Bitumenlos:
Wir stricken uns einen Strassenbelag

Pietro Lura

Infra-Webinar Strassen- und Tiefbau 2021, Lenzburg

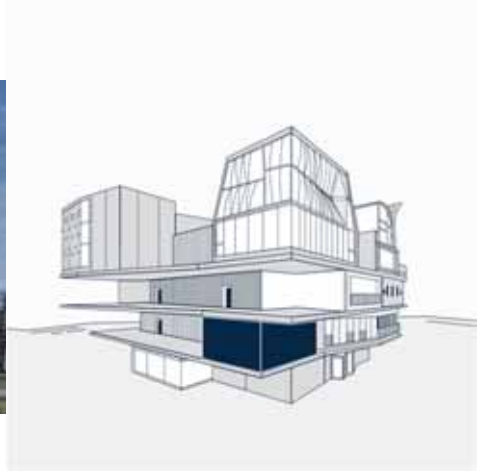
Content of this presentation

- Let’s get to know each other
- The environmental footprint of concrete and asphalt
- Recycling, low temperature pavements
- **Knitting a road with stones and strings … and a helpful robot**
- A radical solution to the CO_2 emissions problem

Concrete and Asphalt Laboratory
Labor Beton und Asphalt

Empa, Swiss Federal Laboratories for Materials Science and Technology is an interdisciplinary research institute for material sciences and technology development within the ETH domain in Switzerland

About 30 research labs, ~1000 employees



Concrete and Asphalt Laboratory

Merger in 2020 of *Concrete and Construction Chemistry* and *Road Engineering/Sealing Components Laboratories*

Outstanding laboratory facilities - new asphalt lab in fall 2021

Our main partners:

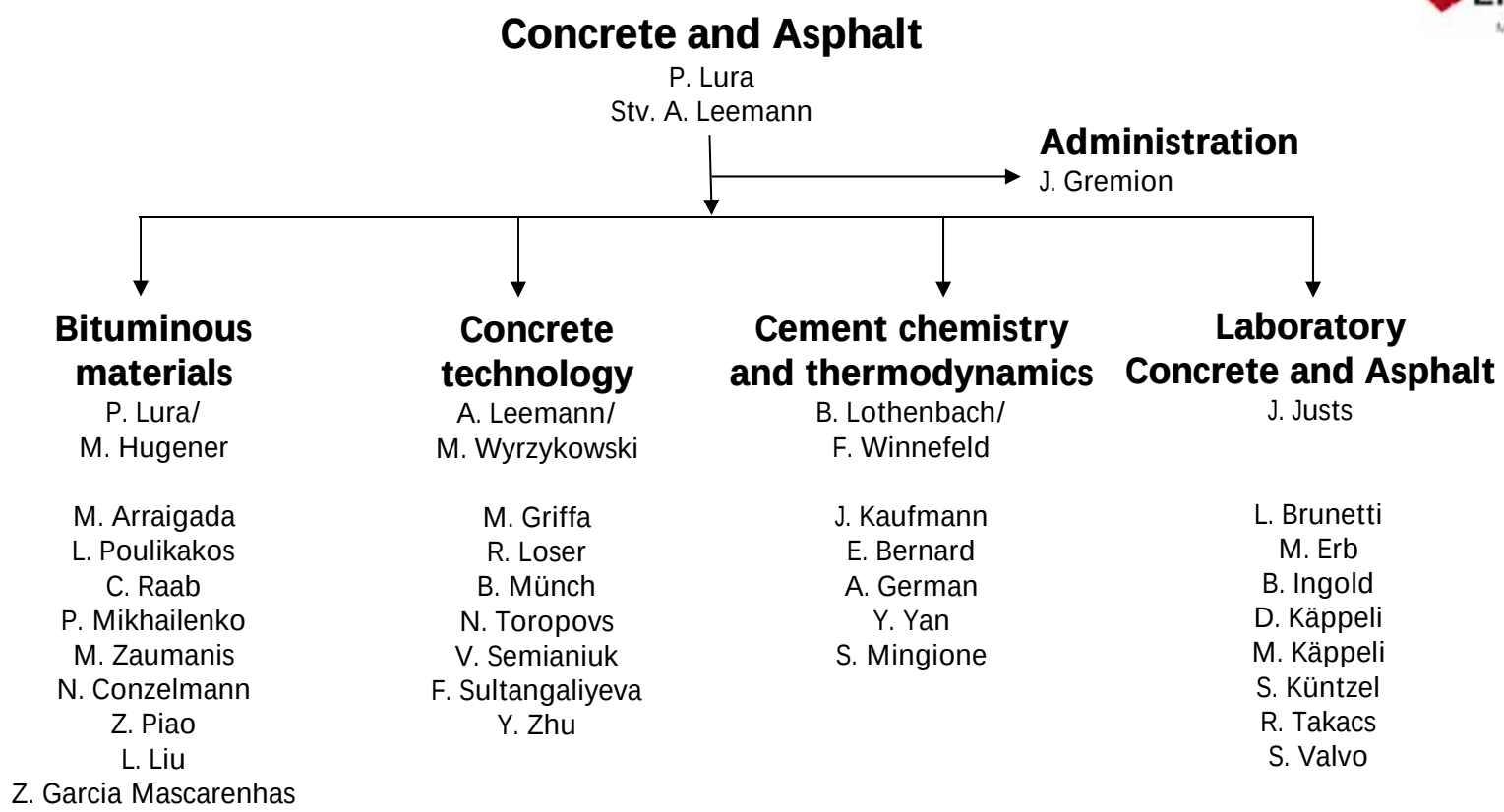
Prof. Dr. Pietro Lura

- 2020 – **Concrete and Asphalt** (~40 people)
- 2008 – 2020 Concrete and Construction Chemistry (~30 people)
- 2011 – Professor (TP) for Concrete Technology

Editor in Chief of Materials & Structures 2016-19
Treasurer from 2019
RILEM Fellow 2019
RILEM L'Hermite Medal 2009

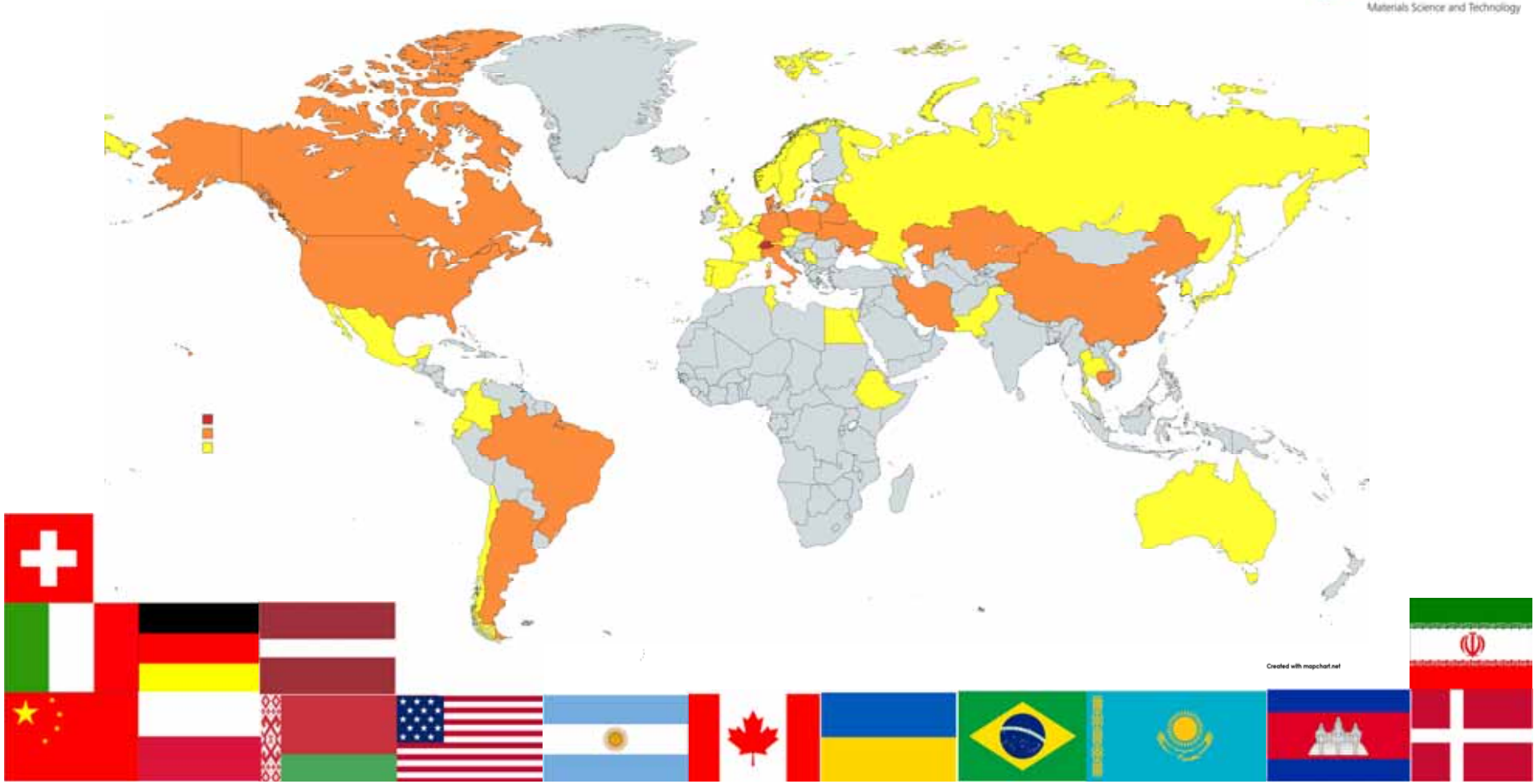
Publications: ~110 SCI(E) papers, h-index 42 and >4500 citations in Web of Science

