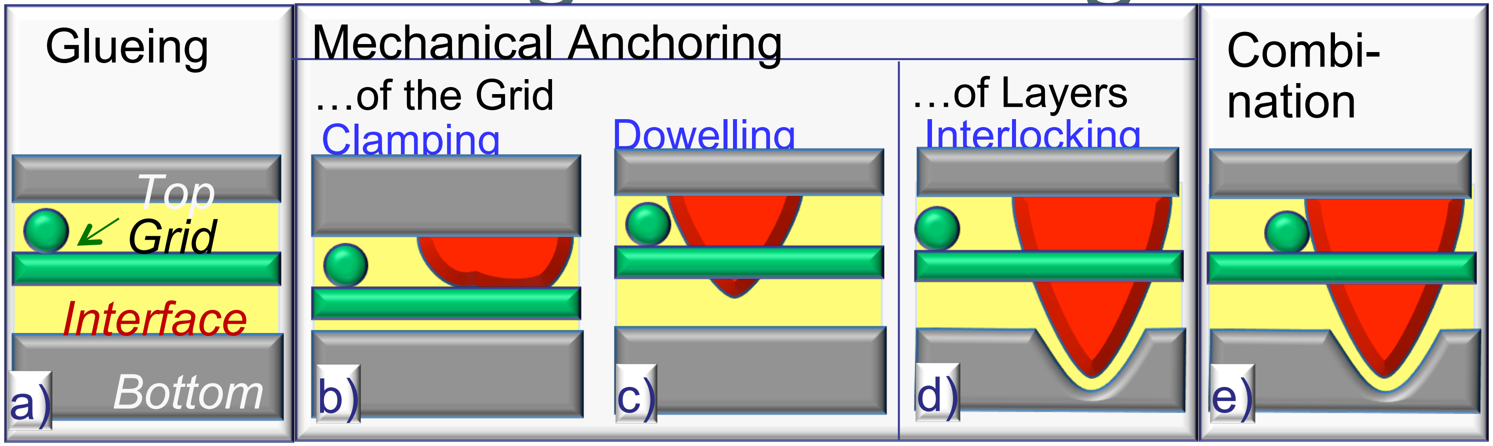


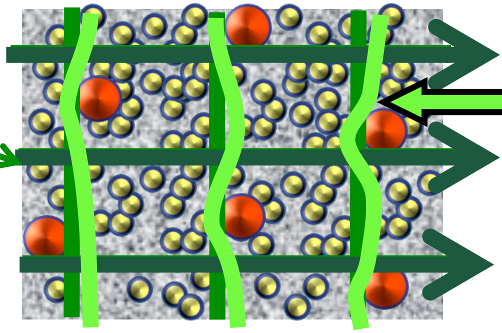
Passings until Full-Depth Longitudinal Cracks

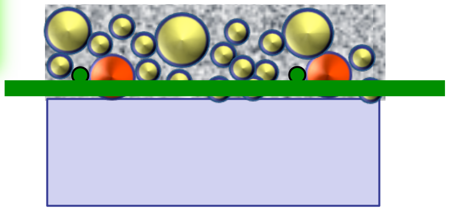
Empa
Materials Science and Technology

Grid Reinforcement Mechnisms: Bonding & Anchoring

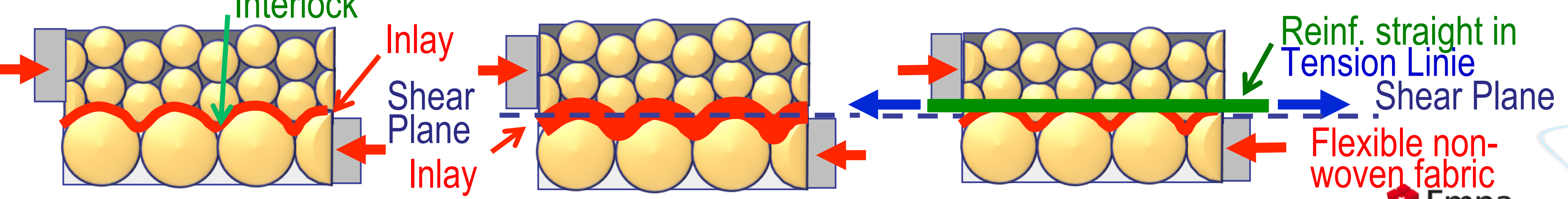
Mecha-nisms:

