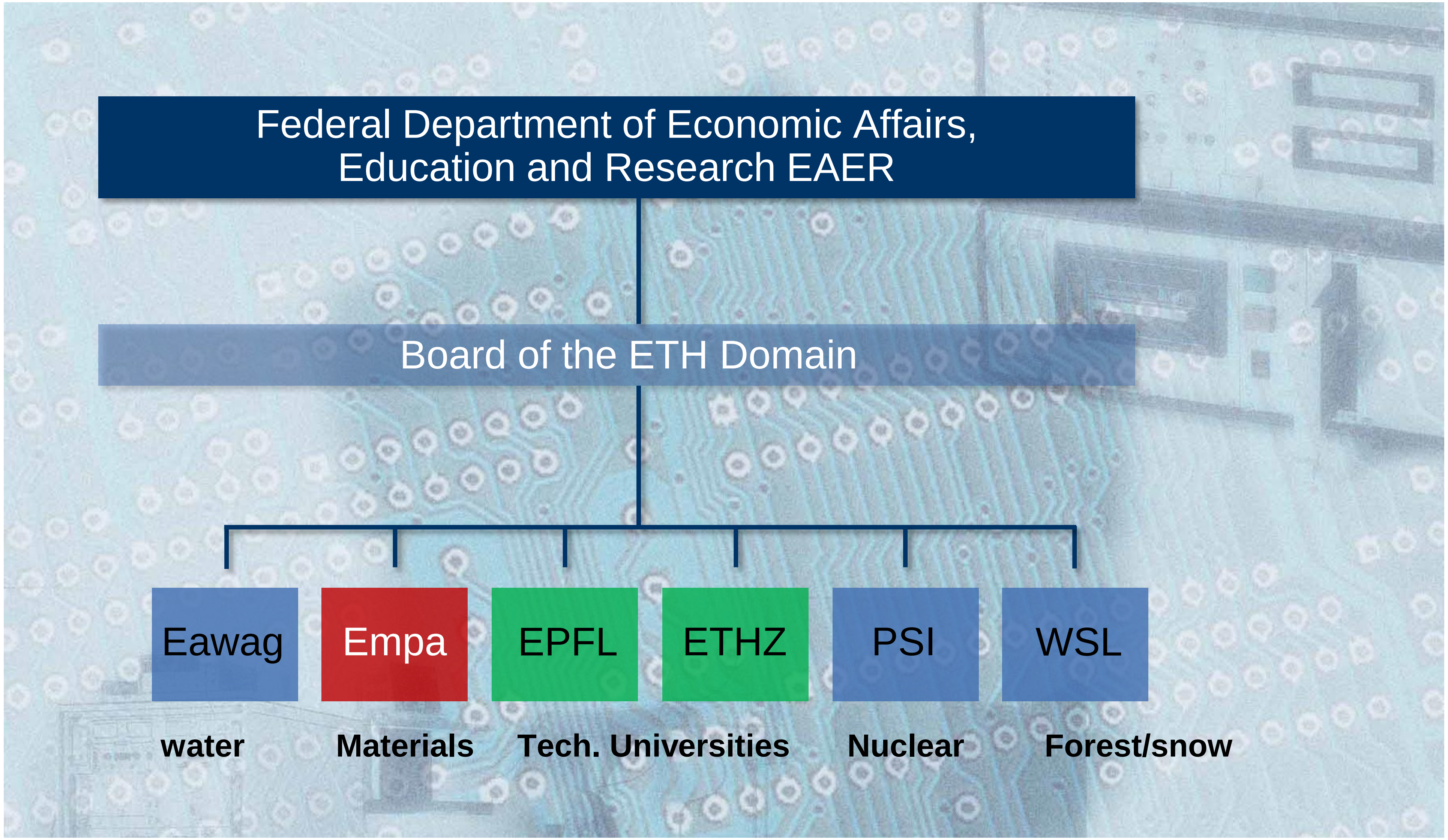
Alternative materials for asphalt: towards a zero waste society

Dr. Lily D. Poulikakos
Concrete and Asphalt Laboratory
Empa, Swiss Federal Laboratories for Materials Science and Technology

Empa within the ETH Domain



Empa in Numbers

EMPA
Materials Science & Technology

- 3 Sites — Dübendorf, St. Gallen, Thun
- 5 Departments — 28 Laboratories
  - 950 Employees (860 FTE; about 30% Women)
  - of which 28 Professors
  - 140 PhD Students
  - 40 Apprentices
  - plus 200 Master Students & Interns
- Budget — 97 Mio. CHF Public Funding
  - 52 Mio. CHF Third Party Means
- Scientific Output — > 500 Peer-reviewed ISI-Publications
  - 90 Seminars & Conferences at Empa-Academy
- Third Party Projects — > 50 running Projects EU Framework Programmes
  - > 90 running SNSF Projects
  - 80 running Innosuisse Projects

Personal Data

Education

- B.S. Structural Engineering, U Co, USA
- M.S. Civil Engineering U Ill, USA
- PhD Civil Engineering, ETHZ, Switzerland

Industry Experience 7 years

- Canada & Walker USA
- Sargent & Lundy USA

Research Activities Since 2001

- Defined, led, managed various projects
- funded by ASTRA, SNF, BAFU, ARE, KTI/CTI
- Various National/ Internationsl Cooperations
- Supervised several BS, MS, PhD students, post docs
- Publications >100

Scientific Activities

Research

- Multi-scale approach
- 2004- 2017 2 Eureka projects Fooprint & Ecovehicle
- Supervised several BS, MS, PhD students, post docs
- Publications >100

Research Fundamental

- Recycling
- Artificial aggregates
- R'Equip AFM-IR
- Ice phobic
- Use of secondary materials in roads

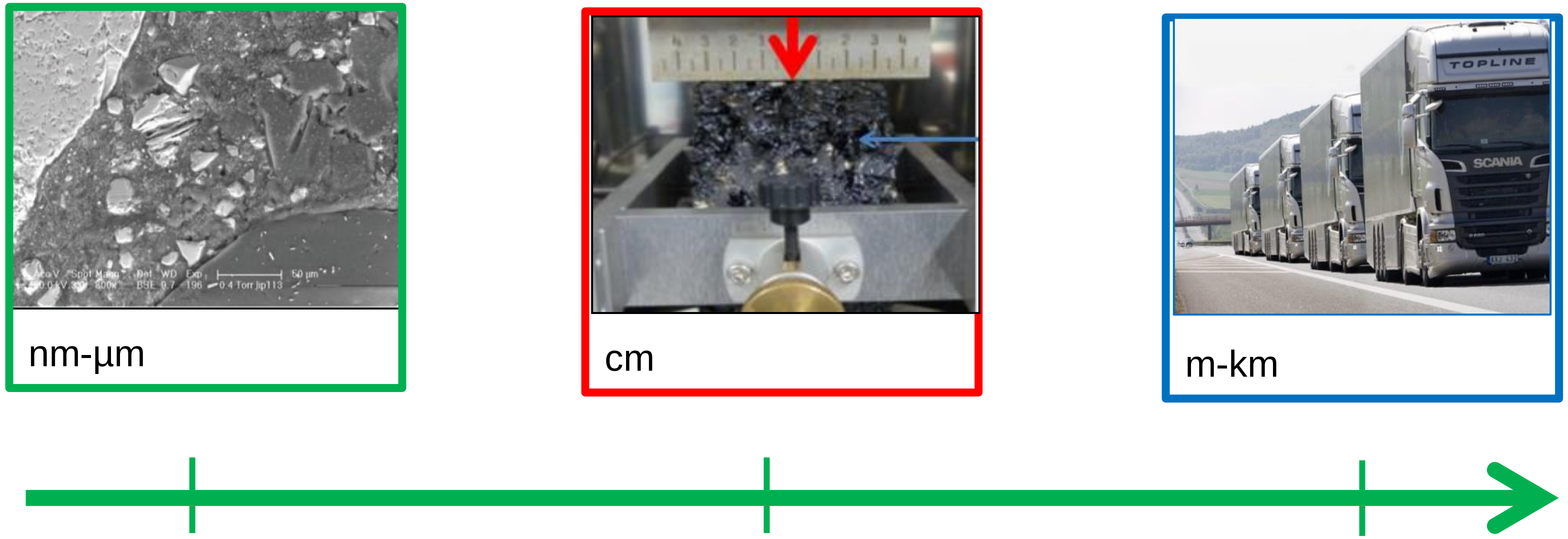
Industry

- KTI Kistler WIM
- UTF Recycling
- KTI Crumb Rubber Modified Asphalt

International Scientific Engagement

- Rilem: led 3 TC's
- Founding member and treasurer of ISWIM
- Reviewer of various journals
- Reviewer for EC FP7 and Horizon (invited)
- Invited external PhD examiner
- Editor Constr & Building Materials

Goals of the lab



- Understanding material behavior at multiple scales
- Developing novel road materials, including multiple functionalities and fabrication methods
- Address and fulfill the needs of the industry and federal offices (noise, pollution, increased traffic, type of traffic including future technologies, standardization).

Outline

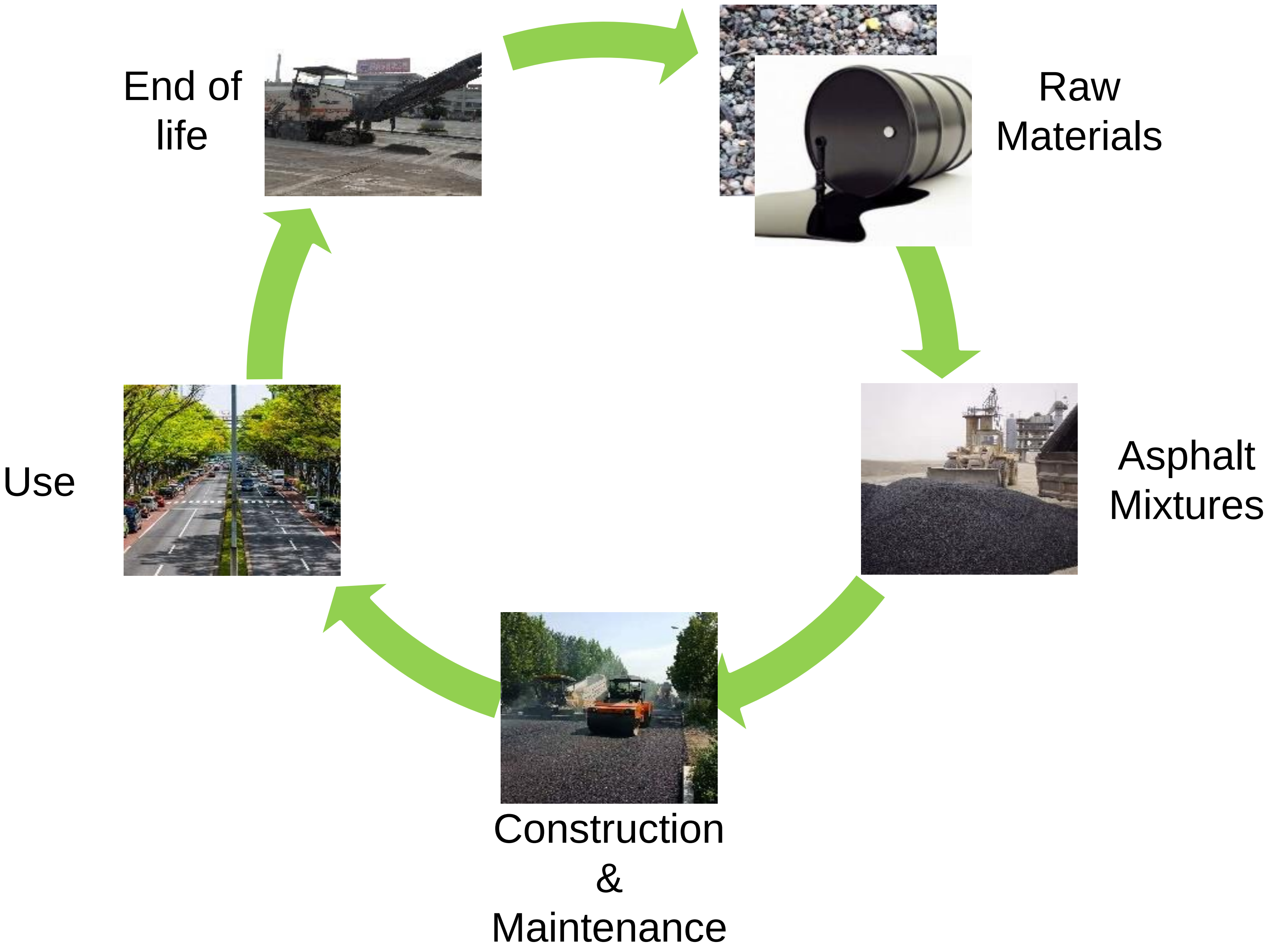
- Introduction (short literature review about wastes in asphalt mixtures and short presentation of TC WMR)
- Waste PE and Crumb rubber as binder additives
- Crumb rubber, Waste PE; RCA in asphalt mixtures; Steel slags in asphalt mixtures
- Acoustic performance
- Environmental assessment

EMPA

Materials Science & Technology

Introduction (short literature review about wastes in asphalt mixtures and short presentation of TC WMR)

Motivation: Circular economy



Piao 2020

The Numbers in Europe

Material	Source	Generated Mt/y	Available Mt/y
Concrete	C&D	350	262.5
Ceramics	C&D	200	162
Glass	Var.	20.2	5.4
Steel slag	Steel industry	21.8	15.7
Plastics	MRF	15.1	4.5
Tires	ELV	3.3	1.8

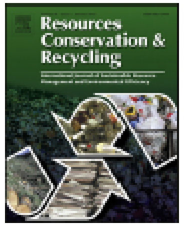
Waste is a substantial problem worldwide

Resources, Conservation and Recycling 116 (2017) 32–44

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec



Review

Harvesting the unexplored potential of European waste materials for road construction

L.D. Poulikakos[a,*,1], C. Papadaskalopoulou[b,1], B. Hofko[c], F. Gschösser[d], A. Cannone Falchetto[e], M. Bueno[a], M. Arraigada[a], J. Sousa[f], R. Ruiz[g], C. Petit[h], M. Loizidou[b,1], M.N. Partl[a,1]

[a] Empa, Swiss Federal Laboratories for Materials Science and Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland
[b] National Technical University of Athens, Heroon Polytechniou 9 Zographou C, 15780 Athens, Greece
[c] Technical University of Vienna, Karlsplatz 13, 1040 Vienna, Austria
[d] Dr. Dipl.-Ing. Florian Gschösser, Heinrich von Schullernweg 7 Top 1, Natters, 6161, Austria
[e] Technical University of Braunschweig, Beethovenstraße 51b, 38106 Braunschweig, Germany
[f] Consulpav, Rua da Zona Industrial, no. 6A, Casais da Serra – Mafra, 2665-305 Milhara, Portugal
[g] Valoriza Servicios Medioambientales, S.A., C/Juan Esplandiu, 11-13. Planta 13, 28007 Madrid, Spain
[h] University of Limoges, Centre universitaire de génie civil, 19300 Egletons, France

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Glass

ABSTRACT

This paper demonstrates how a considerable amount of waste produced in the urban and peri-urban environment can be recycled in asphalt roads. The example presented is from Europe, however, the barriers and conclusions are universal. It was shown that various waste materials such as glass, asphalt, concrete, wood, plastics etc. have a potential for re-use in asphalt roads. The available quantities of the European target waste materials that would otherwise be incinerated or disposed in landfills were considered. It was shown that there is high potential in Europe for recycling in road construction, in particular, under the hypothetical scenario where 33% of new roads would be made of the target waste materials (excluding RAP which is already recycled), it is estimated that 16% of the available waste quantities could be recycled in roads. Four hypothetical roads were analysed showing a considerable savings in costs, CO2 and energy in comparison to conventional asphalt mixtures using all virgin components.