Personal research interests: shrinkage and cracking of concrete, concrete durability, concrete in fire, cement-bitumen emulsion composites, carbon sequestration in concrete and asphalt, 3D imaging, machine learning

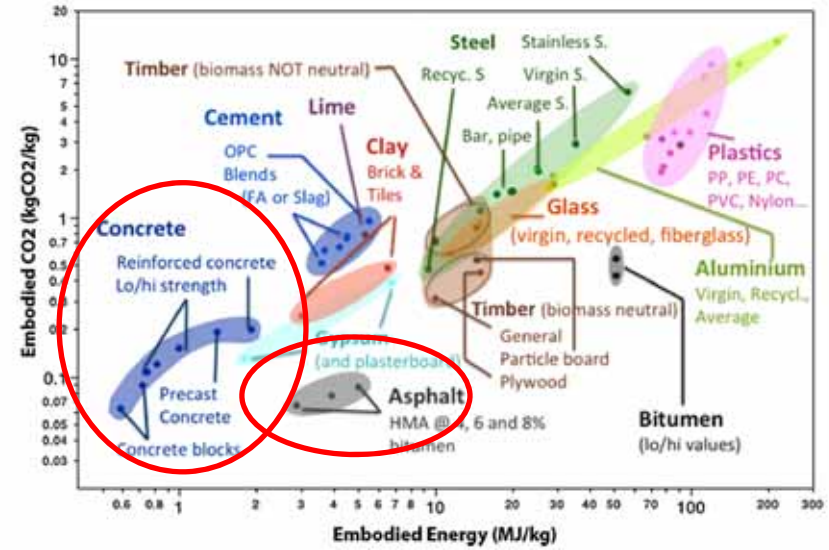

Concrete and Asphalt
P. Lura
Stv. A. Leemann
Administration
J. Gremion
Bituminous materials
P. Lura/
M. Hugener
M. Arraigada
L. Poulikakos
C. Raab
P. Mikhailenko
M. Zaumanis
N. Conzelmann
Z. Piao
L. Liu
Z. Garcia Mascarenhas
Concrete technology
A. Leemann/
M. Wyrzykowski
M. Griffa
R. Loser
B. Münch
N. Toropovs
V. Semianiuk
F. Sultangaliyeva
Y. Zhu
Cement chemistry and thermodynamics
B. Lothenbach/
F. Winnefeld
J. Kaufmann
E. Bernard
A. German
Y. Yan
S. Mingione
Laboratory Concrete and Asphalt
J. Justs
L. Brunetti
M. Erb
B. Ingold
D. Käppeli
M. Käppeli
S. Küntzel
R. Takacs
S. Valvo

Empa

Materials Science and Technology



Concrete and Asphalt: the present challenges



Moderate specific embodied CO_2 / energy

But large impact due to huge quantity produced
(CH: ~34 Mt concrete + 6.5 Mt asphalt in 2018)

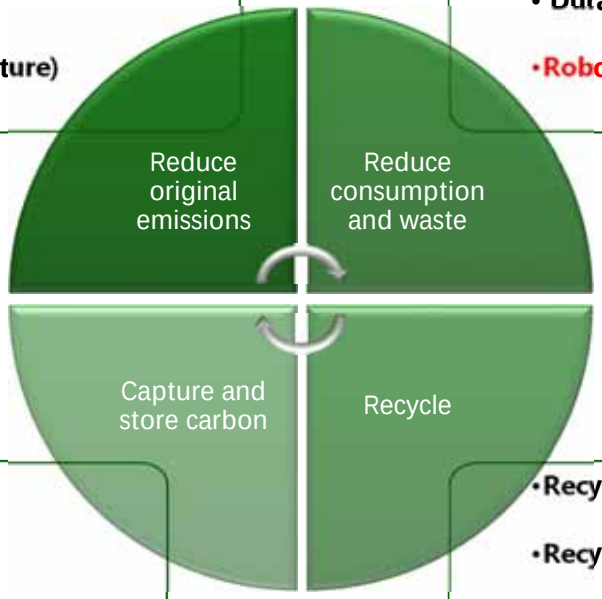
Production of cement causes ~8% CO_2 emissions
Bitumen is a byproduct of oil refinement
Aggregates for concrete and asphalt are becoming scarce

Concrete and Asphalt: the sustainable future

Empa
Materials Science and Technology

- Eco-friendly cement (alternative binders/less clinker)
- Optimized binder content in concrete
- **Warm/cold asphalt (lower/no heating of mixture)**

- Durable concrete (less repair)
- **Durable, noise reducing roads**
- **Robotic pavements**



- Net-negative CO_2 cement
- CO_2 sequestration in recycled concrete aggregates
- **Carbon sequestration in concrete and asphalt**

- **Recycled aggregates (asphalt and concrete)**
- **Recycled tires, plastics**
- **Cross-recycling concrete/asphalt**

Recycled Asphalt Pavements (RAP)

Empa
Materials Science and Technology

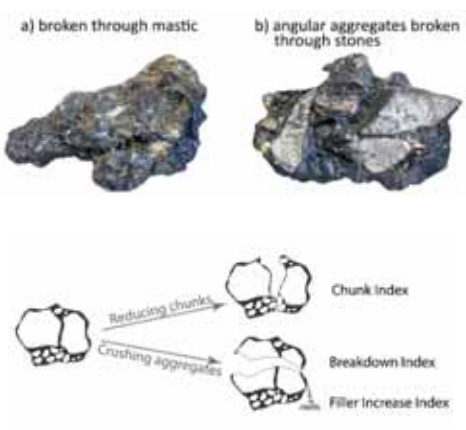
HighRap Project *M. Zaumanis*

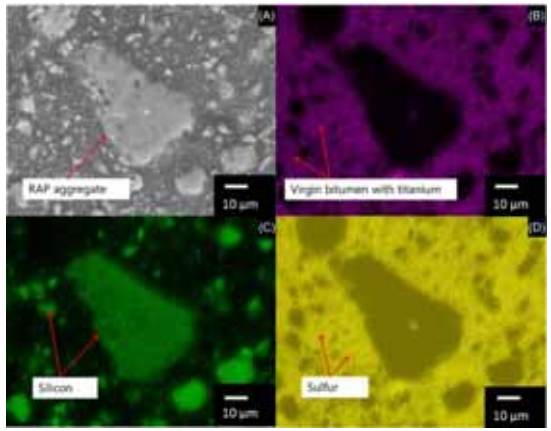
- Morphology of milled RAP and how RAP is incorporated into new asphalt
- Develop new admixtures (rejuvenators)
- Increase amount of RAP used

AMMANN

Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAM
Uffizi federal d'ambient UFAM

Schweizerische Eidgenossenschaft
Bundesamt für Strassen ASTRA

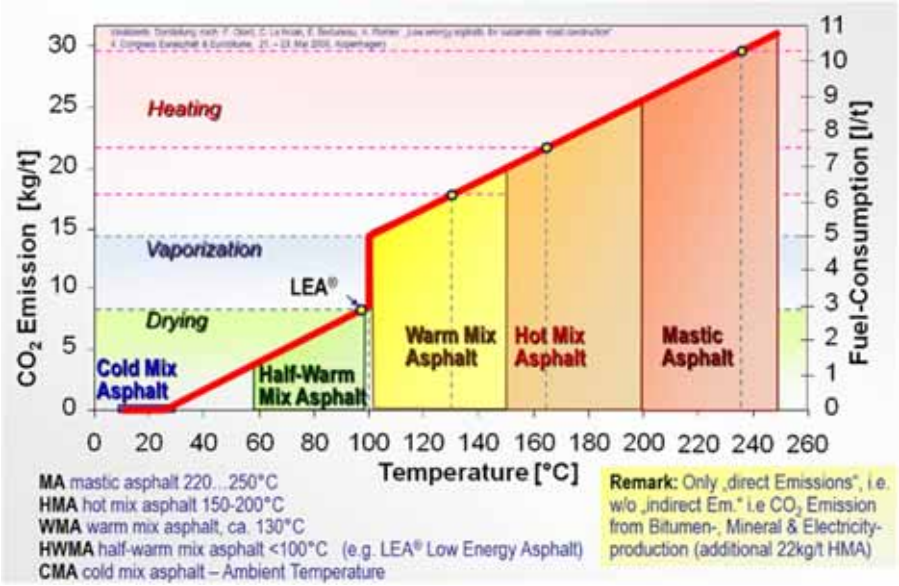


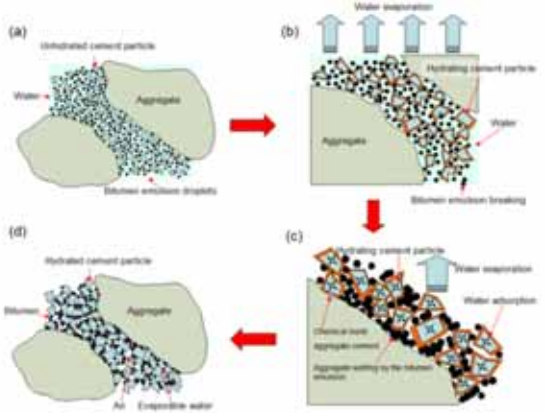


Cavalli, Griffa et al. J of Microscopy 2016

Bitumen emulsions (1)

- Slurry seal: thin layer, quick drying
- Slow breaking and drying: limit for applications in cold-mixed asphalt (thick layers)
- Without cement or $Ca(OH)_2$ addition, cold mixes have poor mechanical performance and high moisture susceptibility
- Cement or $Ca(OH)_2$ have high CO_2 emissions!