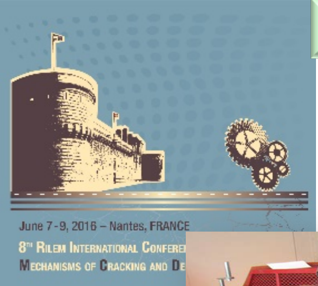




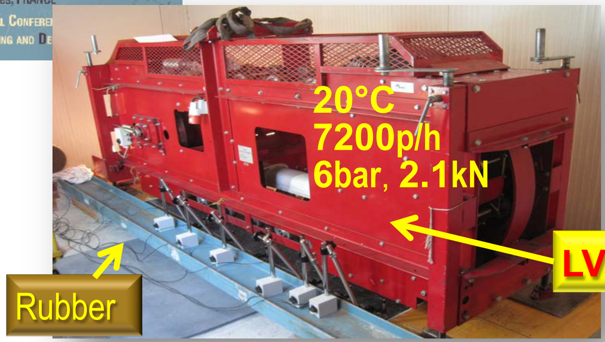


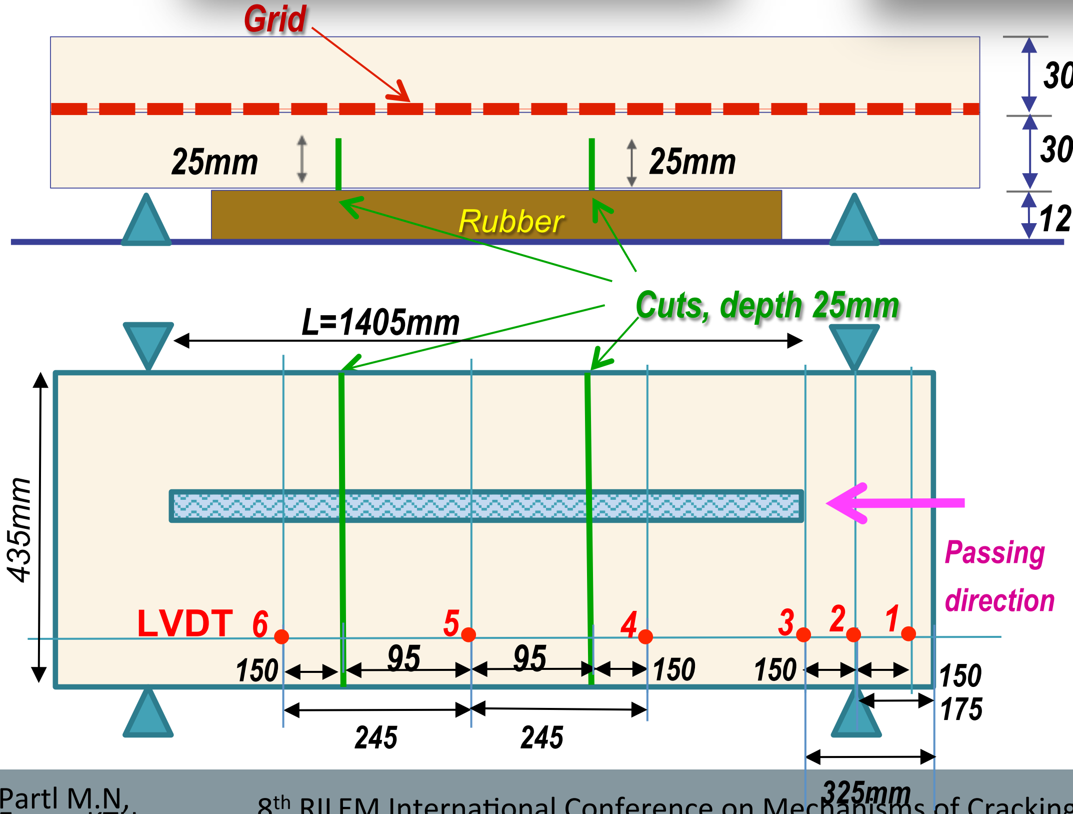
Reinforcement Effect

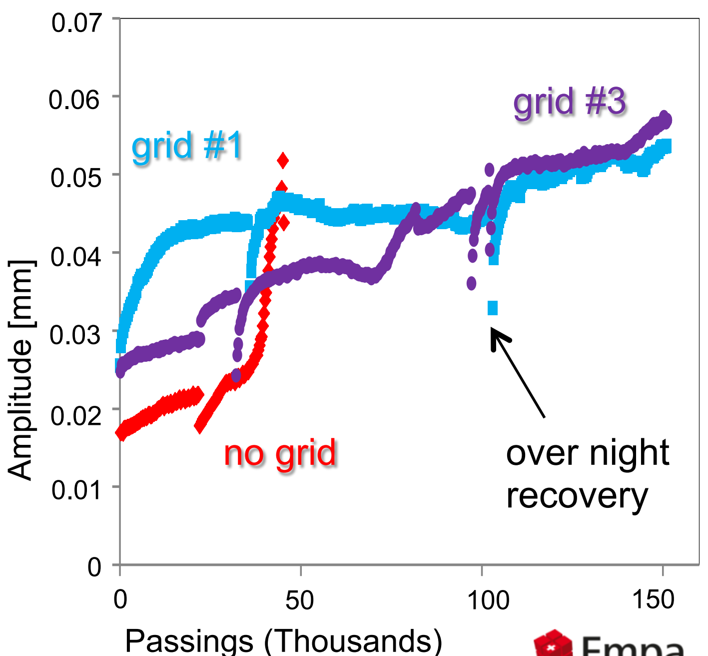