Outcome of Review Paper

Harvesting the Potential of European Waste Materials for Road Construction

(available on line: Resources, Conservation & Recycling)

- Use of various waste materials in roads is a viable option that needs to be exploited further.
- Using LCA, LCC four possible scenarios for using waste products in roads it was demonstrated that a significant savings in costs, CO_2 and energy can be derived from using waste products in road in comparison to mixtures made of all virgin components
- The technical readiness level (TRL) among the investigated materials varies greatly.
  - crumb rubber is very advanced technically as well as legislatively example in California USA, CR finds obstacles in France, Italy because of local national legislations and sometimes lack of trust in scientific research.
- In order to achieve this efficiently, the involvement of various stakeholders is needed. On the one hand, the waste management professional needs to direct the waste to be used for road construction and, on the other, the road construction professionals have to have access to knowledge regarding handling, preparation and costs as well as the resulting quality associated with the use of such materials
- The scientific community needs to make a more significant effort to bring the acquired knowledge to the practicing professionals
- Appropriate legislation and standards need to be in place to guide the professionals on the use of waste for road construction

Technology Readiness Level (TRL)

Urban wastes	Estimated TRL
Crumb rubber (wet process)	7 – 9 (application is partially or completely industrialized)
Crumb rubber (dry process)	5 – 7 (application is validated in the field)
Recycled concrete aggregate (RCA)	< 4 (laboratory scale or lower)
Recycled ceramics	< 4 (laboratory scale or lower)
Recycled glass	< 4 (laboratory scale or lower)
Recycled plastics	5 – 7 (application is validated in the field)

Banke, J., 2017. Technology Readiness Levels Demystified. https://www.nasa.gov/topics/aeronautics/features/trl_demystified.html. (Accessed May 2019).
Piao, Z., Mikhailenko, P., Kakar, M.R., Bueno, M., Hellweg, S., Poulikakos, L.D., 2020. Urban Mining for Asphalt Pavement: A Review. Journal of Cleaner Production 280 (2021)

Suitable waste materials for roads

Table 2
Summary of the effects using waste materials in the asphalt mixture at laboratory scale.

Waste material	Rutting resistance	Moisture resistance	Stiffness modulus	Fatigue resistance
CR from ELT (wet process)[a]	↑	↯	↯	↑
CR from ELT (dry process) [b]	↑	↓	↑	↯
RCA[c]	↯	↯	↑	↯
Waste ceramics[d]	↯	↯	↑	↑
Waste PE (wet process) [e]	↑	↑	↑	↑
Waste PE (dry process) [f]	↑	↑	↯	→
Waste PET[g]	↑	↑	↯	↑
Waste PVC[h]	↑	↑	×	×
Waste PP[i]	↑	↯	↑	→
Steel slag[j]	↑	↑	↑	↑

Source: Piao, Z., Mikhailenko, P., Kakar, M.R., Bueno, M., Hellweg, S., Poulikakos, L.D., (2021). Urban mining for asphalt pavements: A review. Journal of Cleaner Production 280, 124916. https://doi.org/10.1016/j.jclepro.2020.124916.

Overview of Rilem
TC Waste and Marginal Materials WMR

- Chair:Lily Poulikakos, Empa, Switzerland
- Deputy Chair: Emiliano Pasquini, U Padua, Italy

- The TC will be active for 5 years (2017-2022)

- Combination of literature review, experimental work and test protocol descriptions documented in a STAR report and papers

- Workshop 2020 Rilem symposium Lyon

- Dedicated TC day at end of TC: EATA2023

Rilem: International Union of Laboratories and Experts in Construction Materials, Systems and Structures
https://www.rilem.net/

Overview Technical Groups (TG)

- TG1: Waste plastic modified asphalt binders
- Leader: **Marjan Tušar, ZAG**

- TG2: Crumb rubber modified asphalt binders
- Leader: **Jorge Pais, U Minho**

- TG3: Waste aggregates in asphalt mixtures
- Leaders: **Fernando Moreno, U Granada; Augusto Cannone Falchetto, U Alto; Emiliano Pasquini; U Padova**

- TG4: Environmental Risk assessment
- Leaders: **Oumaya Marzouk, Cerema, Gaetano di Mino U Palermo**

- TG5: Life cycle assessment
- Leaders: **Davide Lo Presti U Palermo, Ana Jiménez del Barco Carrión U Granada**

Quiz 1

What are the barriers for using waste and marginal materials in roads

1. **Lack of performance**

2. **Lack of knowlegde on their use**

Materials Science & Technology

Waste PE as binder additive (Empa Project +TG1 activities)

Waste Plastics

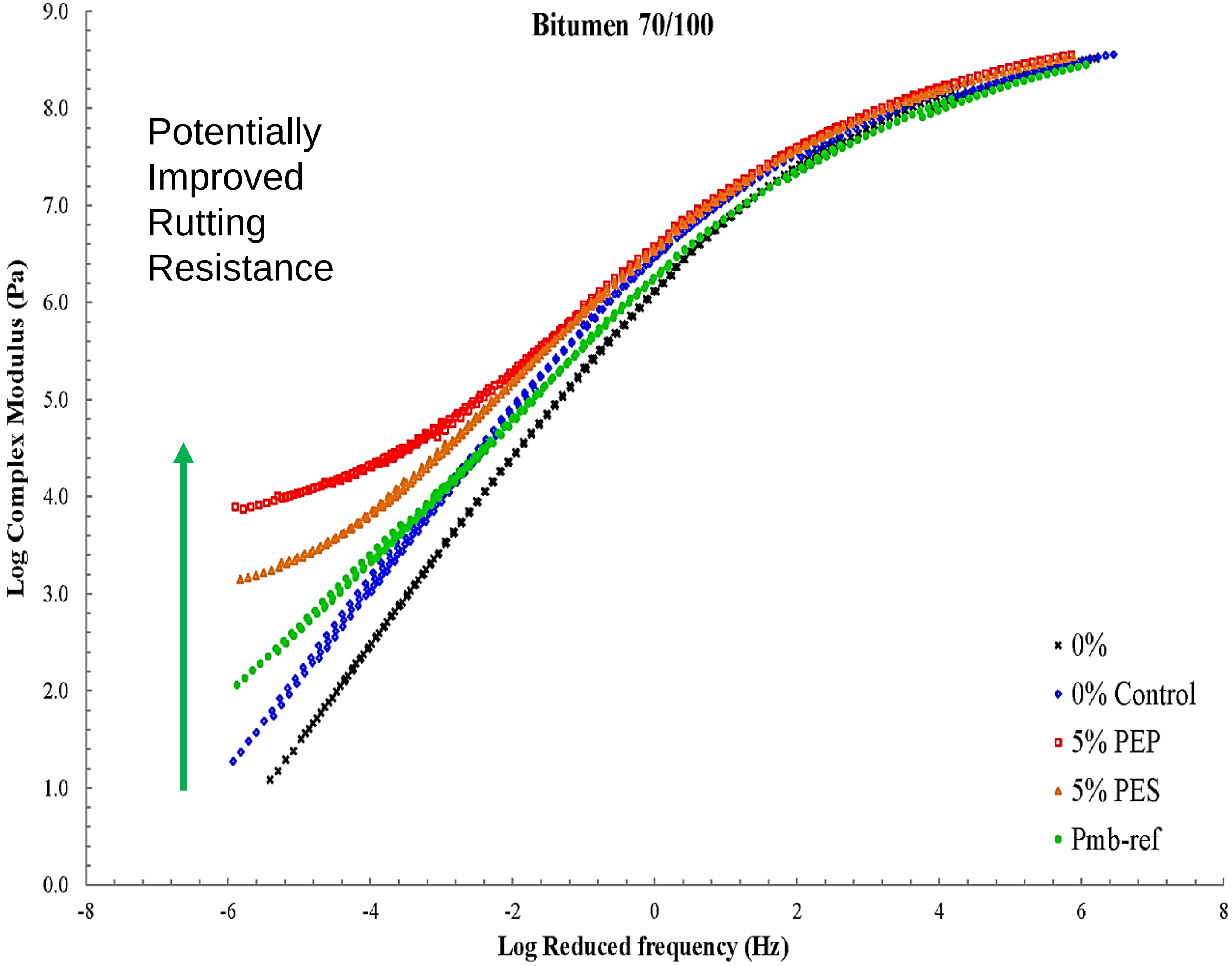
- Inno-recycling produces 16’000 Tonnes/year of PE „Regranulate“.

PE-Pellets

PE-Shreds

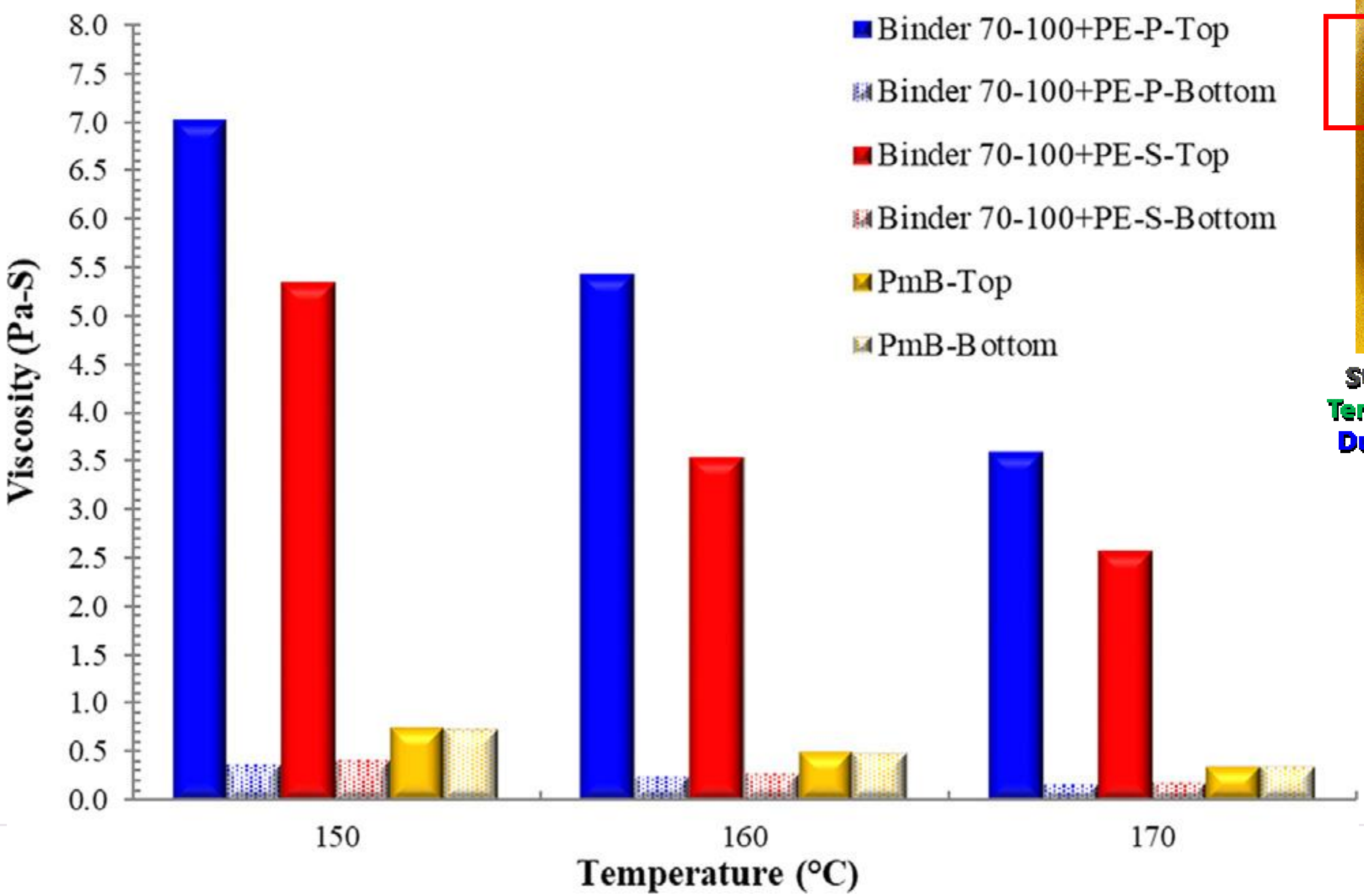
https://innorecycling.ch/

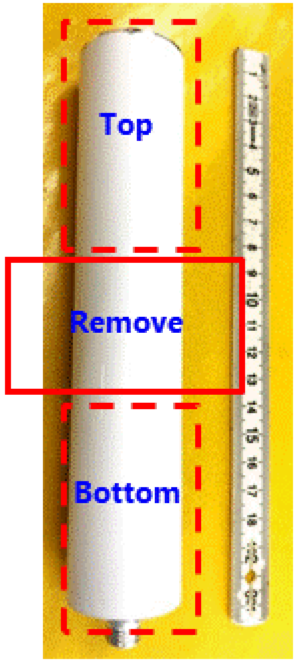
Binder performance: Dynamic Shear Rheometer



Modification of asphalt binder using polyethylene (PE) recycling by-products, *M R Kakar, P Mikhailenko, Z Piao, M Bueno, L Poulikakos Construction and Building Materials 280 (2021)*

Plastics: Stability





Stability Test Tube
Temperature = 180°C
Duration = 72hours

Modification of asphalt binder using polyethylene (PE) recycling by-products, *M R Kakar, P Mikhailenko, Z Piao, M Bueno, L Poulikakos Construction and Building Materials 280 (2021)*

Modulus

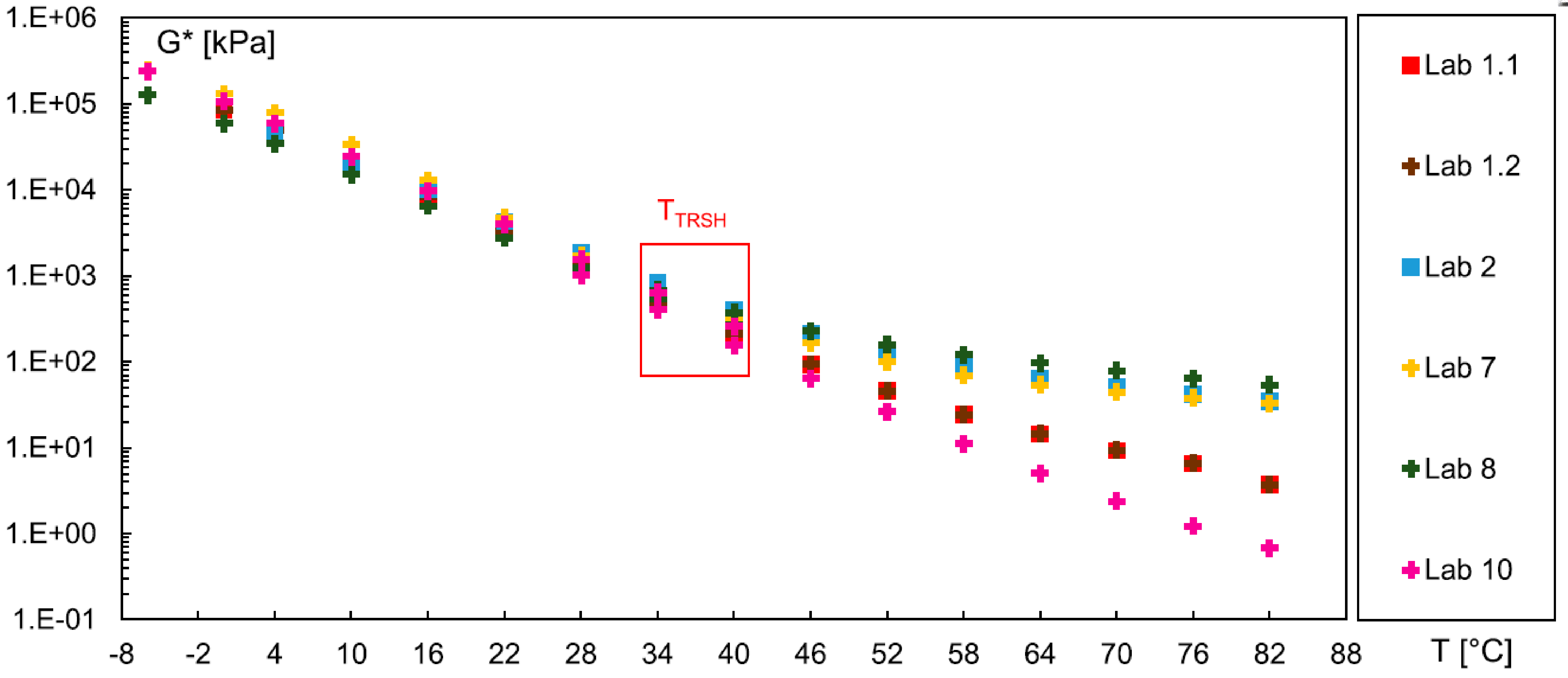


Figure 7. Modulus isochronal plot ($|G*|$ vs. T) at 1.59 Hz for $B_{+pellets}$.