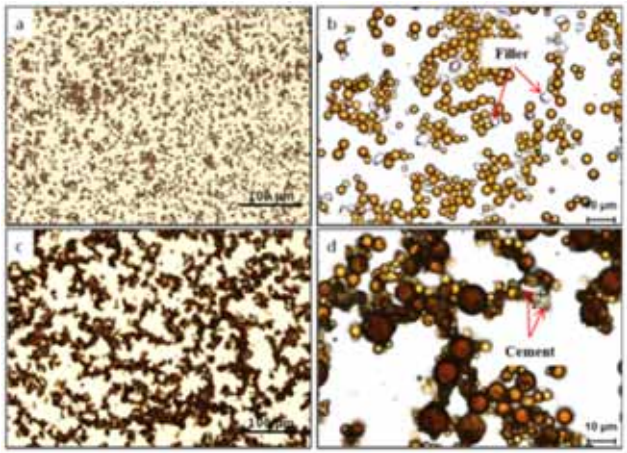




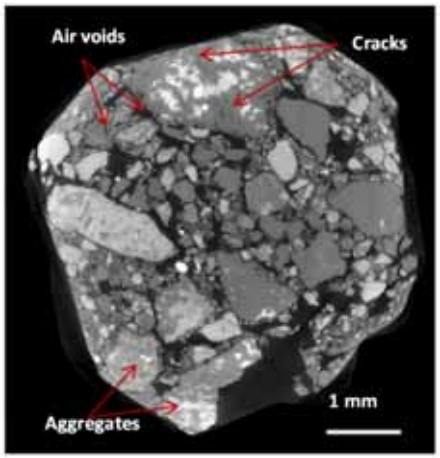
Garcia, Lura et al. M&S 2013

Bitumen emulsions with cement additions (2)

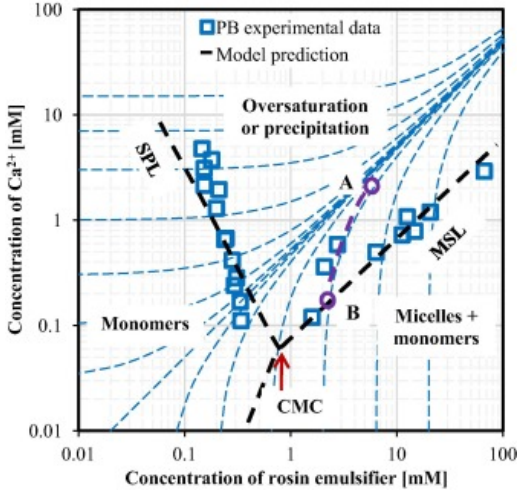
PhD Xing Fang ETH Zürich (2016)



Stability of diluted emulsions



X-ray microtomography of composite



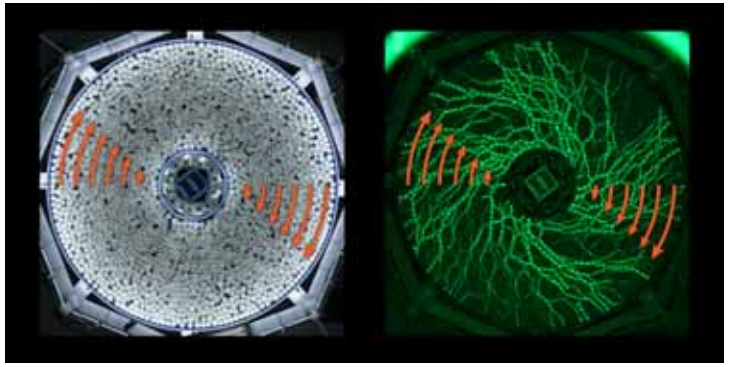
Influence of Ca^{2+} ions on emulsifier

Fang, Garcia, Winnefeld, Partl, Lura Mat Struct 2016, J Mat Civ Eng 2016, J Coll Int Sc 2016, RILEM Tech Lett 2016

New ideas (IRC NET Zero 2021, Empa funding)

- Emulsion breaking triggered by with ultrasound / electric current

Granular systems

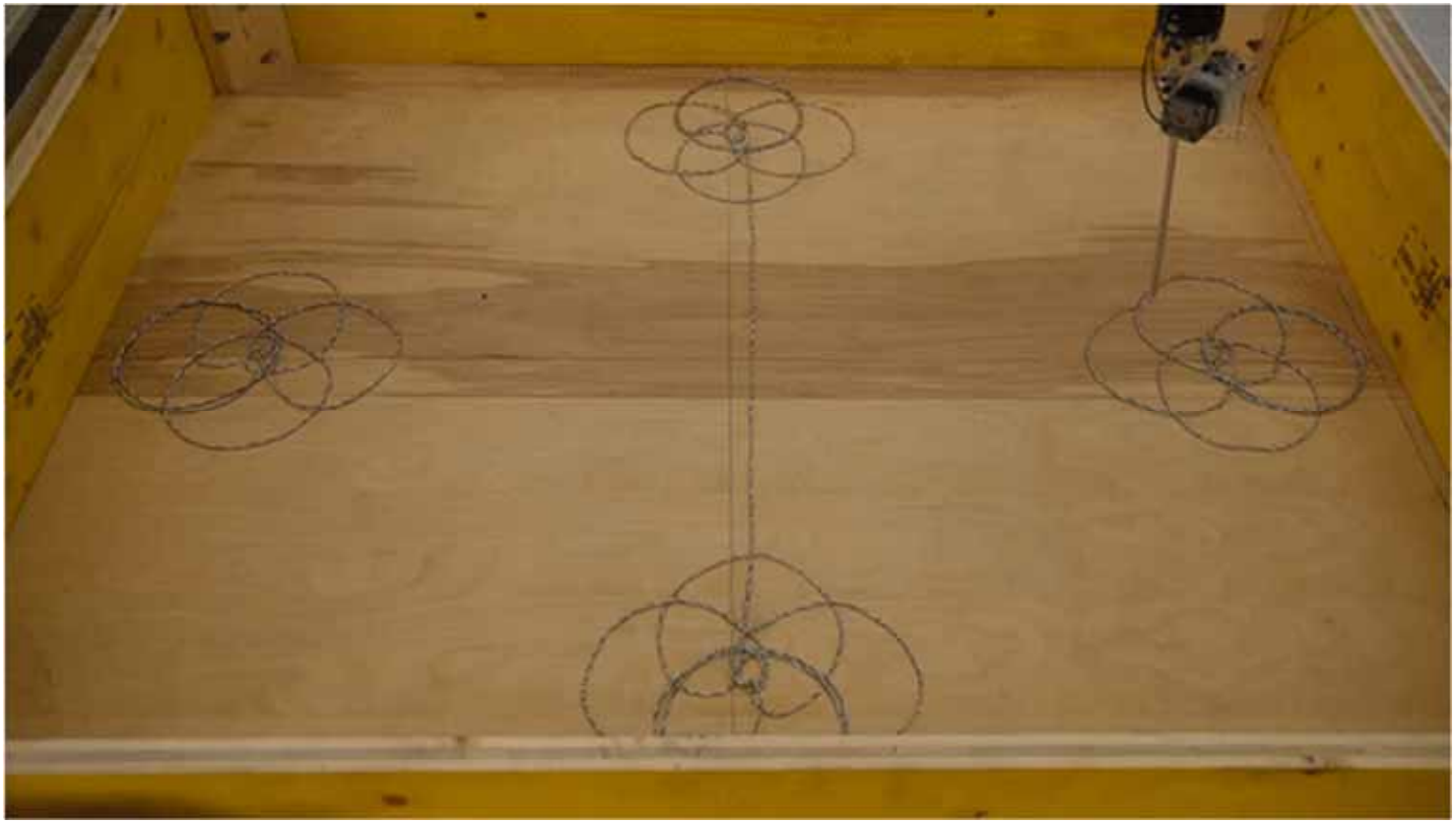


Yiqiu Zhao, Duke University

- Granular systems: fluid ⇔ solid (*jamming transition*), depending on external forces
- Jamming is important e.g. in earthquakes (stick-slip)
- No permanent bond between particles (cohesionless), but interlocked to form marginally stable structures
- **Provide ”cohesion” with a continuous fiber deployed along a predetermined path**