Grid Reinforcement

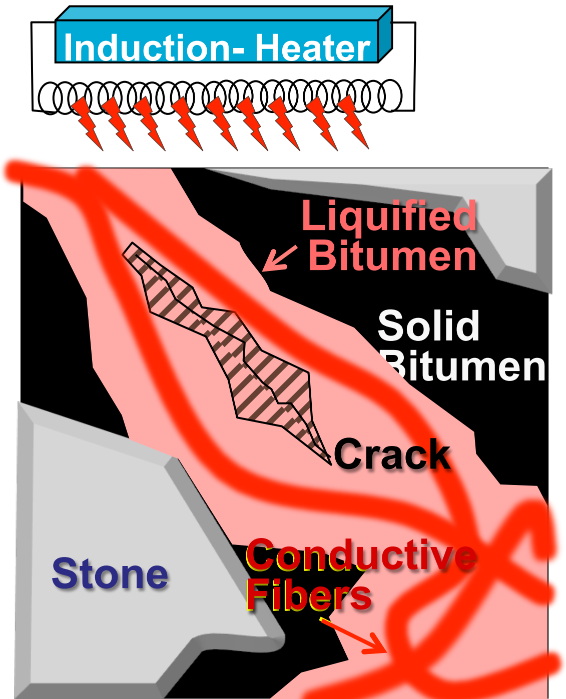


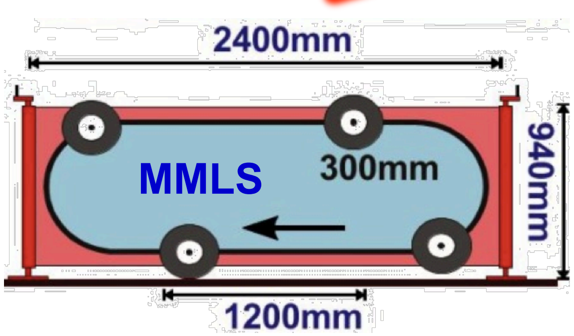


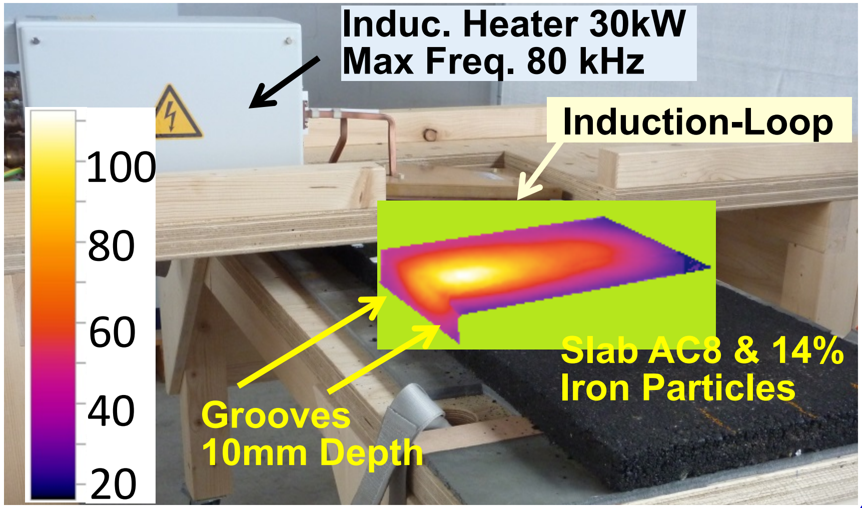


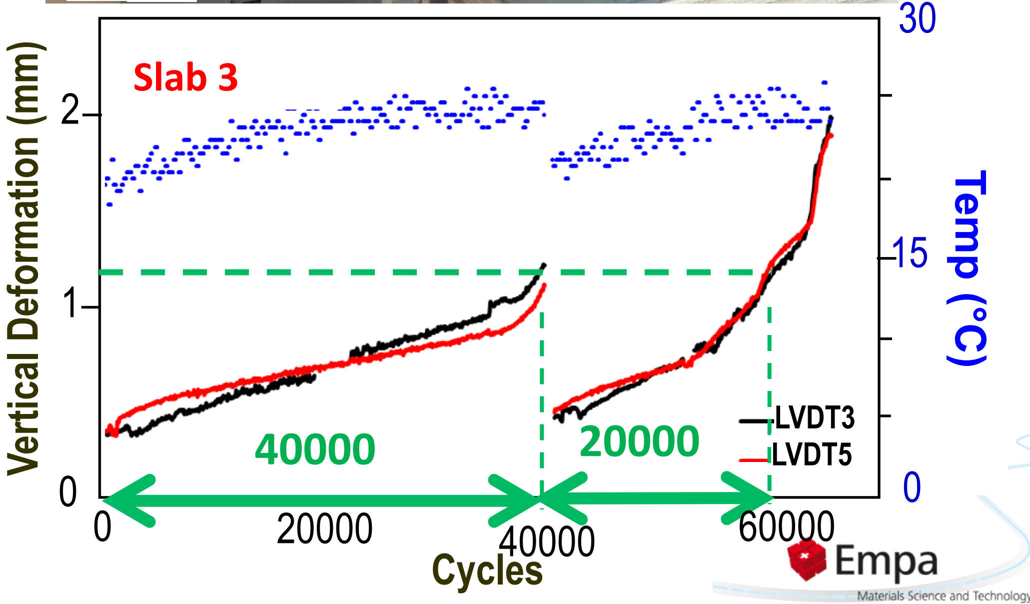
Induction Heating & Fatigue

Bueno, M., Andrés, J..Arraigada, M., Partl, M.N.: Digital Image Correlation for monitoring Induction Healing of Cracks in Asphalt Roads. RILEM-MCD Nantes (2016)