Tusar et al RILEM TC 279 WMR round robin study on waste polyethylene modified bituminous binders: advantages and challenges, Road Materials and Pavement Design, DOI: 10.1080/14680629.2021.2017330

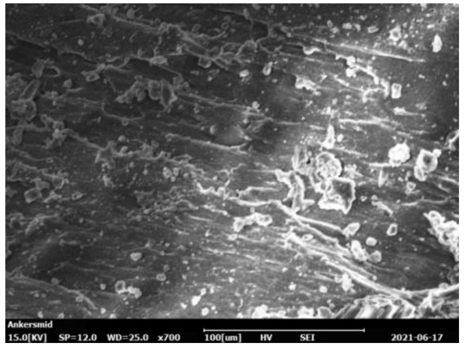
Crumb rubber as binder additive (TG2 activities)

Lily Poulikakos, Empa

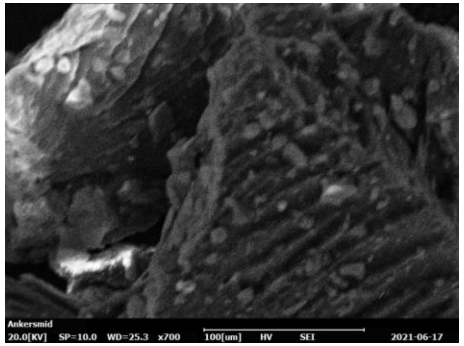
Exerpts from the publication below under review:
Effect of crumb rubber technology 1 **on the performance of crumb rubber modified bitumen**
Jorge C. Pais, Lily D. Poulikakos, Patricia Kara De Maeijer, Nicolas Schüwer, Maria Chiara Cavalli, Augusto Cannone Falchetto, Muhammad Rafiq Kakar, Johan Blom, Maeva Tobler, Marcel Perecmanis

Materials

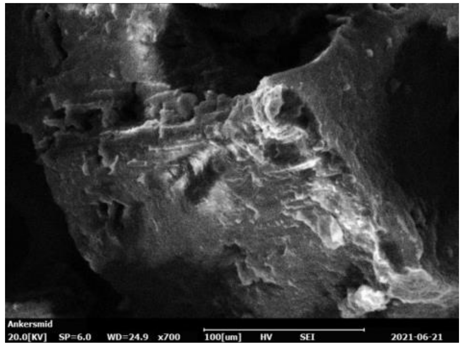
- Three base bitumens: 35/50, 50/70, and 70/100
- CR from the mechanical, cryogenic, waterjet grinding processes and RAR
- Mix of car and truck waste tires with a maximum dimension of 4-6 mm



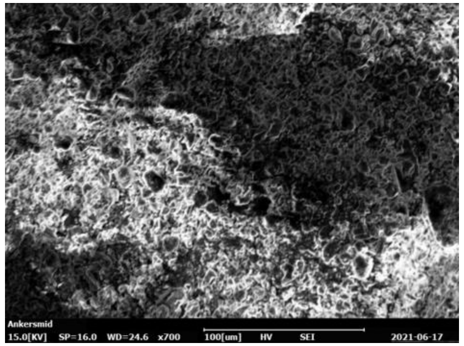
Mechanical CR-M



Cryogenic CR-C



Water Jet-W



RAR CR-R

Wet Process

Requires thorough mixing of the crumb rubber in hot asphalt binder

and holding the resulting blend at temperatures (180°C to 230°C) for a

designated minimum period of time (typically 45 minutes) to permit an interaction between the crumb rubber and asphalt.

- Requires special blending equipment.

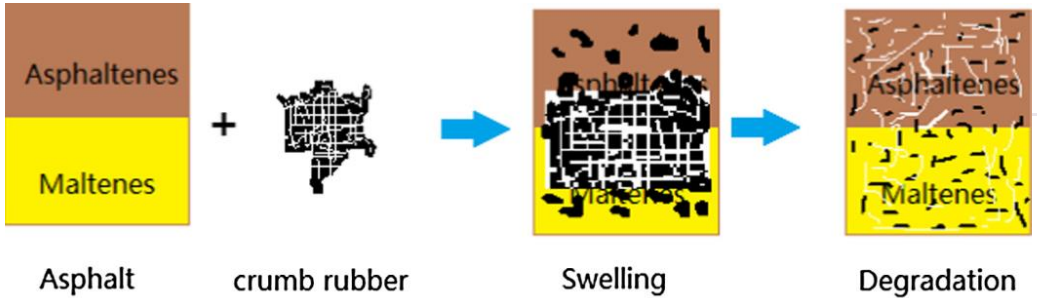
- Requires constant agitation once mixed.

- Binder contents are typically 0.2-1.5% higher depending on crumb

rubber particle size.

- Tire Rubber filler must be considered when determining actual

binder content within the mix.



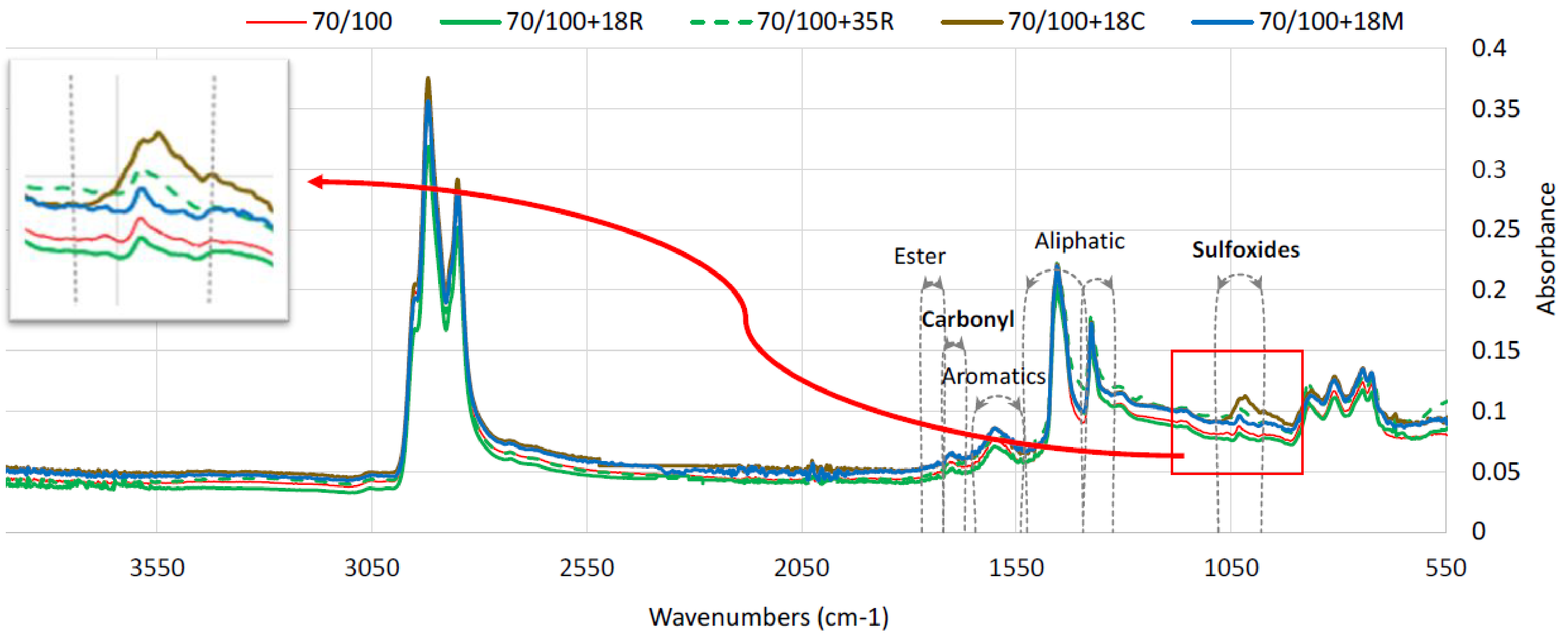
Source: wright asphalt products company
S. Wang et al. / Construction and Building Materials 131 (2017) 101–113

CRMB Production

- **CRMBs were produced at 175 ºC with a digestion time of 1 hour at 3500 rpm in a high shear mixer. One laboratory (L5) used a 300 rpm low shear mixer (electric stirrer mixer).**

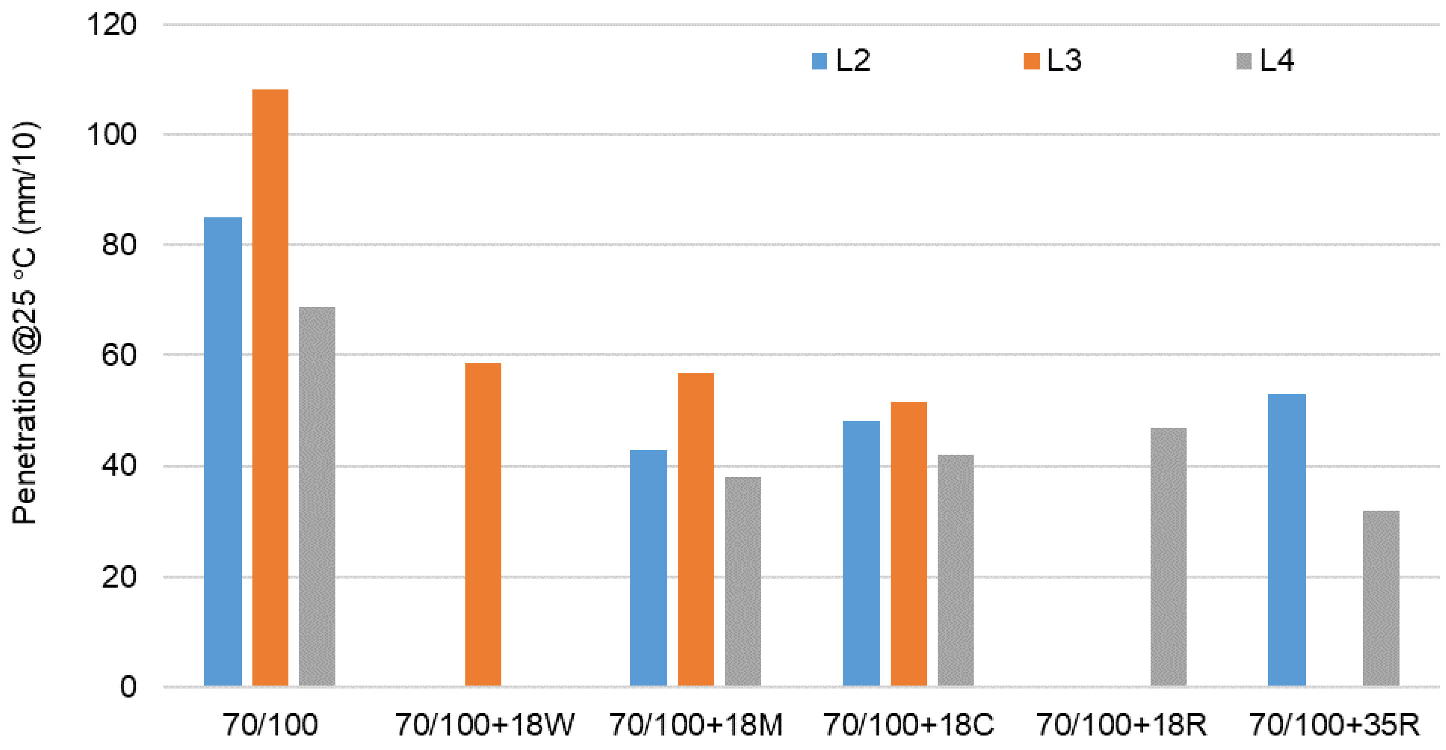
- **The crumb rubber content was 18% for all rubber types. Additionally, 35% for the RAR was used because this RAR content produces CRMB with viscosity similar to 18% of the other CRs.**

Chemical information: FTIR



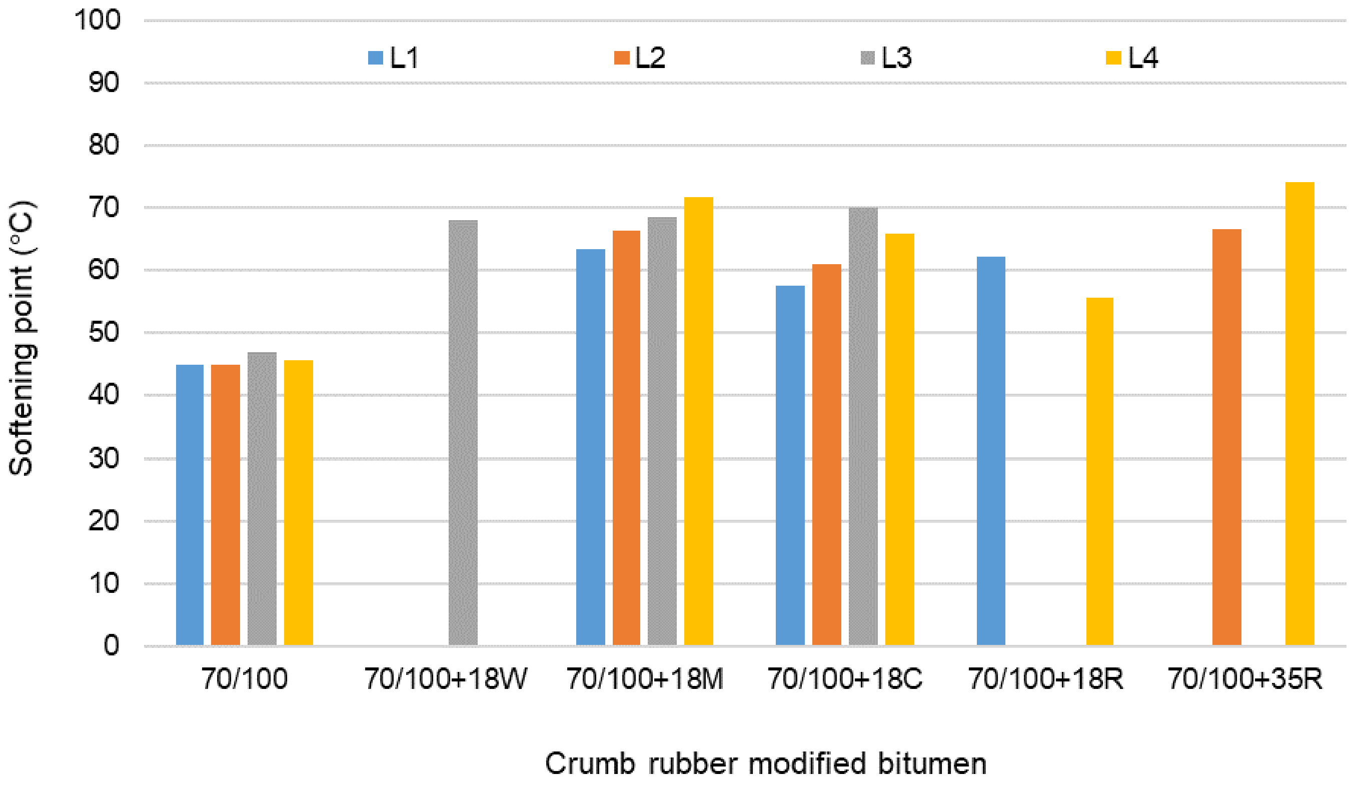
No additional peaks, physical blending

Penetration of CRMB produced with 70/100 bitumen



- ❖ Change in the mechanical properties of the modified bitumen with CR is affected by the swelling of the CR particles in the bitumen, which form a viscous gel that increases the viscosity of the bitumen
- ❖ Reduced penetration with addition of CR
- ❖ CR type has an effect on penetration