Rock Print

Empa
Materials Science and Technology



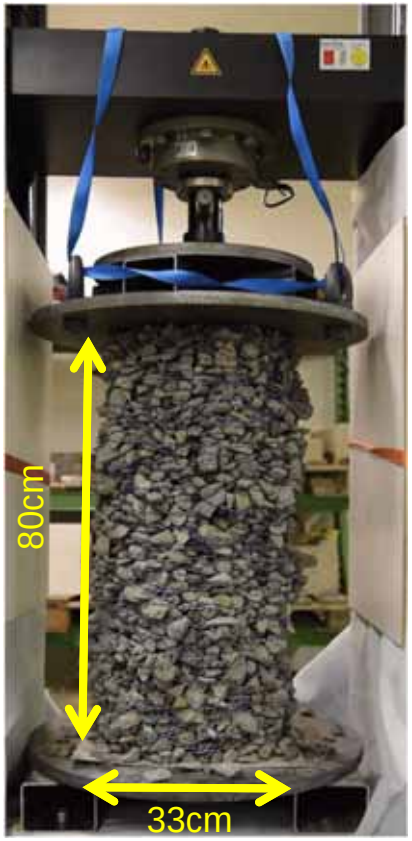
Gramazio Kohler Research, ETH Zurich, and the Self-Assembly Lab, MIT. Chicago (2015)

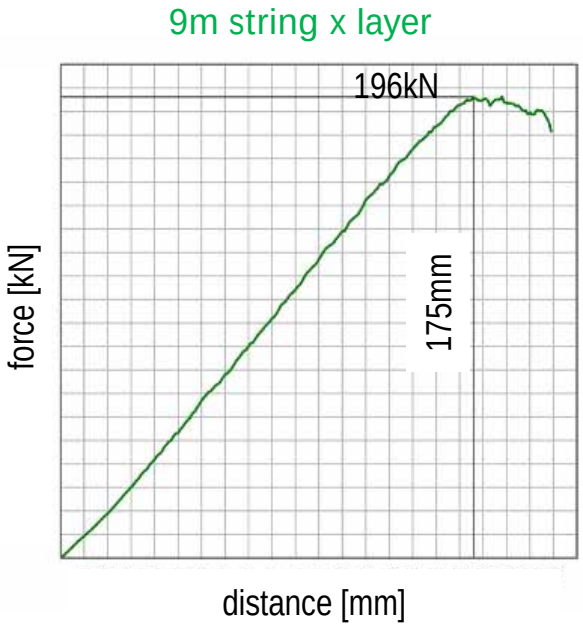
Rock Print Pavilion

Gramazio Kohler Research
Rock Print Pavilion, Winterthur (2018)

Video:
https://vimeo.com/294086902

Mechanical behaviour





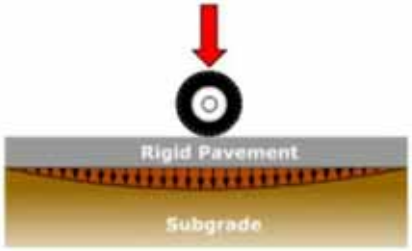
Rusenova, G., Wittel, F. K., Aejmelaeus-Lindström, P., Gramazio, F., & Kohler, M. (2018) 3D Printing and Additive Manufacturing

Application to pavements

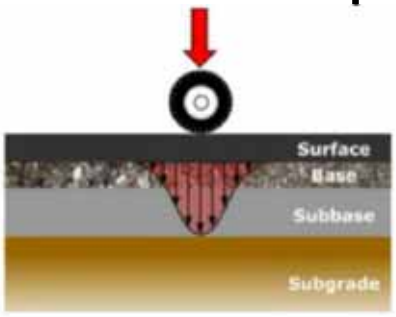
Schweizerische Eidgenossenschaft
Bundesamt für Strassen ASTRA

Empa
Materials Science and Technology

M. Arraigada, S. Abbasion



Rigid pavement



Flexible pavement

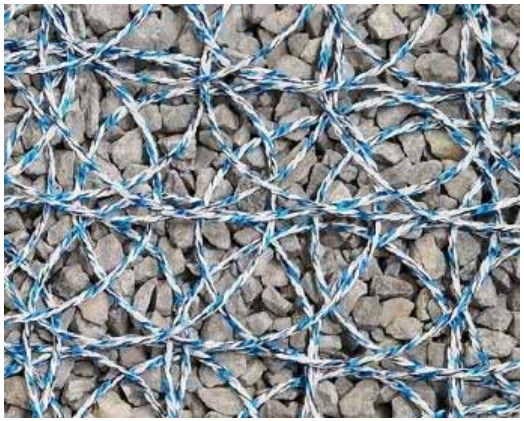
Pavements:

- Multilayer structures (asphalt/concrete/unbound)
- Layers: plates on elastic foundation
- Carry loads from the surface to natural ground

Reframing of the Rock Print idea:

Reinforce unbound layers with strings to distribute loads and reduce thickness

Advantages: **no binder needed**, highly recyclable, very porous



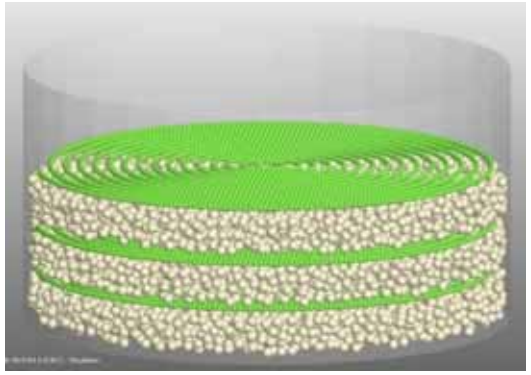
Methods

Laboratory experiments:

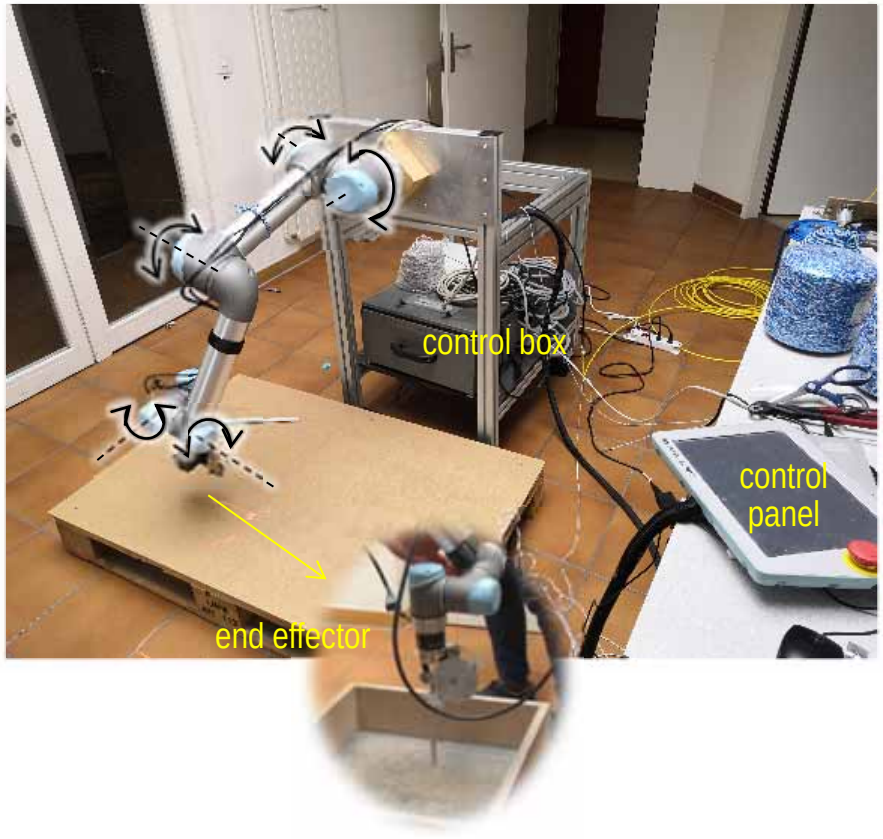
- Lab specimens with different aggregates, fiber material and reinforcement deployment strategies
- Mechanical tests: static and dynamic uniaxial plate loading
- Rutting tests using confined slabs on rubber mats

Numerical modelling:

- Structural configuration of selected material will be simulated utilizing Discrete Element Method (DEM) to different types of loading
- Simulate reinforcement strategies, particle size and deployment: parametric study



Robotic arm (1)



Universal Robots- UR5

6 degrees of freedom

Payload 5 kg

Max reach 85 cm

Pattern designed with Rhino® and Grasshopper®/Python plugin

End effector pulls string at same speed of the robotic arm, controlled with Arduino

Robotic arm (2)