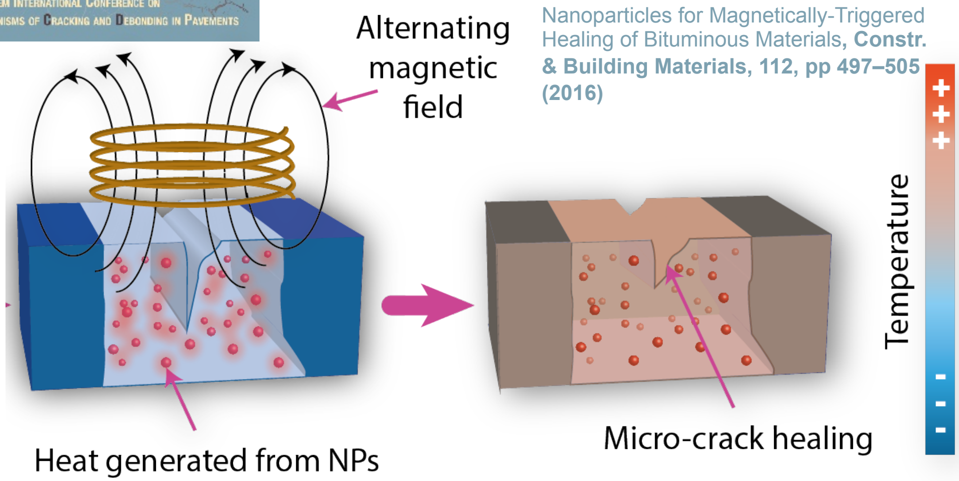


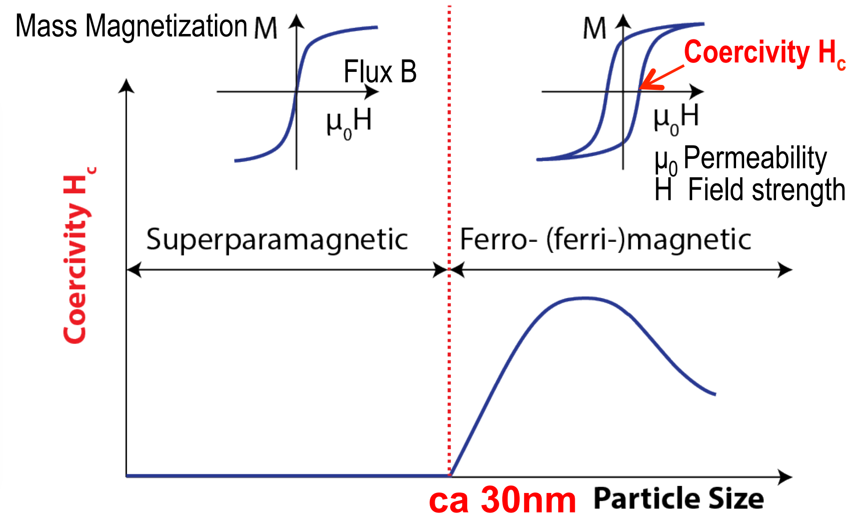




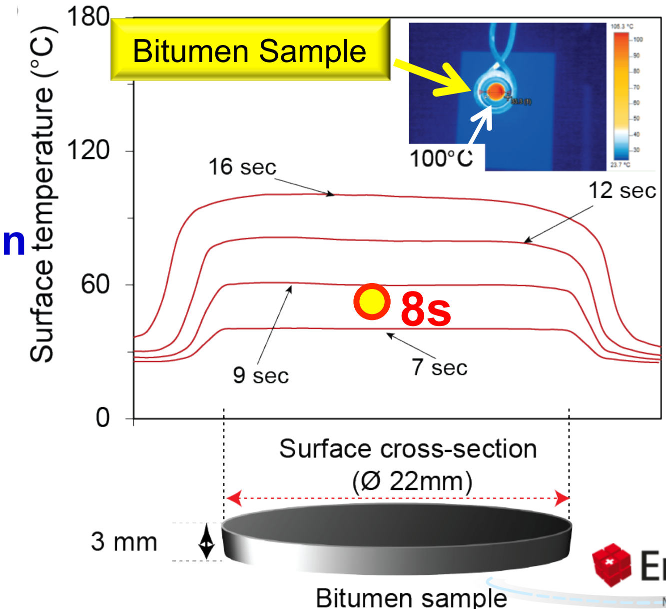
Healing w. Magnetic Nanoparticles

Joeffroy, E., Koulialias, D., Yoon, S., Partl, M.N., Studart, A.R.: Iron Oxide Nanoparticles for Magnetically-Triggered Healing of Bituminous Materials, **Constr. & Building Materials, 112, pp 497–505 (2016)**





- Nanoparticles generate **hysteresis** through magnetization reversal
- The **heat** generated corresponds to the hysteresis area (the larger, the hotter…)
- The area & coercivity H_c is maximum near **transition** superparamagnetic/ferromagnetic (≈ 30 nm)



Results

- 50°C increase reached in **8s** with 1 vol.% 50nm
- Iron oxide nanoparticles: **Homogeneous** heating!

Empa
Materials Science and Technology

Conclusions

- Characterization and detection of **debonding phenomena** in asphalt pavements and on bridge decks are key issues for functionality of pavements but still need a lot of research
- **Adhesion testing** between bit. binders & aggregates: Variability of results is still high & new advanced tests are needed. Influence of aggregate appears larger than of the binder type.
- **Pumping** has a tremendous effect on stripping in case of PA. With MMLS3 it was found that lifetime can be reduced by 1/3.
- **Interlayer properties** need more fundamental understanding, in particular regarding roughness and combined mechanical and climatic effects
- **GPR** may be helpful for detecting debonding and blistering

Empa
Materials Science and Technology

Conclusions

- Interayer bond is an important **quality** issue for construction
- **APT** clearly demonstrates the importance of full interlayer bond for structural functioning of pavements
- **Construction joints** are neglected in research but a key for functionality and durability; test methods are still missing.
- **Reinforcement** without fundamental understanding of bonding may be useless and risky
- **Micro-crack healing** with induction or magnetic nanoparticles has a some potential to reduce adhesive and cohesive damage; it is still at the beginning of research and still far from implementation

June 7-9, 2016 – Nantes, FRANCE
8th RILEM International Conference on Mechanisms of Cracking and Debonding in Pavements

Thank You

7TH EATA CONFERENCE – EUROPEAN ASPHALT TECHNOLOGY ASSOCIATION
12 – 14, JUNE 2017, ZÜRICH, SWITZERLAND
VENUE – EMPA, DÜBENDORF
eata

Empa
Materials Science and Technology