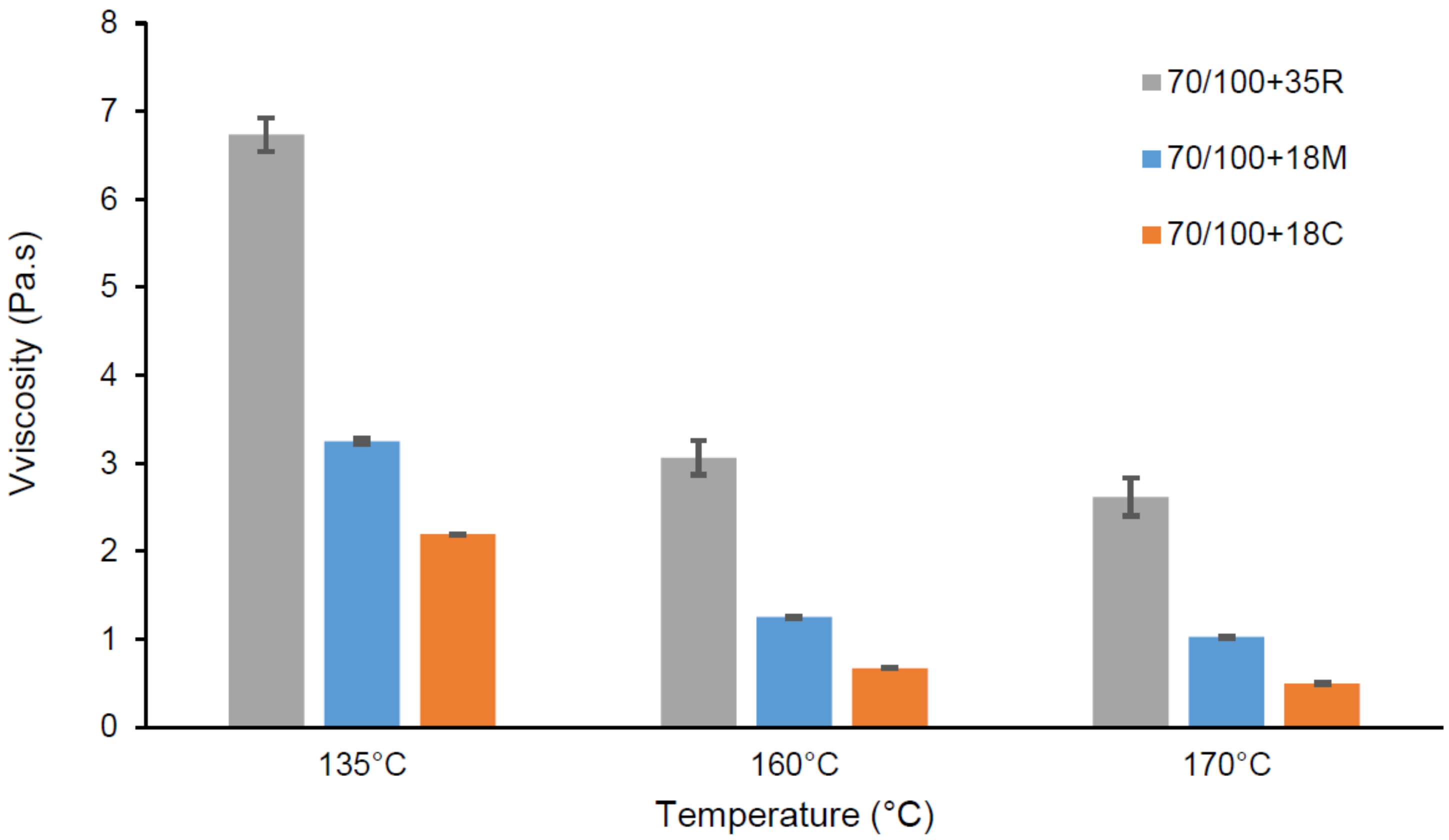
Softening point of CRMB produced with 70/100 bitumen



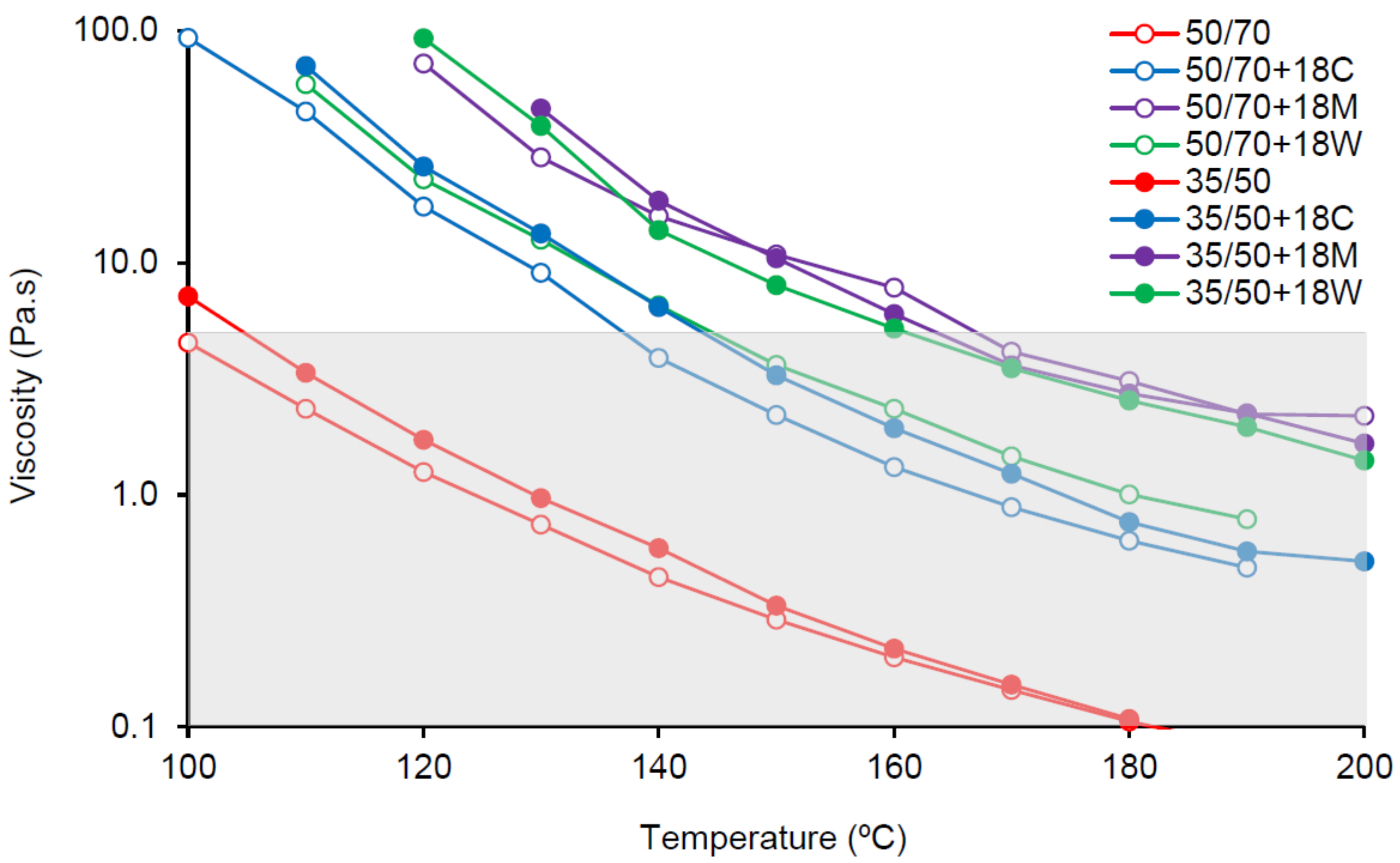
- Scattering>10%
- Base bitumen: scatter due to batch differences
- CRMB the scatter is associated with the production process

Viscosity results of 70/100 CRMB using the standard spindle (CC27) by L1

❖ Change in viscosity with addition of CR
❖ CR type has an effect on viscosity

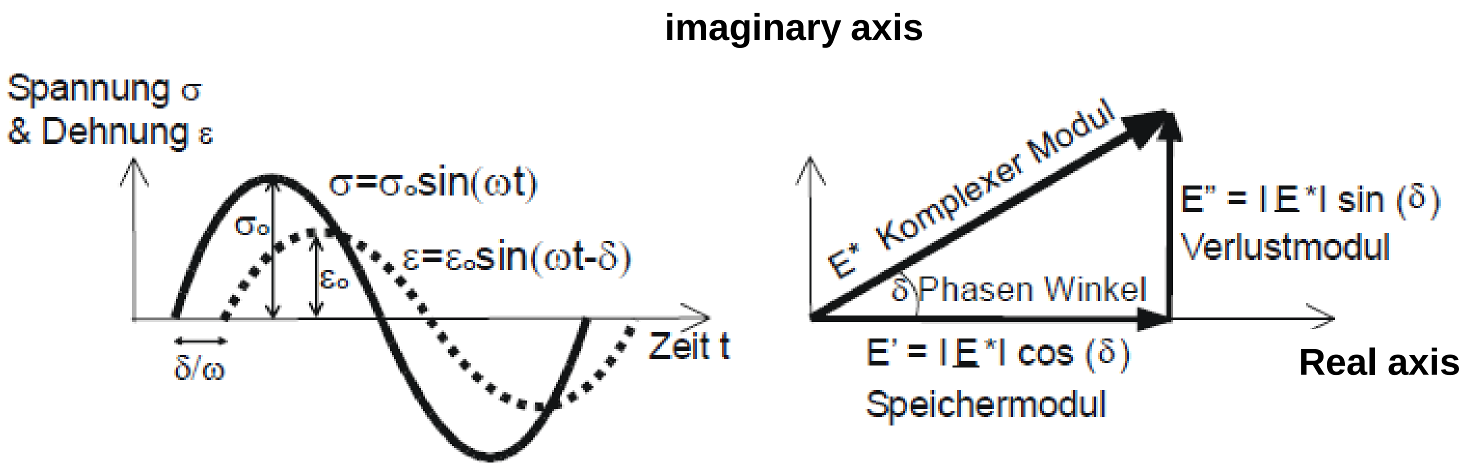


Viscosity results for 35/70 and 50/70 CRMBs by L5



ASTM D6114 standard for CRMB, where the 5 Pa.s is defined as the viscosity limit, these CRs can be used as bitumen modifiers for temperatures starting at 140 ºC.

Theoretical Background

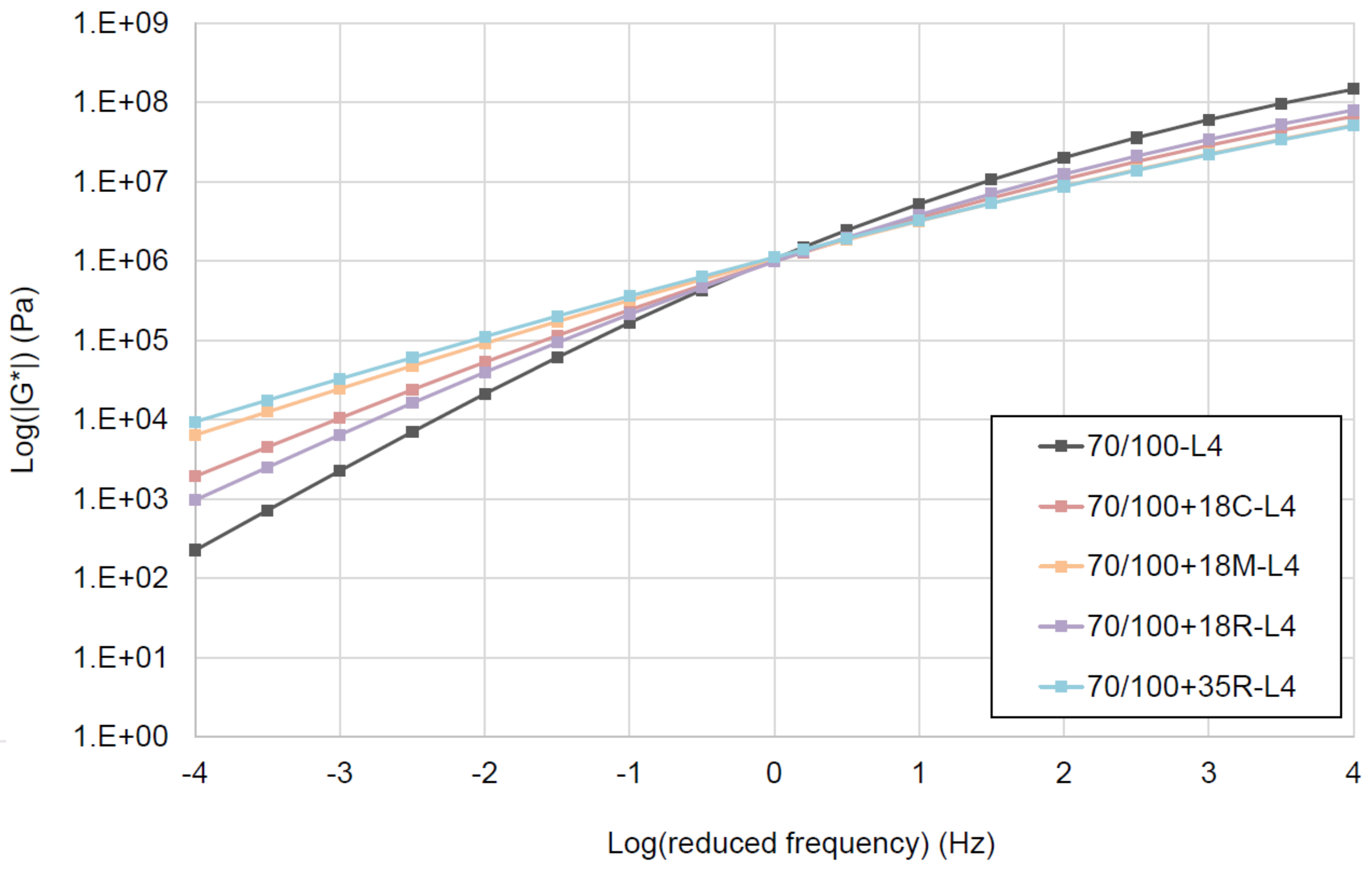


- Viscoelastic behavior under harmonic loading
- Development of complex modulus, phase angle

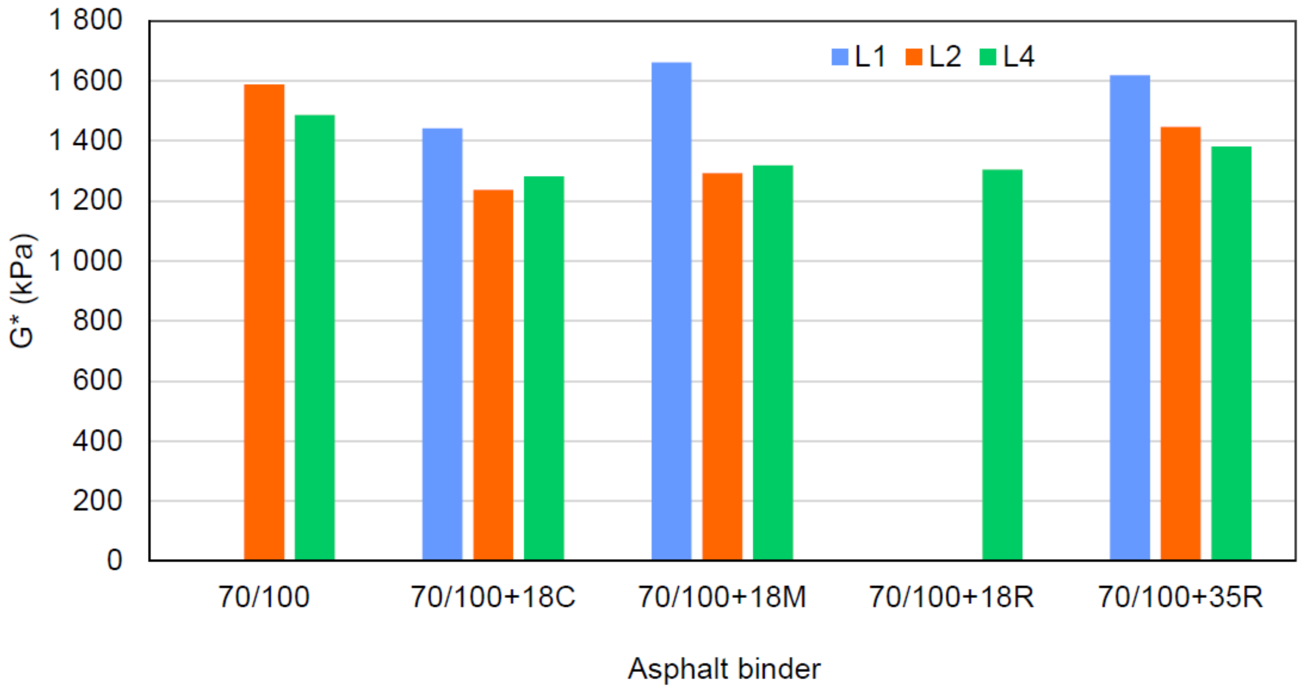
$$\left|E^*\right| = \frac{\sigma_0}{\varepsilon_0} \qquad \frac{E''}{E'} = \tan\delta \qquad E' = \frac{\sigma_0}{\varepsilon_0}\cos\delta \qquad E'' = \frac{\sigma_0}{\varepsilon_0}\sin\delta$$