Empa
Materials Science and Technology

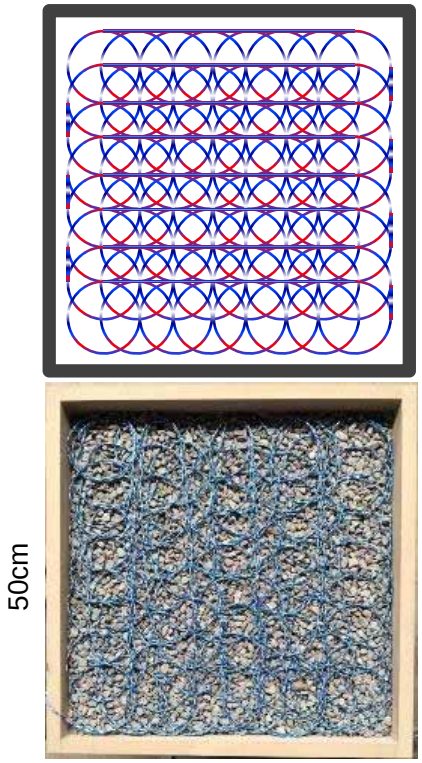
old end-effector

new end-effector

New, redesigned end effector

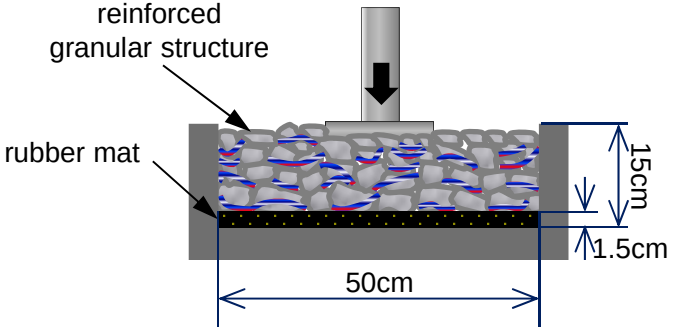
Cyclic plate loading tests (1)

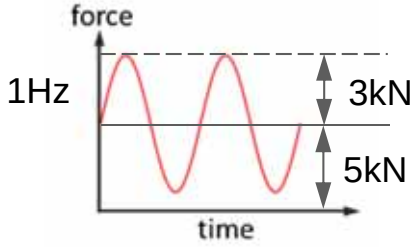
string pattern



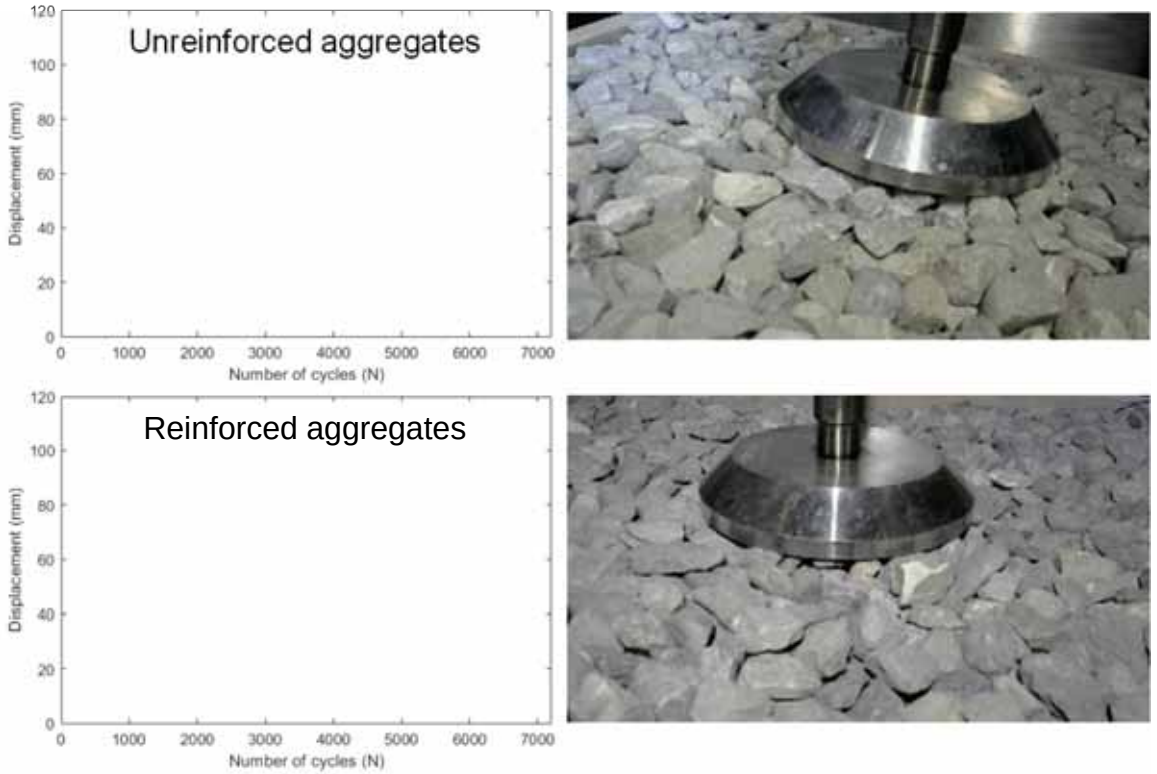
compaction

loading plate



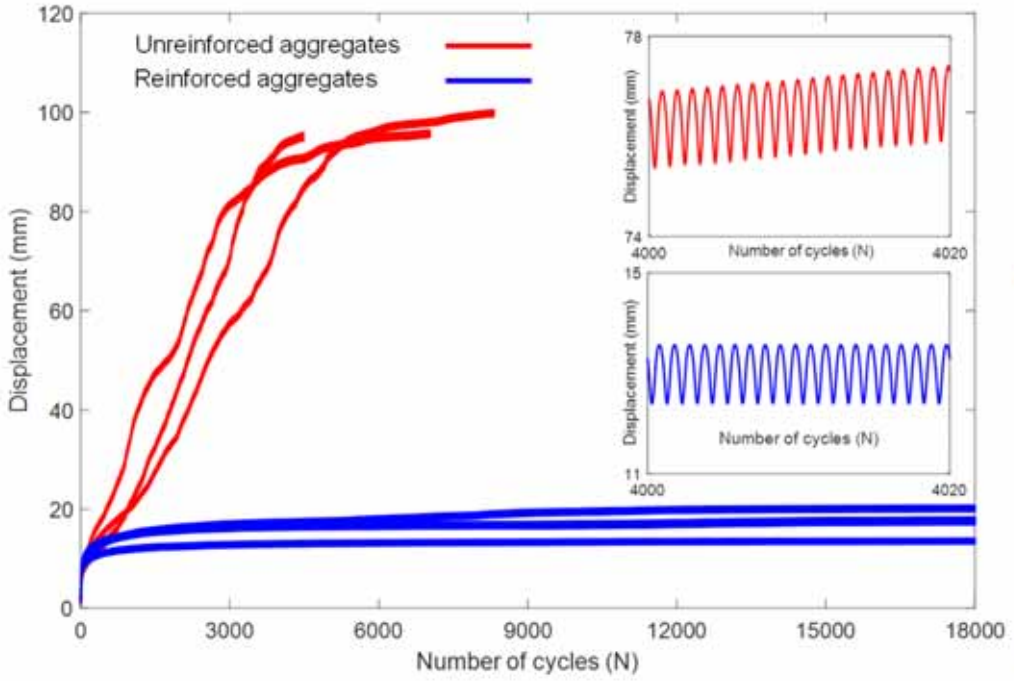


Cyclic plate loading tests (2)



Cyclic plate loading tests (3)

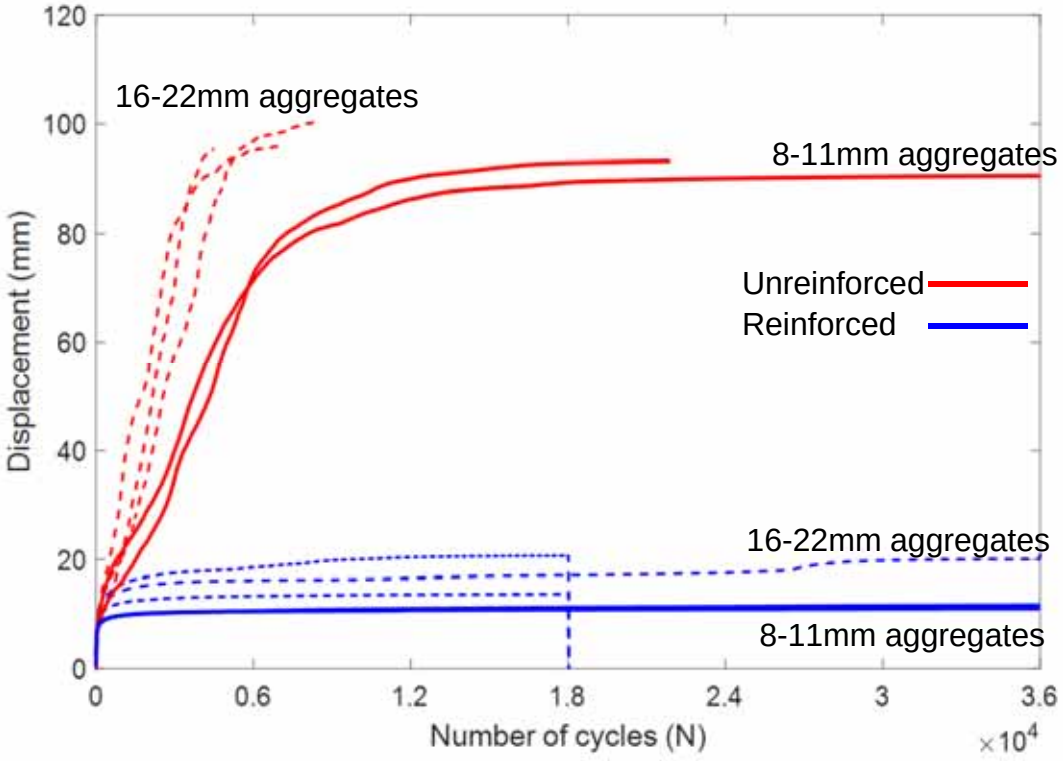
Repeatability



Cyclic plate loading tests (4)