G* master curves (Dynamic Shear Rheometer, DSR) for CRMB produced with 70/100 base bitumen with 3 types of CR, 2 Doses, 1 Lab

- High temp: Increased G* with addition of CR
- Low temp: decreased G* with addition of CR
- CR type has an effect on G*

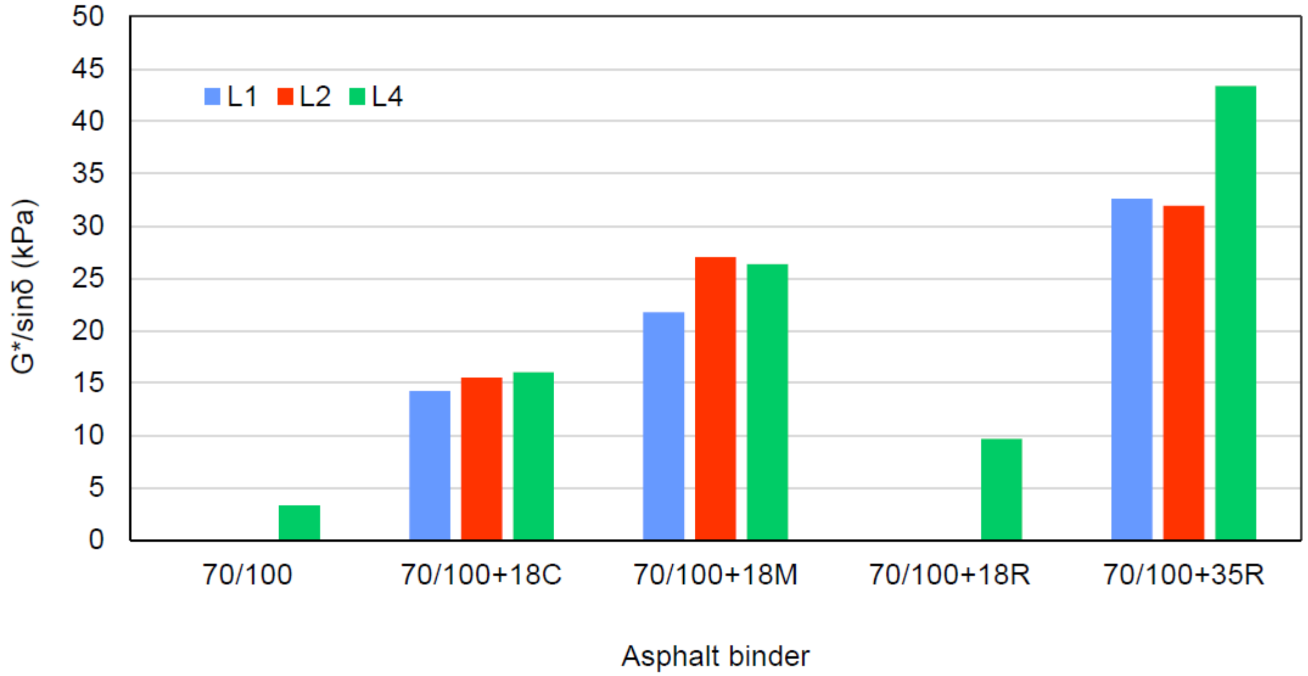


Low Temperature: *G** at *T*=22°C and f= 1.59Hz



- In most cases, Reduced G* with addition of CR
- CR type has an effect on modulus

High Temperature: G/sinδ at T=58°C and f= 1.59Hz*



- Increased G*/sin δ with addition of CR
- CR type has an effect on rutting property

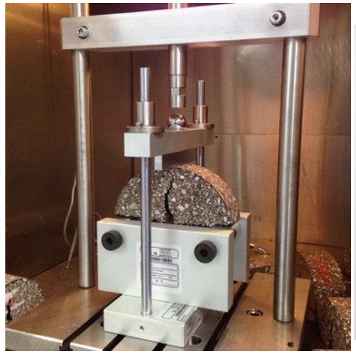
Qiuz 2

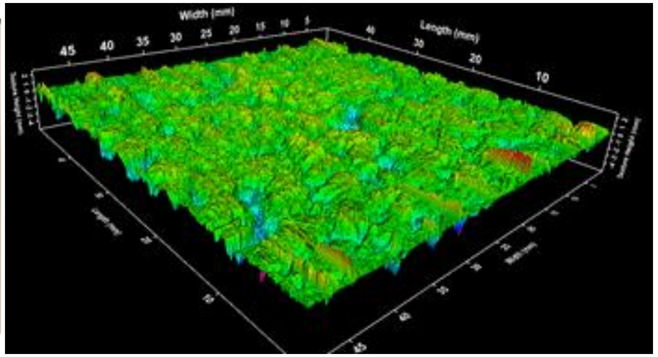
When plastic is added to the binder what can happen

1. **Storage stability problem**

2. **Binder becomes soft**

10 min break





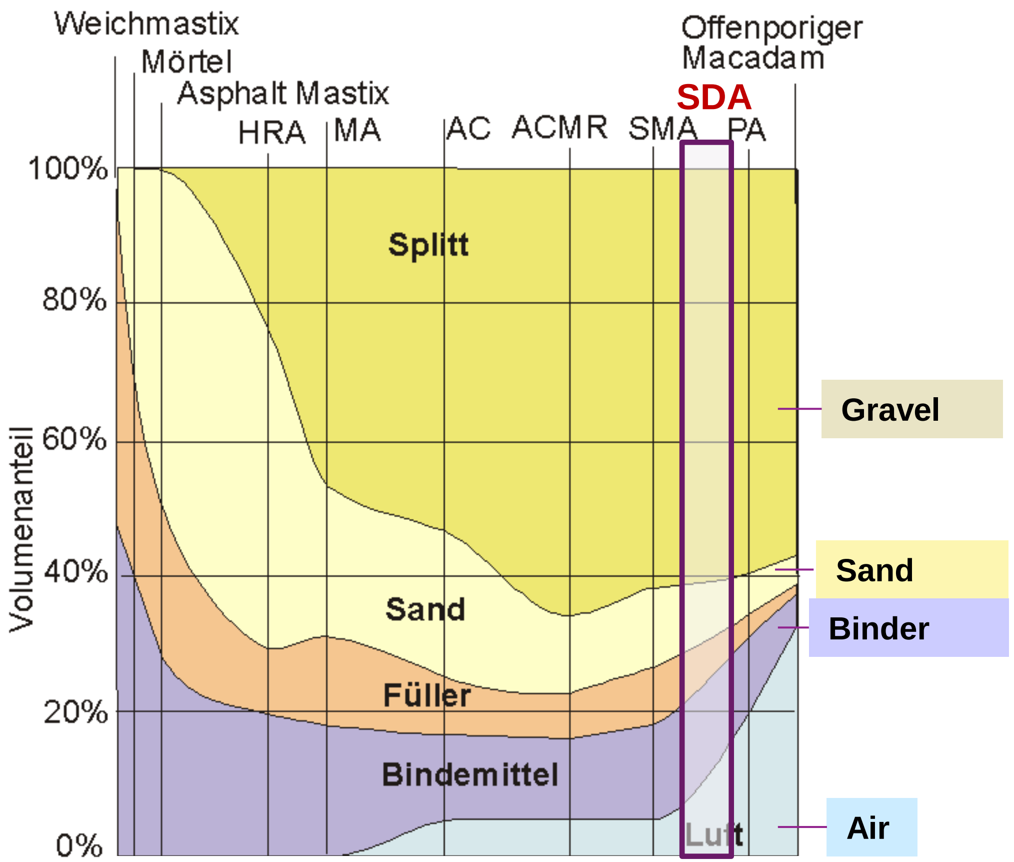
Crumb rubber modified mixtures (Empa Project)

Lily Poulikakos, Empa

Poulikakos, L.D., Buttlar, W., Schüwer, N., Lo Presti, D., Balmer, T., Bueno, M. Can crumb rubber modifier effectively replace the use of polymer- modified bitumen in asphalt mixture? (2021) Sustainable and Resilient Infrastructure, DOI: 10.1080/23789689.2021.1965428

Bueno, M., Haag, R., Heeb, N. et al. Functional and environmental performance of plant-produced crumb rubber asphalt mixtures using the dry process. Mater Struct 54, 194 (2021). https://doi.org/10.1617/s11527-021-01790-y

Semi-Dense Asphalt (SDA)

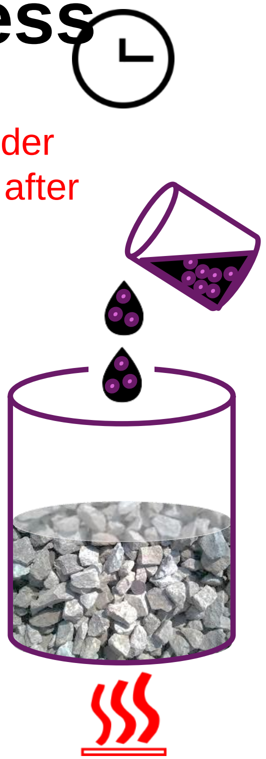


Source: Partl, M.N., 2007. Lecture notes Bituminöse Werkstoffe HS07, ETH Zürich

- Air Voids = 12-16%; Binder content 6.1% and 6.5%-Mass, 0.3%-Mass PE

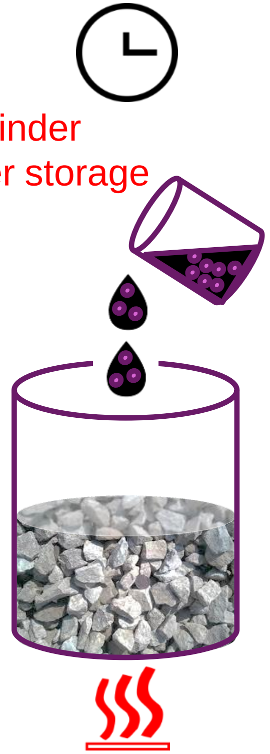
Process of Mixing Waste Materials with Bitumen

Semi Wet Process



Modified binder added soon after blending

Wet Process

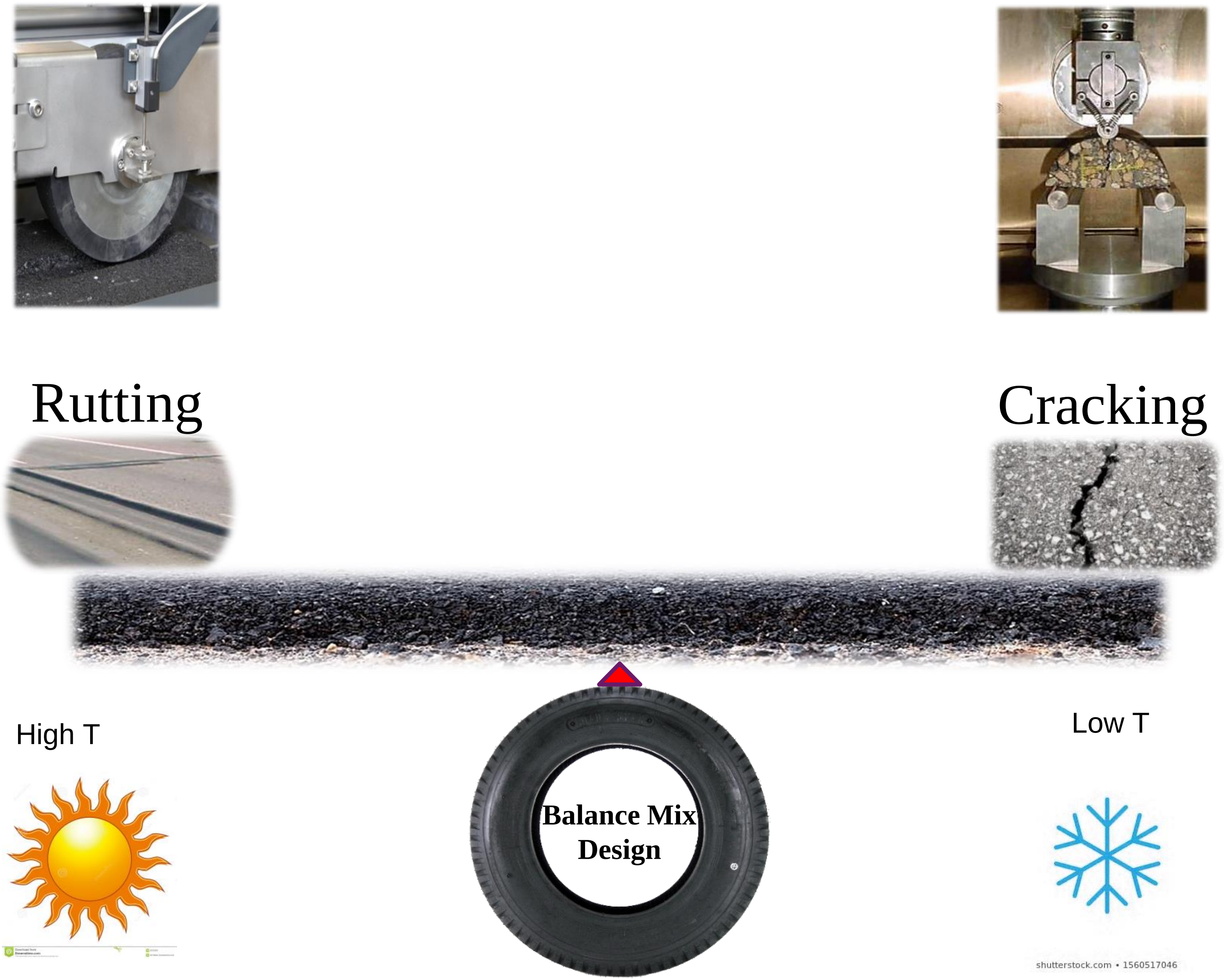


Modified binder added after storage

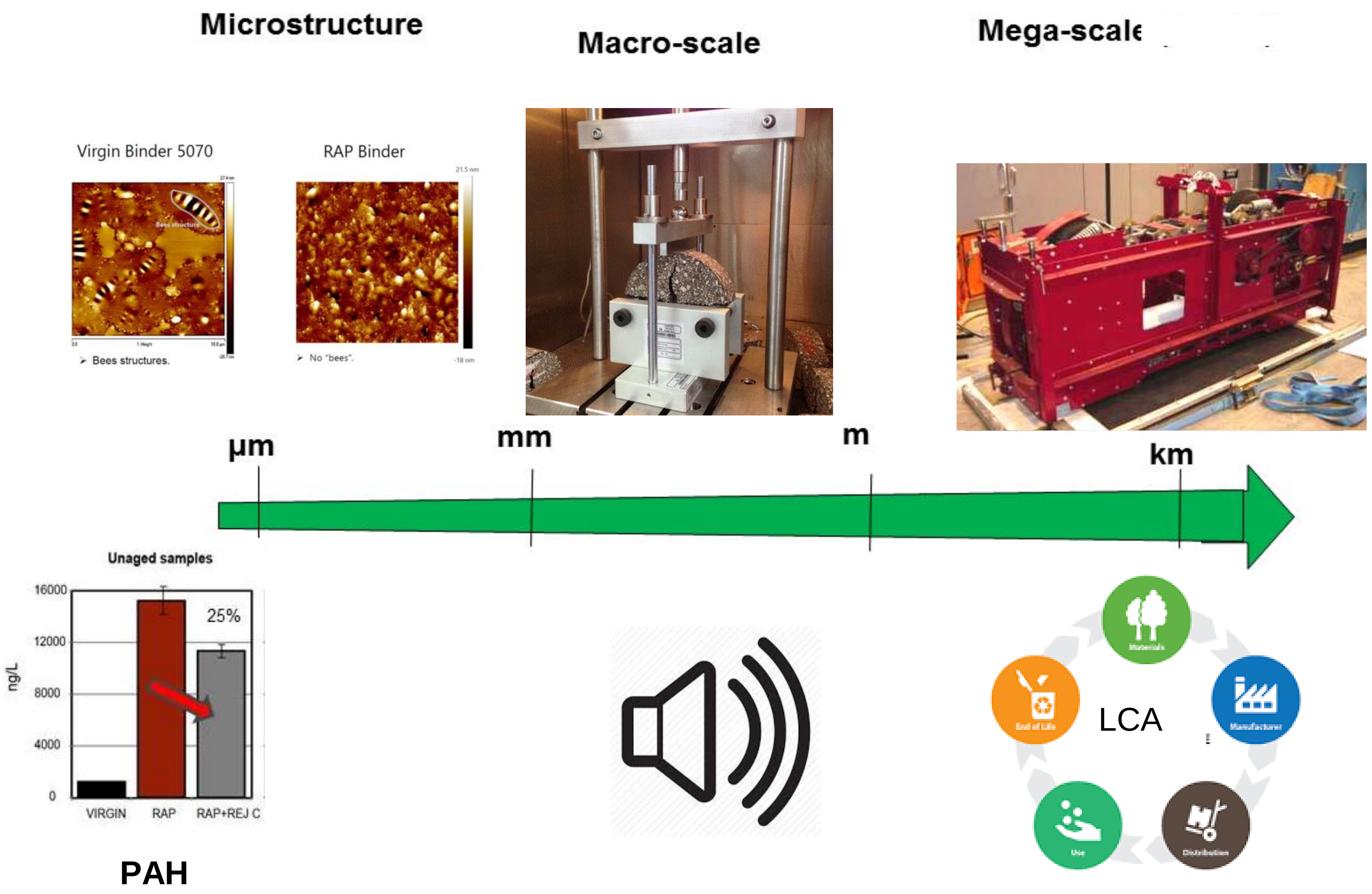
Dry Process

Kakar et al.