Empa
Materials Science and Technology

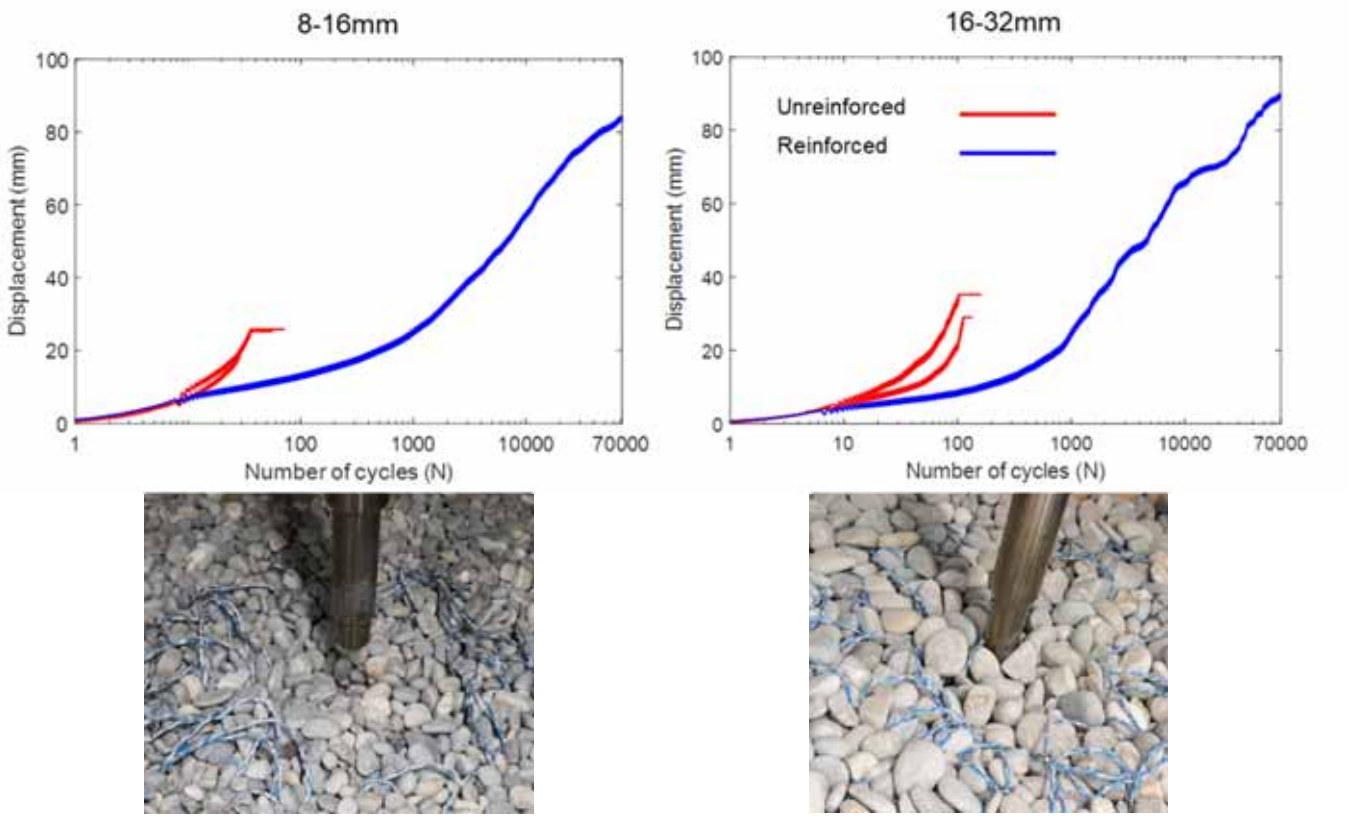
Effect of aggregate size



Cyclic plate loading tests (5)

Empa
Materials Science and Technology

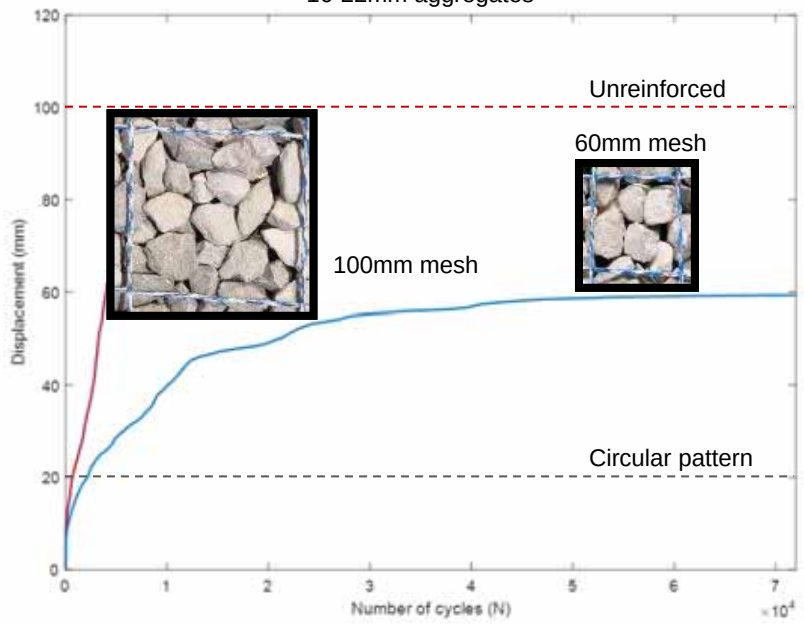
Rounded aggregates



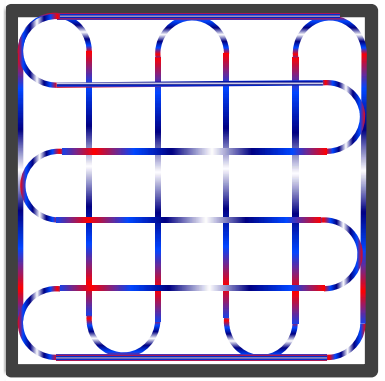
Cyclic plate loading tests (6)

Effect of string pattern

16-22mm aggregates



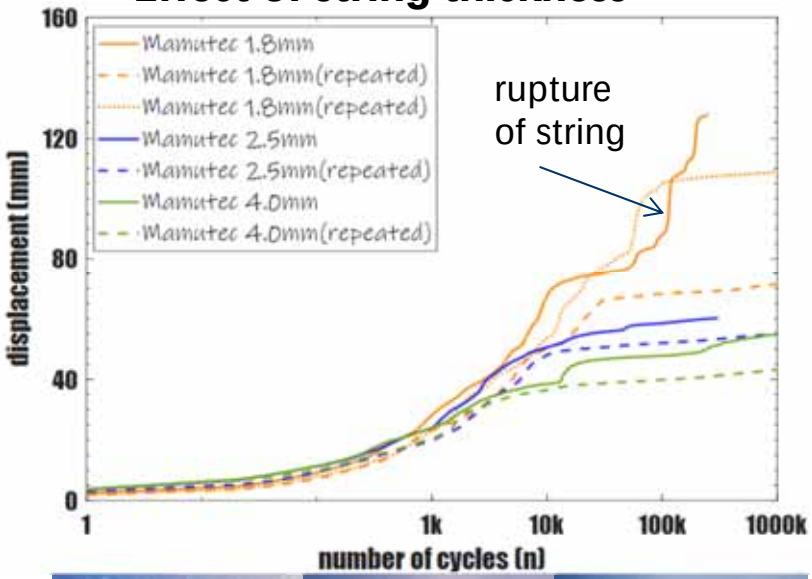
String pattern

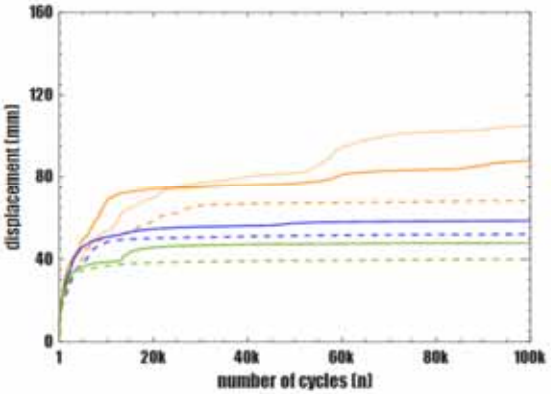


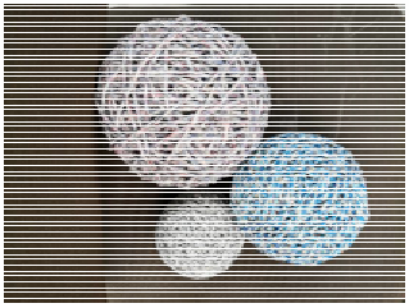
Cyclic plate loading tests (7)