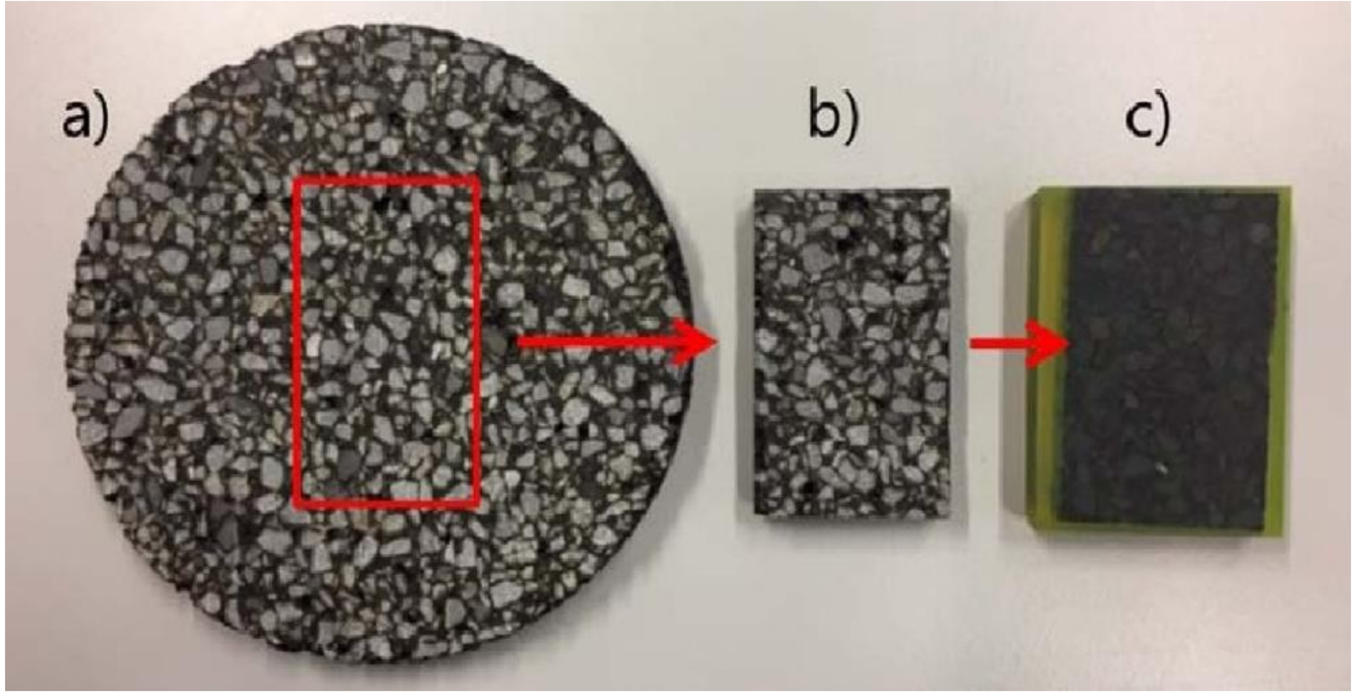
Balance Mix Design



Empa Asphalt Research: Multi scale evaluation approach



Environmental Scanning Electron Microscopy (ESEM) specimen preparation

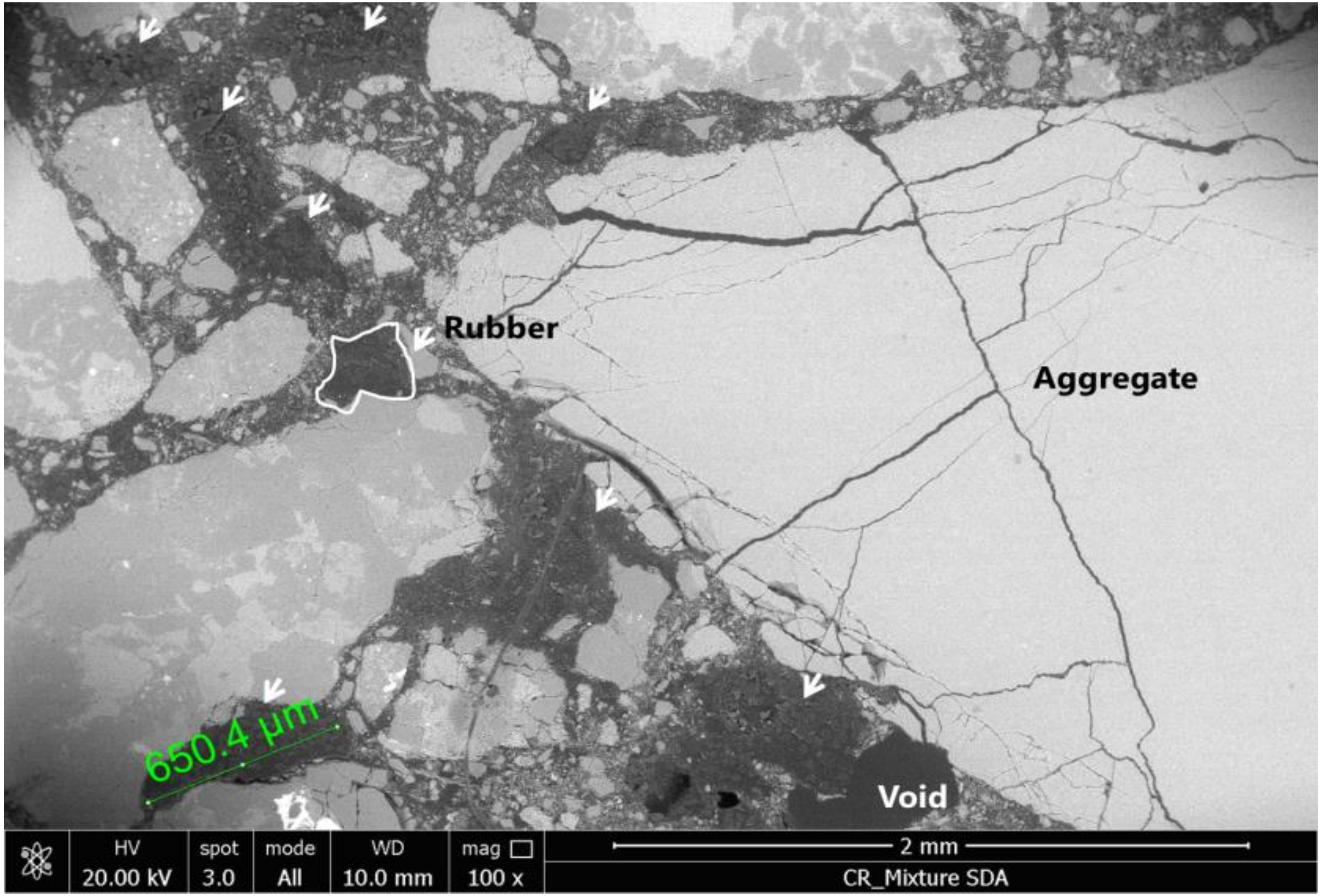


Rodríguez-Fernández et al Construction and Building Materials 259 (2020) 119662

Microstructure of Crumb Rubber Modified Mixture

Innosuisse

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

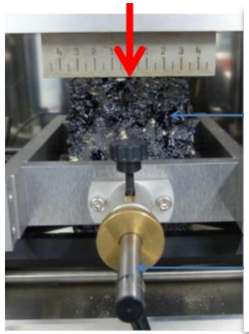


Testing at a Range of Temperatures

SCB

0°C

ITS



22°C

MMLS

30°C

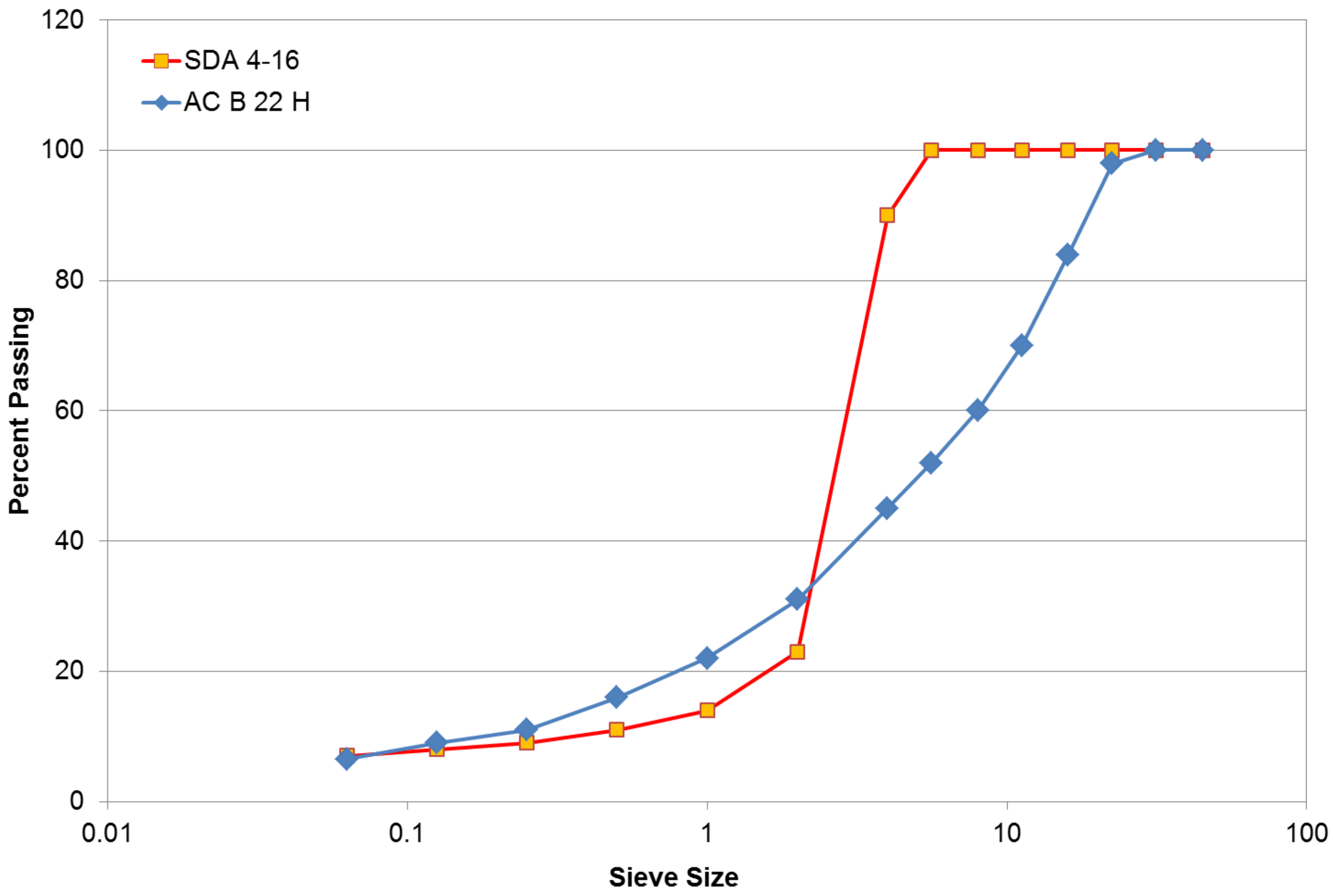
CCT

50°C

HWT

50°C

Aggregate Gradation Plant Production



Indirect Tensile Strength
Ref: EN 12697-23

Cyclindrical specimen

Loading speed: (50 ± 2) mm/min

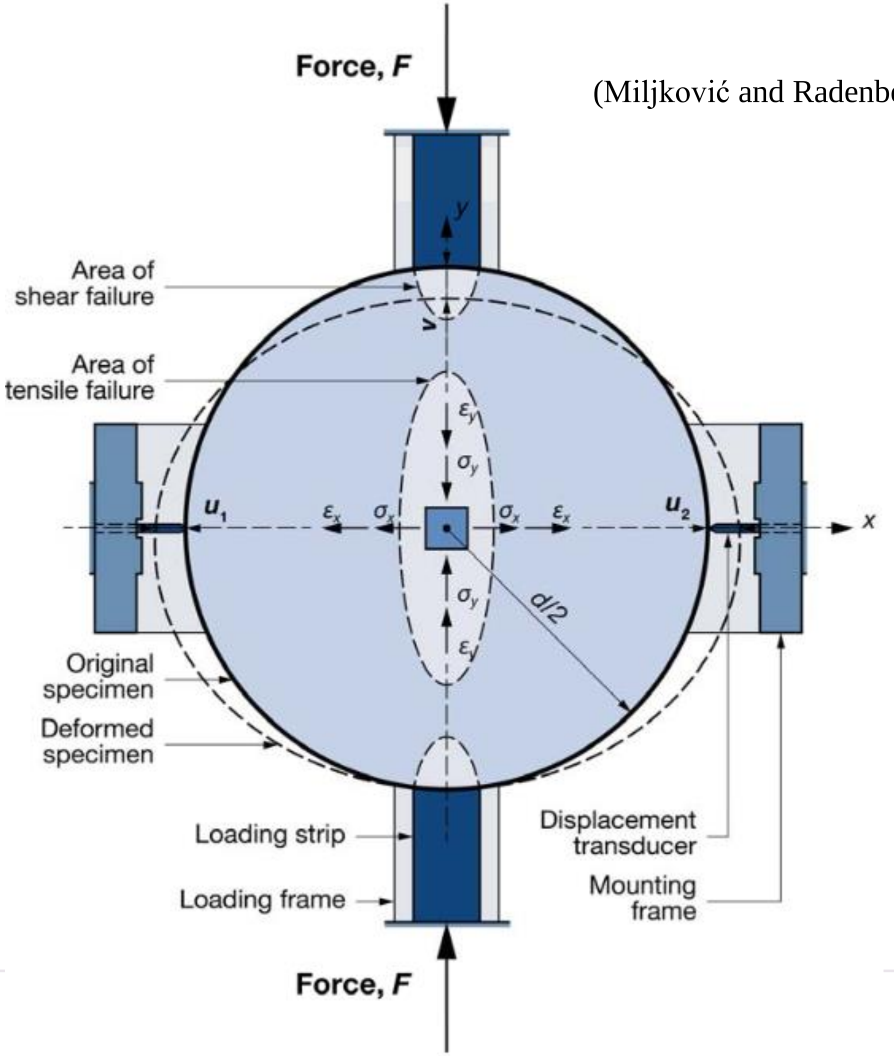
ITS=$\frac{2.F}{\pi.D.H}$***1000**

F=maximum force

D=Diamter

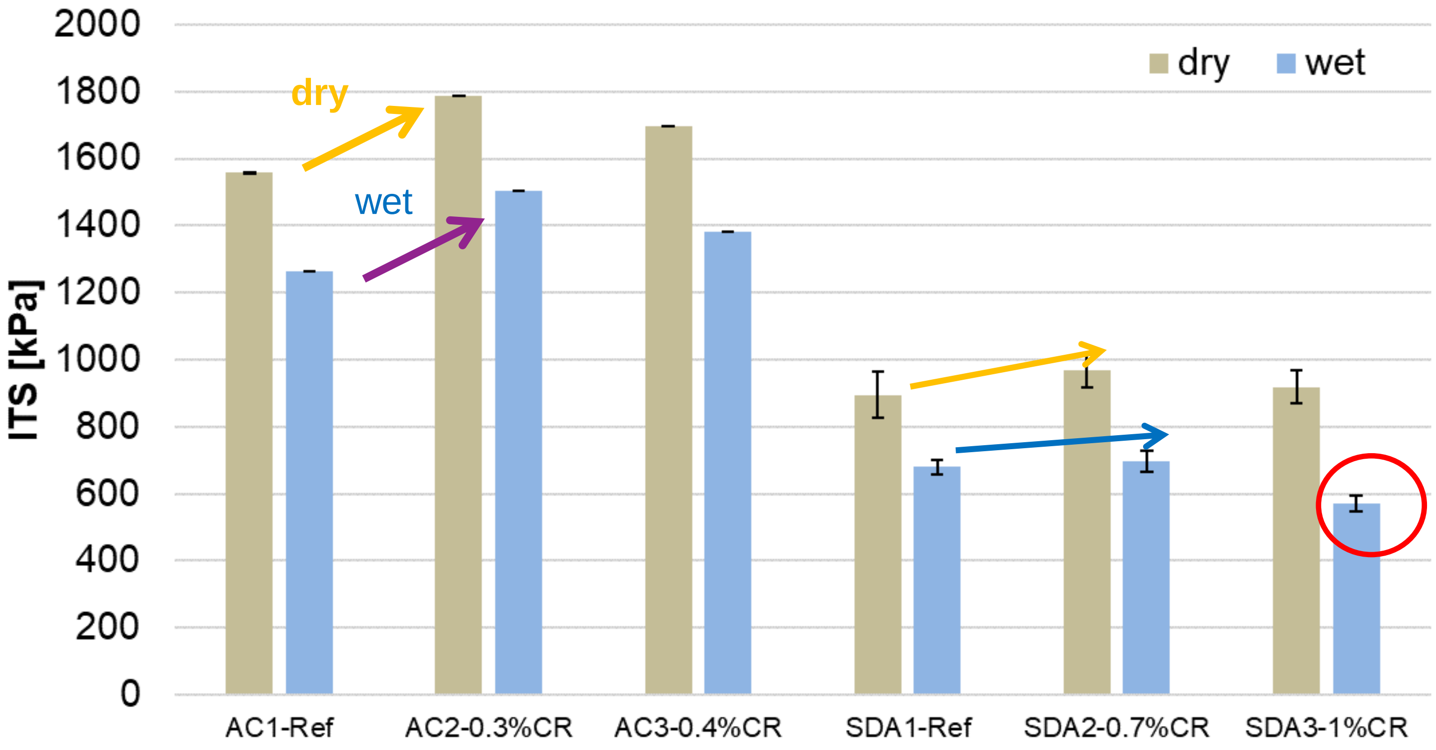
H=Height

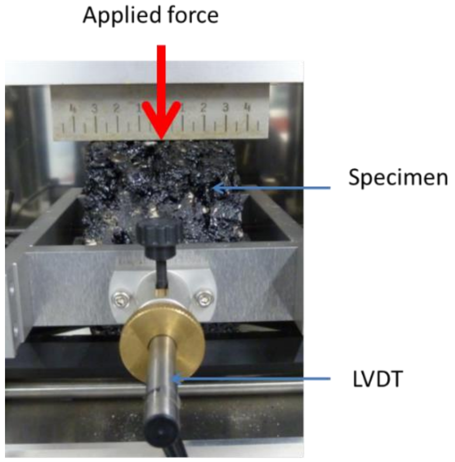
(Miljković and Radenberg, 2014)



Crumb Rubber Modified Mixture Indirect Tensile Strength for Dry and Wet Samples

22°C





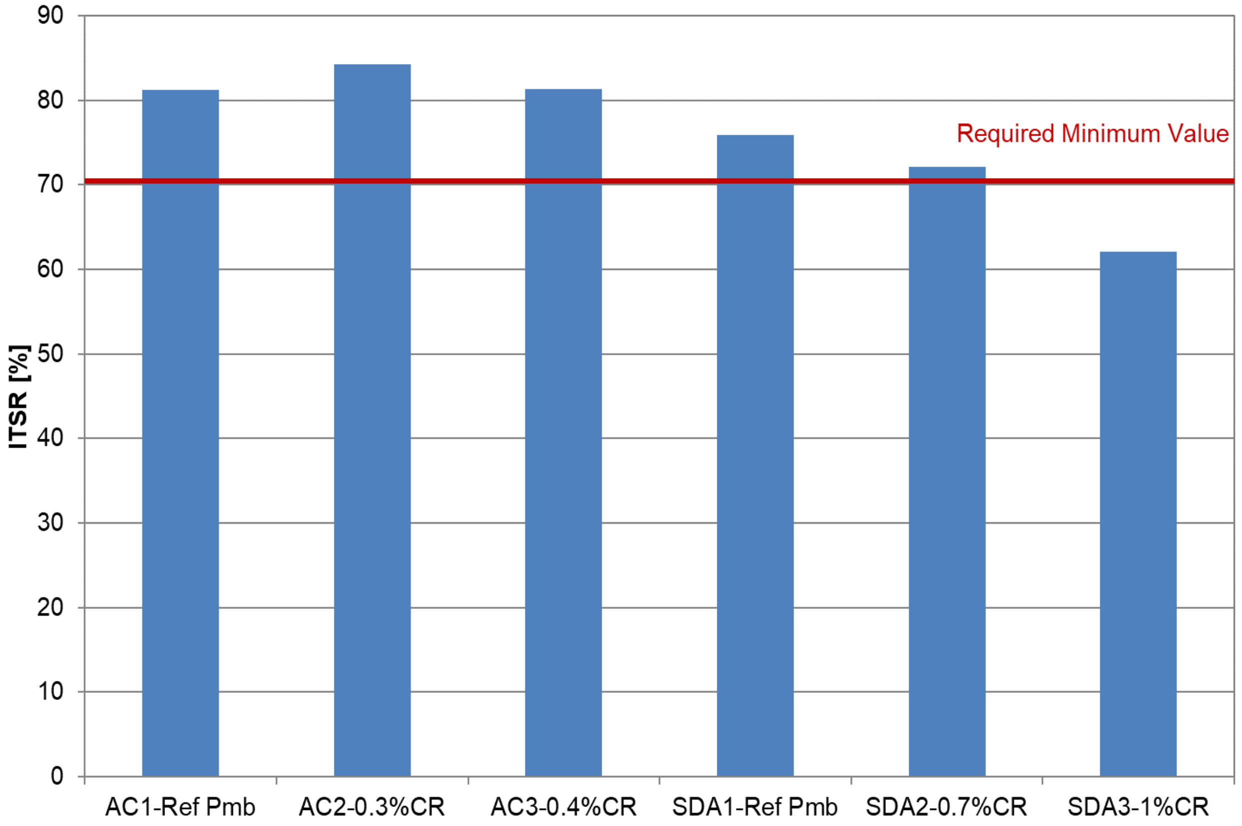
Water conditioning of specimen at 40°C for 68 to 72h

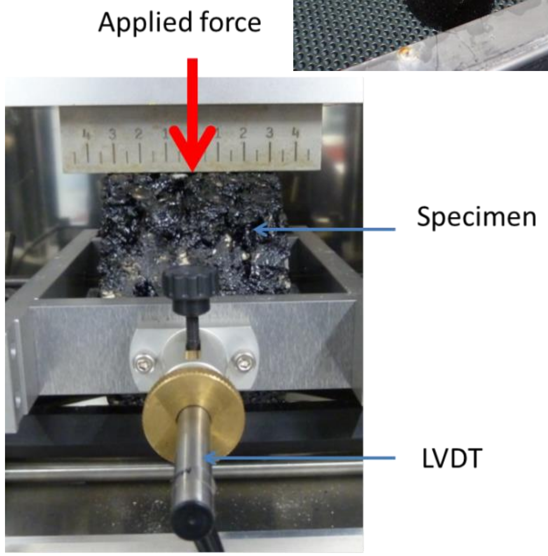
- ❖ CR addition increases ITS, depending on CR amount

Lily D. Poulikakos, William Buttlar, Moises Bueno
Laboratory scale performance of plant produced crumb rubber modified asphalt mixtures using the dry process, submitted

Crumb Rubber Modified Mixture: Moisture Resistance

22°C





Water conditioning of specimen at 40°C for 68 to 72h

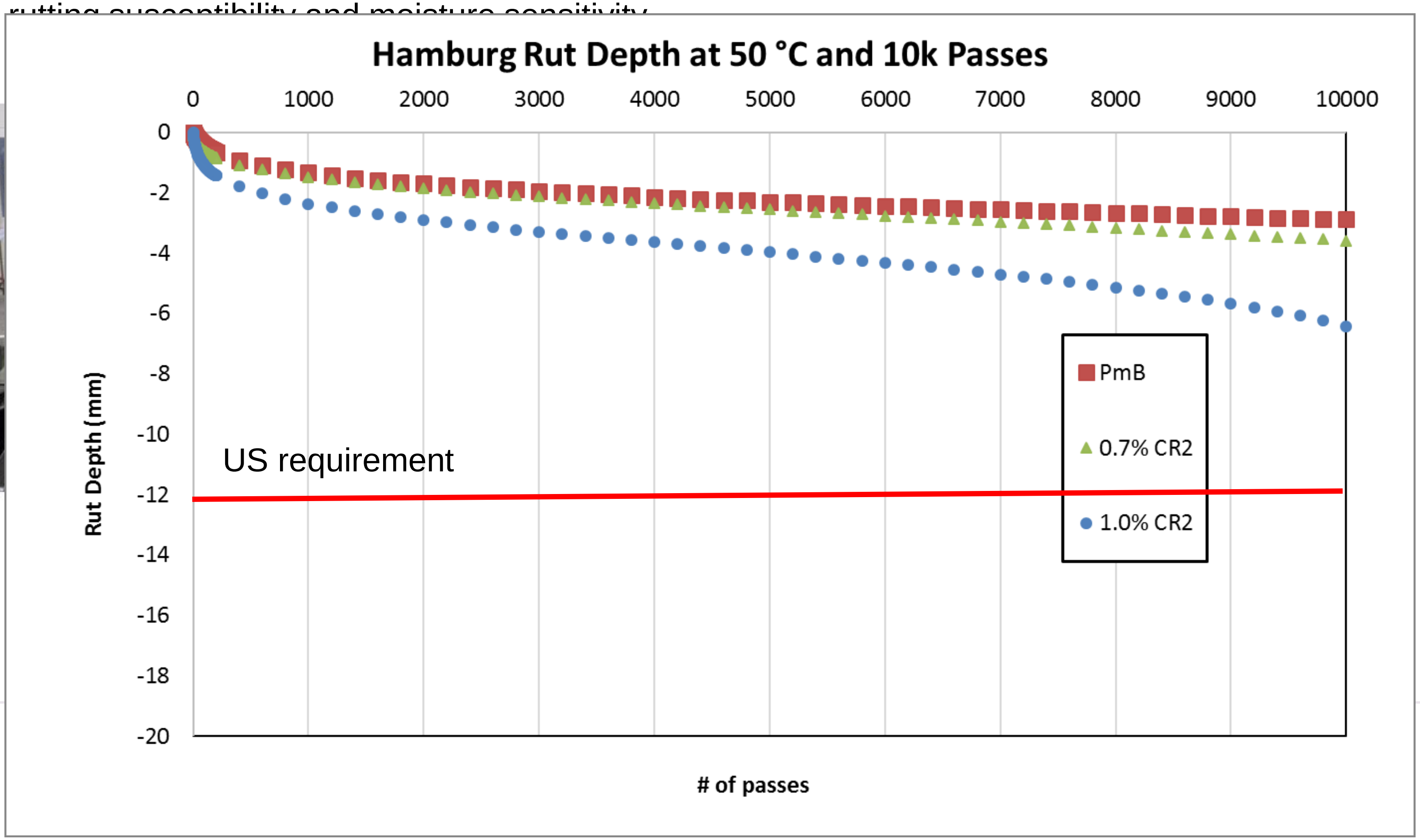
$$ITSR = 100 \cdot \frac{IDT_w}{IDT_d}$$

Crumb Rubber Modified Mixture: Hamburg Wheel Tracking

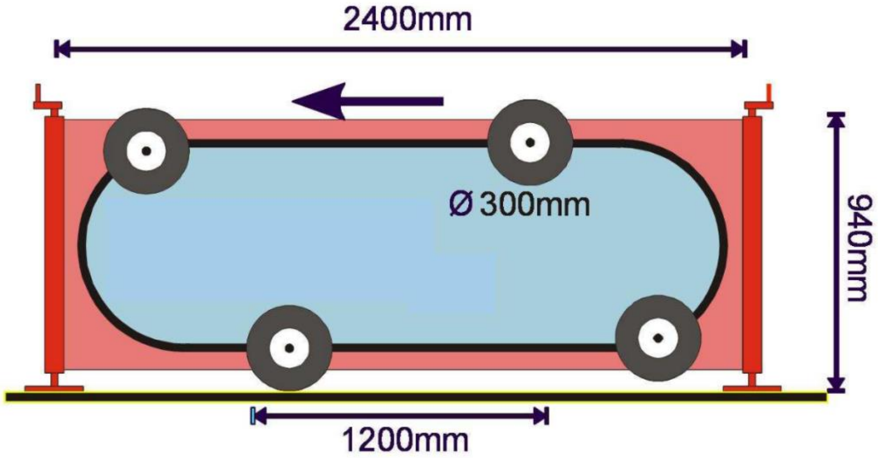
U Missouri, USA (Prof. Bill Buttlar)

50°C

- loaded steel wheel (71.7 kg), over the samples in the heated water bath (50°C) (AASHTO T-324)
- rutting susceptibility and moisture sensitivity