Empa
Materials Science and Technology

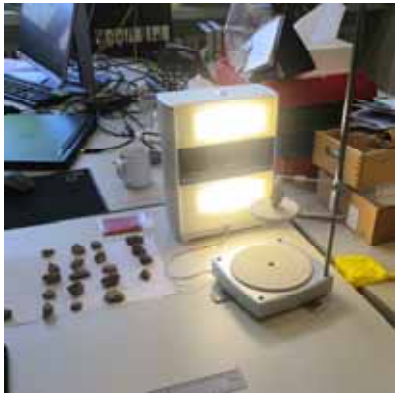
Effect of string thickness

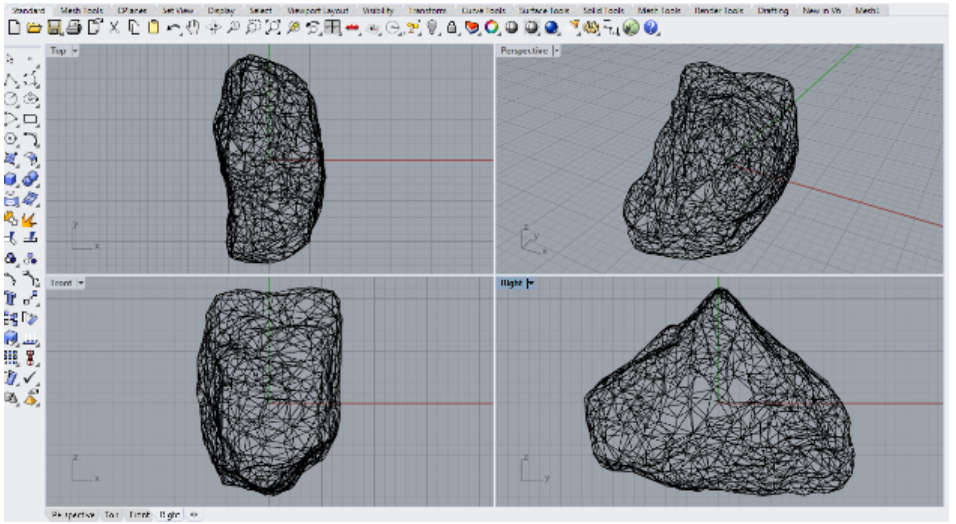


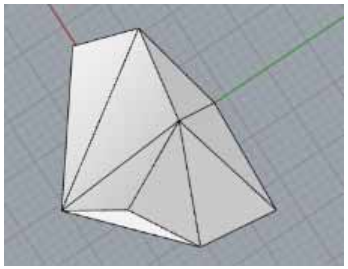


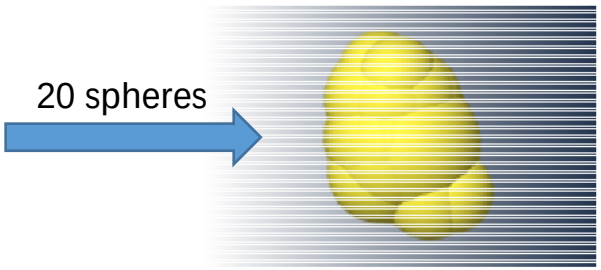


DEM modelling: particle shapes





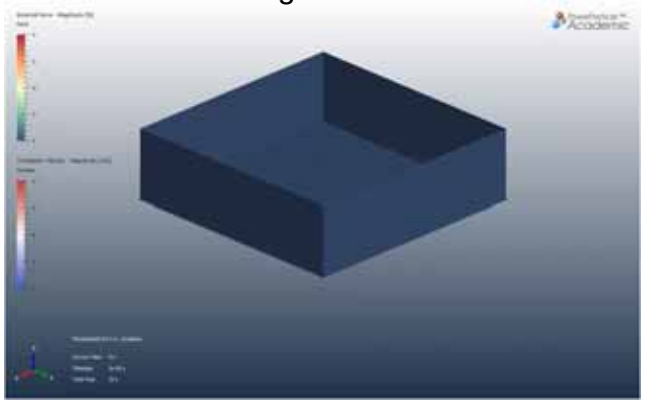




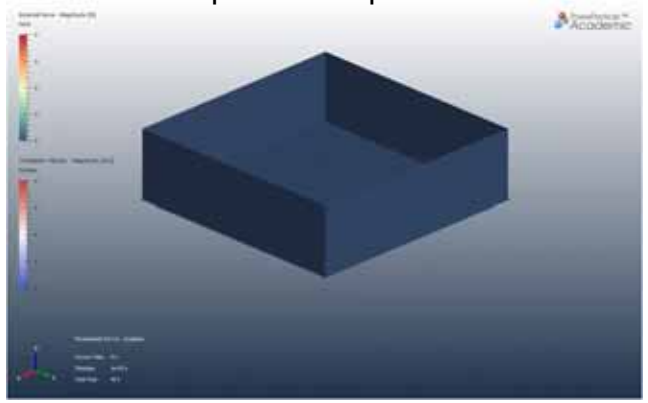
DEM modelling: triang. meshes/sphere clumps

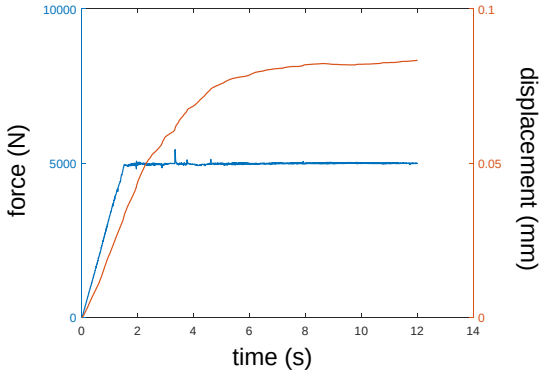
Empa
Materials Science and Technology

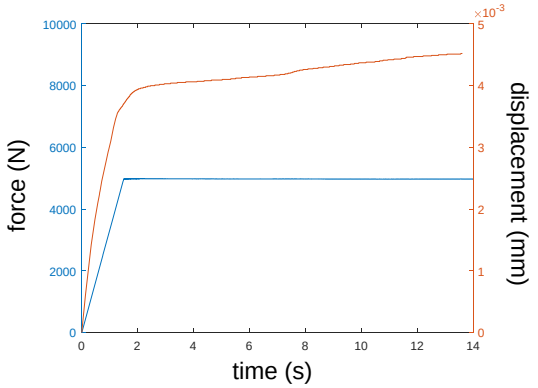
Triangular meshes



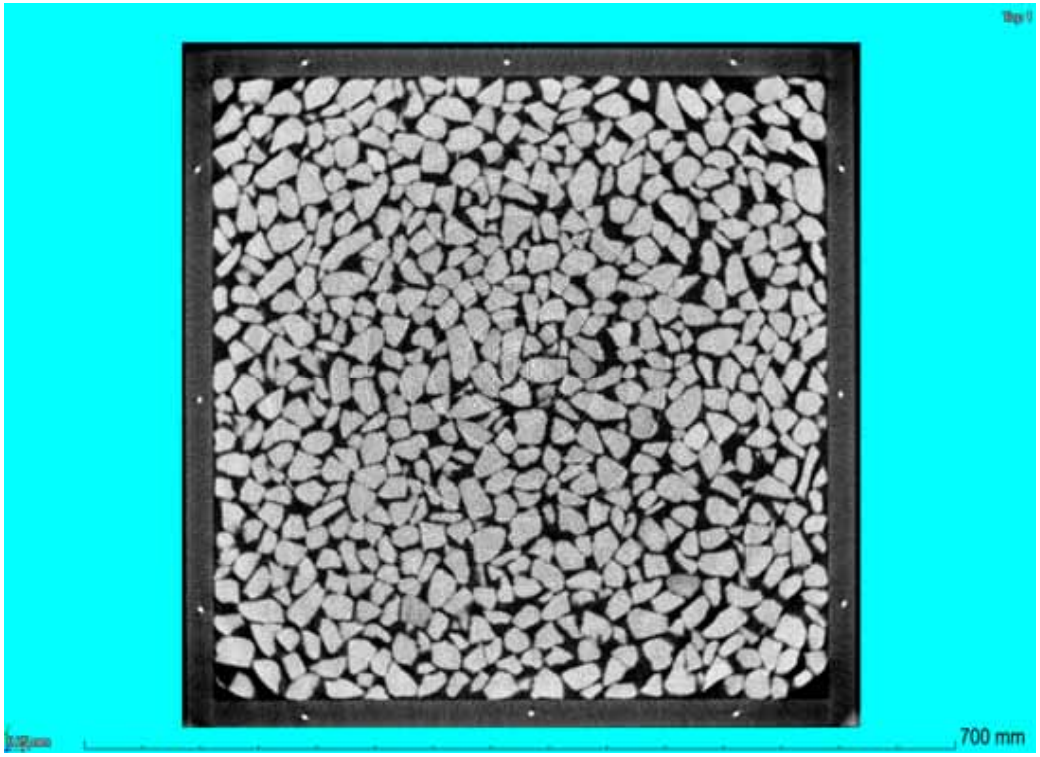
Sphere clumps



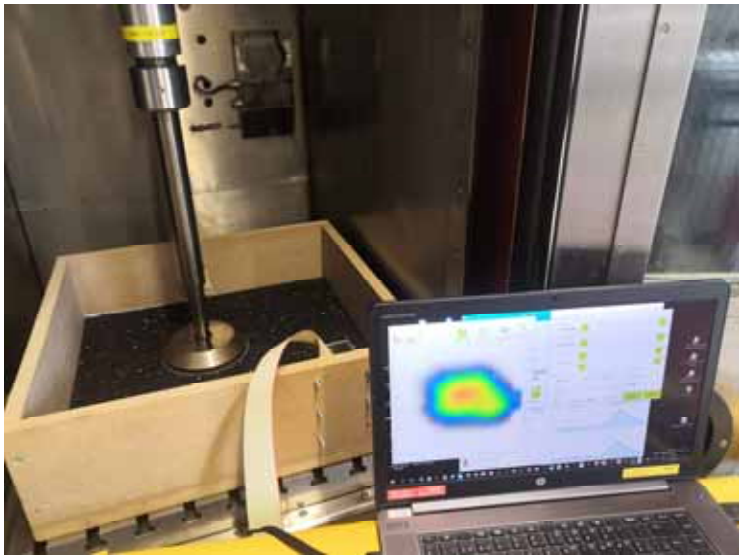




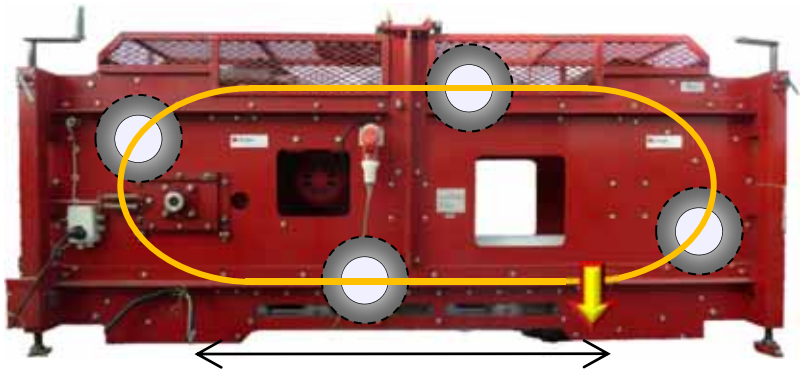
Particle assemblage from X-ray tomography

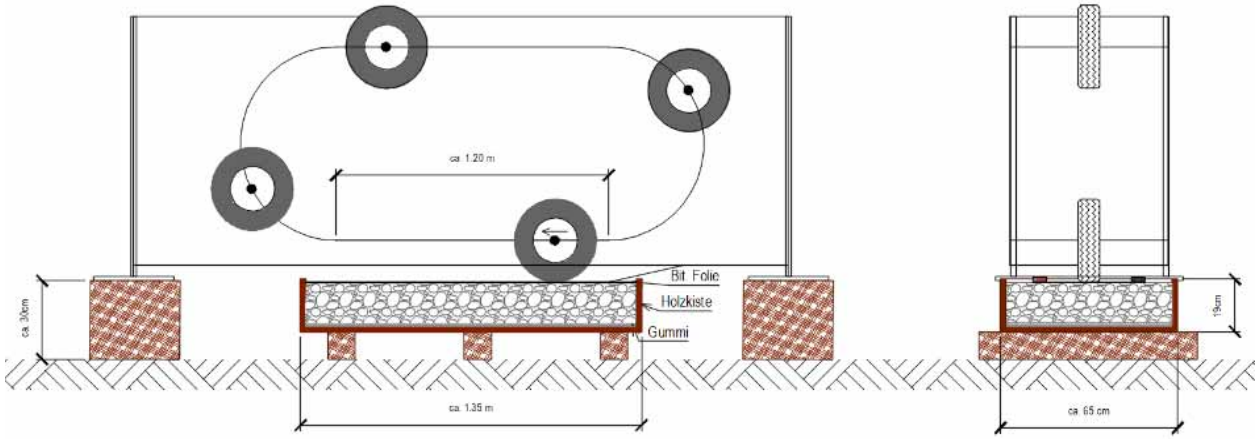


Pressure mat to transfer load



Loading tests with rolling tires (MMLS3)





In the press…

Empa
Materials Science and Technology

Empa
Materials Science and Technology

Digitalized road construction

Knitting roads

NEWS PRODUCTS FEATURES CATEGORIES EVENTS

HOME › NEWS › ASPHALT PAVING, COMPACTION & TESTING › EMPA TESTS STRING AS BITUMEN REPLACEMENT

Empa tests string as bitumen replacement

The Swiss Federal Laboratories for Materials Testing and Research Centre (Empa) has been testing alternate layers of aggregate and string laid out by a robotic arm (photo courtesy Empa)

Asphalt Paving, Compaction & Testing / May 21, 2021 1 minute Read

By Kristina Smith

swissinfo.ch

Preisgünstig, umweltschonend und nachhaltig: "Gestrickte" Strassen

The Economist

Menu Weekly edition Search

Science & technology

May 8th 2021 edition

Engineering

Knitting a road with stones and string

AUTOMOBIL REVUE

HOME NEUHEITEN BRANCHE SPORT DRIVE STYLE VIDEO

Schnur statt Asphalt

Ein Team der Empa hat in einem Versuch einen Strassenbelag entwickelt, der das wenig umweltfreundliche Bitumen ersetzt – mit einer Schnur.

Bauingenieur

Straßenbelag einfach verstärken und recyceln

Ein Roboter und einige Meter Bindfaden helfen einem Forscherteam der Eidgenössische Materialprüfungs- und Forschungsanstalt bei ihren Untersuchungen. Ihr Ziel ist es, Straßenbelag zu verstärken und ihn nach Gebrauch einfach zu recyceln.

…soon in our roads?

Sequestration of solid carbon in concrete and asphalt

P. Lura
M. Wyrzykowski
F. Winnefeld

Challenge & main objectives

By pyrolysis of biomass, biogas and urban waste and reuse of the solid carbon, the equivalent of 6.5 Mt/y of CO_2 can be sequestered in Switzerland alone (more than 50% of the emissions projected for 2050).
This technology would yield vast amounts of solid carbon-rich matter, > 2Mt/y in CH. How to sequester it for centuries?
This project will investigate the following approaches:

1. Use the finest solid carbon as partial replacement of **cement** (5% by mass) and **bitumen**. Sequestration of ~0.8 Mt/y CO_2 in CH
2. Turn carbon-rich solid matter into synthetic lightweight aggregates (LWA) for lightweight **concrete and asphalt.** Sequestration of ~0.7 Mt/y CO_2 in CH

Current Activities

- IRC Net-Zero “ConcreteBlack” (Empa funding)

Synthetic carbon-rich LWA (5-10 mm in diameter) from fine fractions of biochar bound in a cold-bonding process with cement (mass ratio 2:1). In further steps, industrial waste powders will be used (slag, ashes, etc.)

Advantages compared to CO_2 Capture and Storage (CCS):

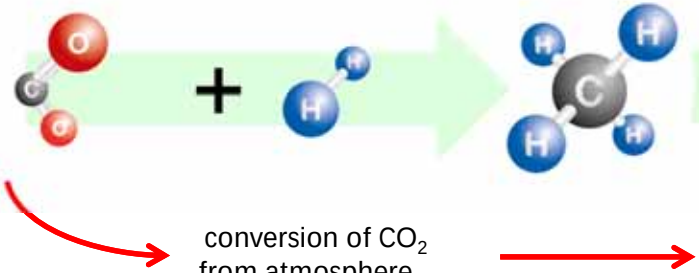
- Higher storage capacity (C vs CO_2)
- No need to ship the CO_2 to Norway/Island (pipeline, ship)
- No leaks (>30% leaks in CCS from underground)
- C is solid, CO_2 needs to be liquefied (wasted energy)

Plasma pyrolysis for methane decomposition in hydrogen and solid carbon

Ch. Bach, B. Niesen, P. Lura, P. Soltic et al.

Empa
Materials Science and Technology

Energetic use



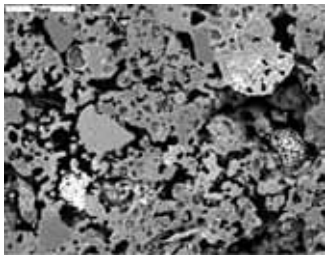
conversion of CO_2 from atmosphere...

...in synthetic methane...

... and finally into $C_{(s)}$ and H_2

Carbon black sequestered in concrete and asphalt

lightweight aggregates for concrete / asphalt



functionalized fine filler for concrete / asphalt

Holcim

Eberhard

BASF
We create chemistry

Conclusions

- The environmental footprint of our roads needs to be reduced
- Work on Reclaimed Asphalt Pavements and on bitumen emulsions
- **ASTRA-funded project on reinforcing unbound layers with robot-placed strings to distribute loads and reduce thickness. Advantages: no binder needed, easily recyclable**
- CO_2 – negative asphalt and concrete by incorporation of solid carbon from pyrolysis