Traffic Load Simulator MMLS3-m Scale



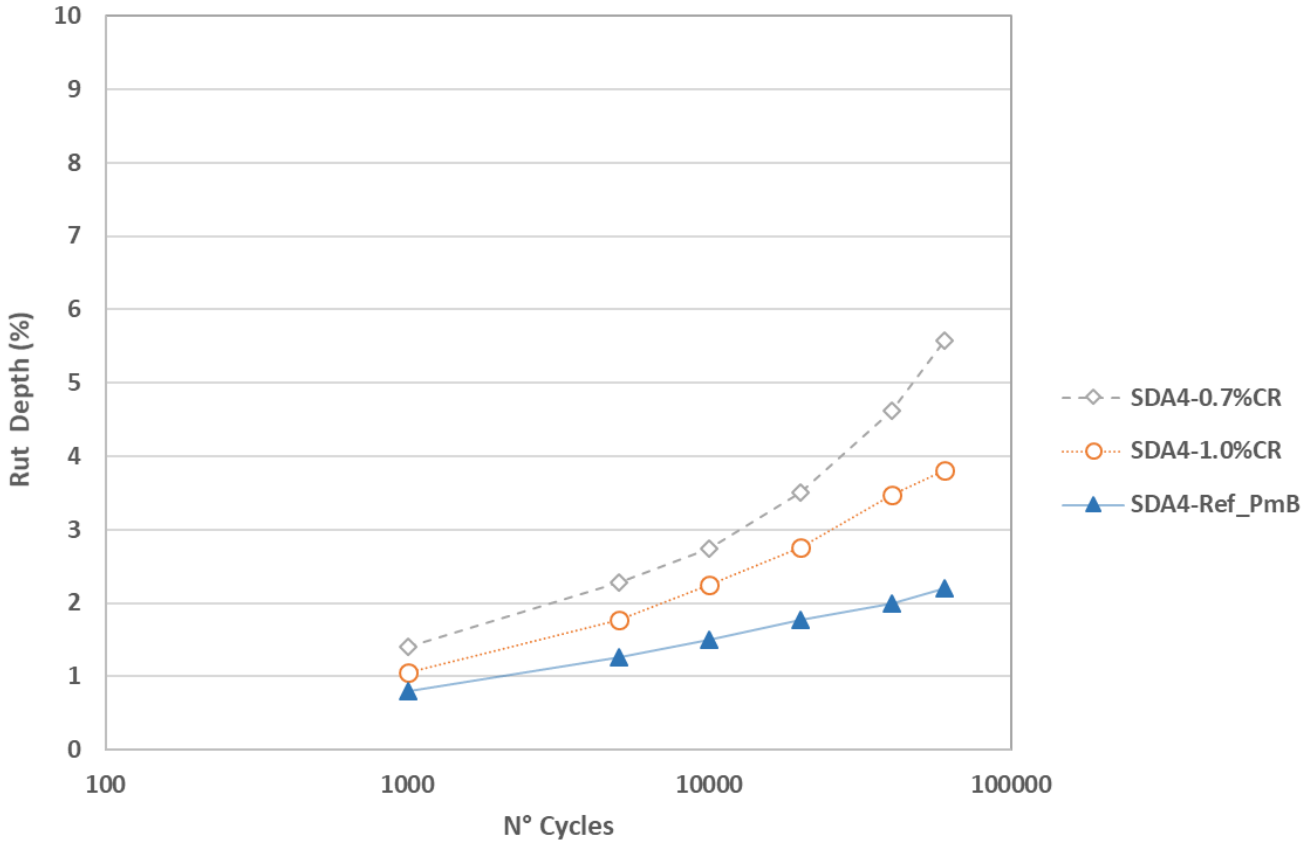
Speech: **9 km/h**
Axle load: **9.1 kN** (212 kg)
125 wheel passes/min
Driving distance **1.2 m**

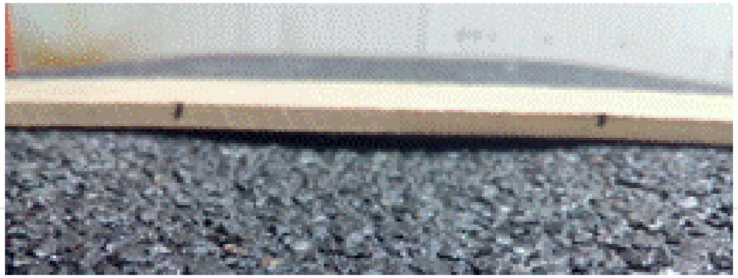
T_{air}: 30°C
T_{sample}: 25-30°C
60,000 cycles (ca.8 h)

Innosuisse
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

MMLS3: m-Scale Mechanical Perfromance: Crumb Rubber Modified Mixture

30°C





Materials Science & Technology

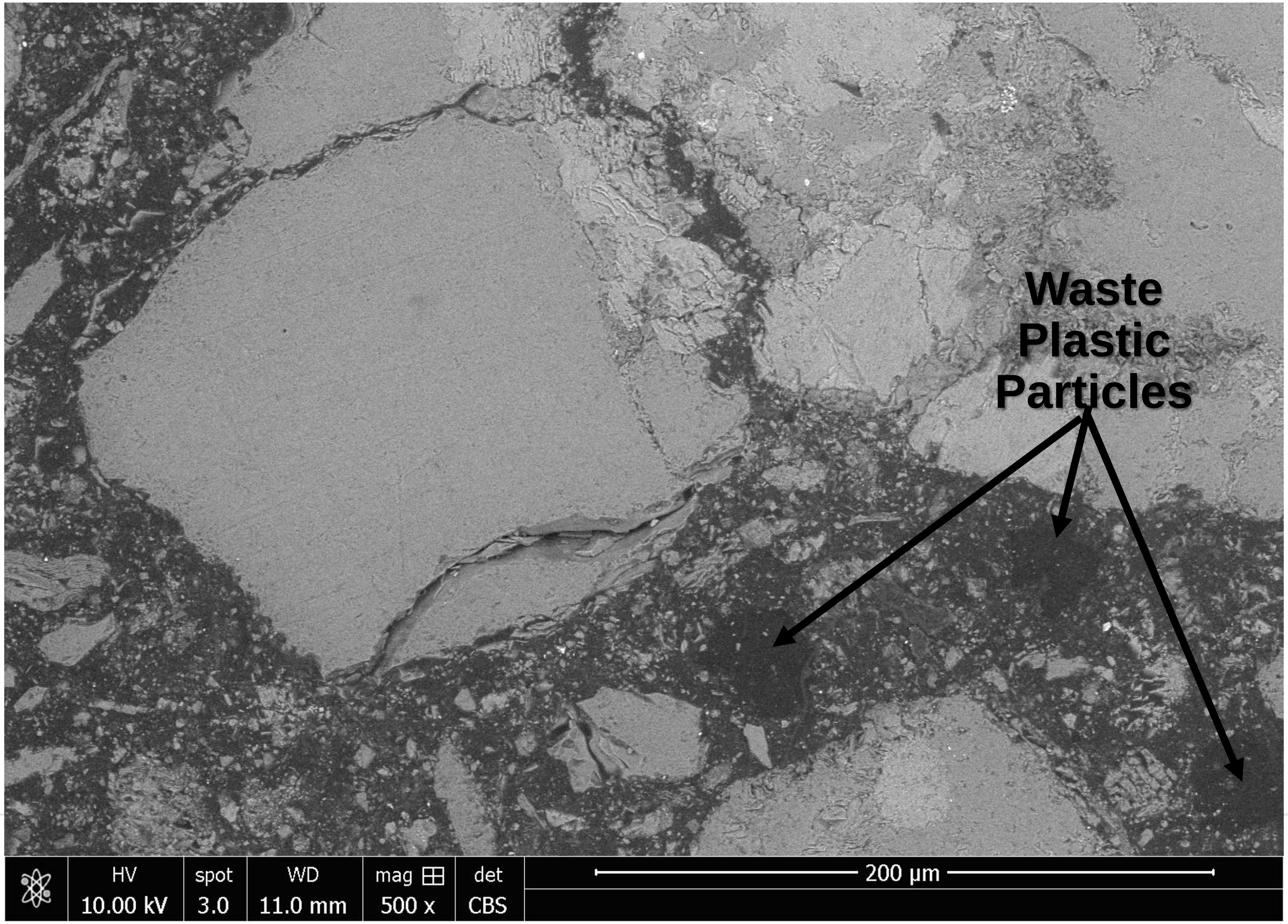
Waste PE in asphalt mixtures

Kakar Rafiq, M., Mikhailenko, P., Piao, Z., Poulikakos, L.D. High and low temperature performance of polyethylene waste plastic modified low noise asphalt mixtures (2022) Construction and Building Materials, 348, art. no. 128633, DOI: 10.1016/j.conbuildmat.2022.128633

(Empa project)

Poulikakos et al, submitted (Rilem Project)

Microstructure of PE Modified Mixtures



Semi Curcular Bend Test
EN 12697-44

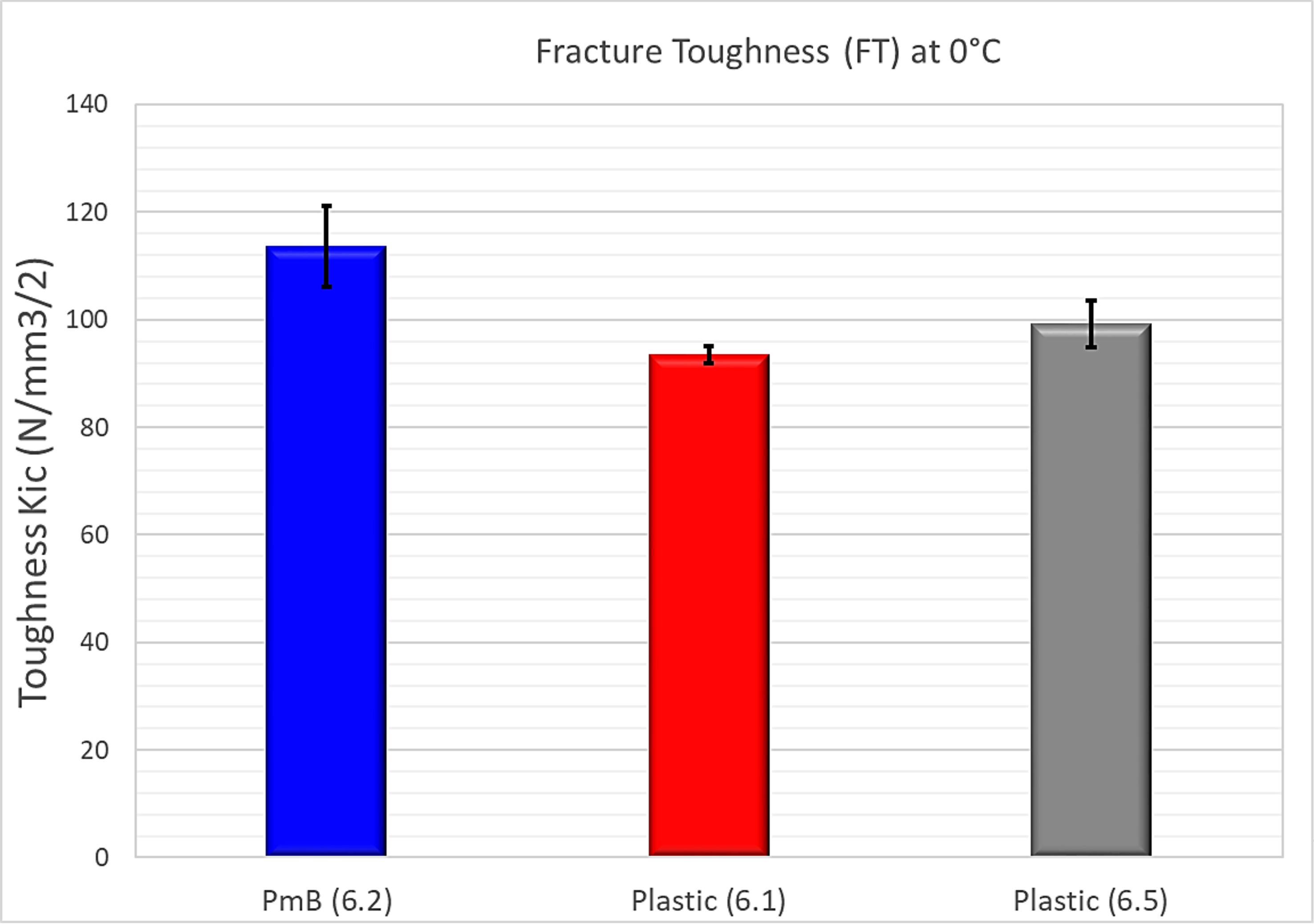
- A notch of 10mm deep and 4mm wide
- Three point testing frame
- load applied at a monotonicly at 5 mm/min along the vertical axes
- Load and displacement-fracture toughness

$$K_{\mathrm{Ic,i}} = \sigma_{\mathrm{max,i}} Y_1 \sqrt{\pi a_{\mathrm{i}}} \quad \mathrm{N / mm^{1,5}}$$

- ai=notch dimensions
- Yi= factor per EN

Fracture Toughness (0C)


shutterstock.com • 1560517046



Cyclic Compression Test
EN 12697-25

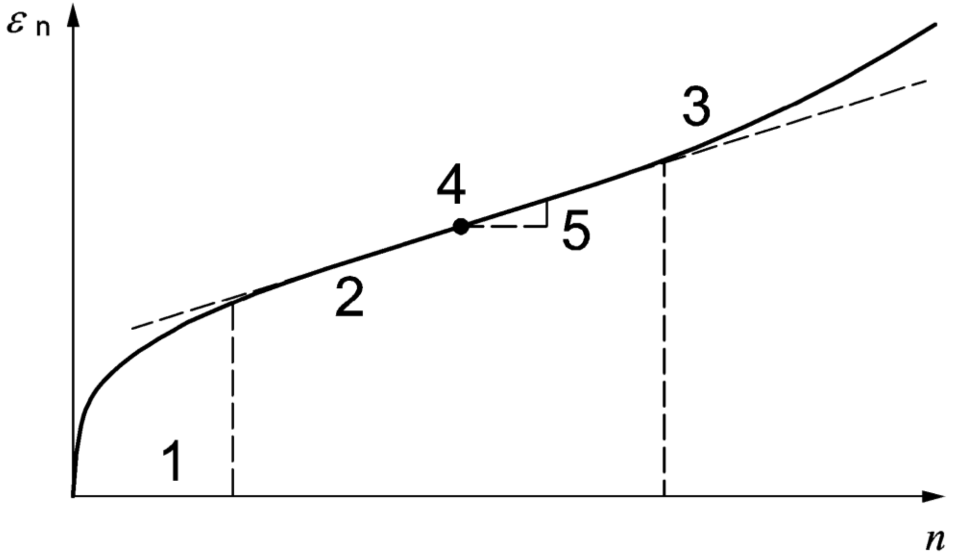
determining the resistance of bituminous mixtures to permanent deformation by cyclic compression tests at high temperature

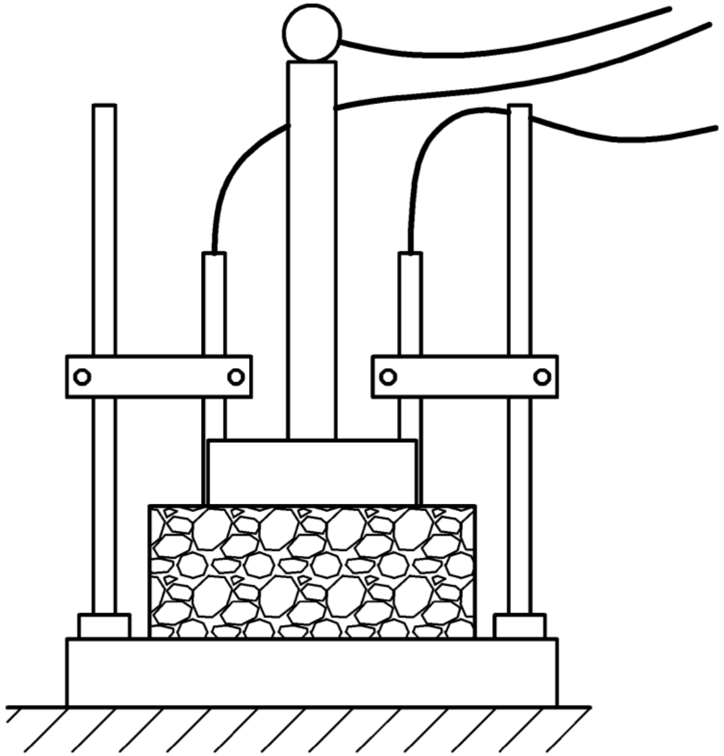
-haversine loading cycle was 1.7 s

with a rest period of 1.5 s.

-upper and lower stresses of 0.35 MPa

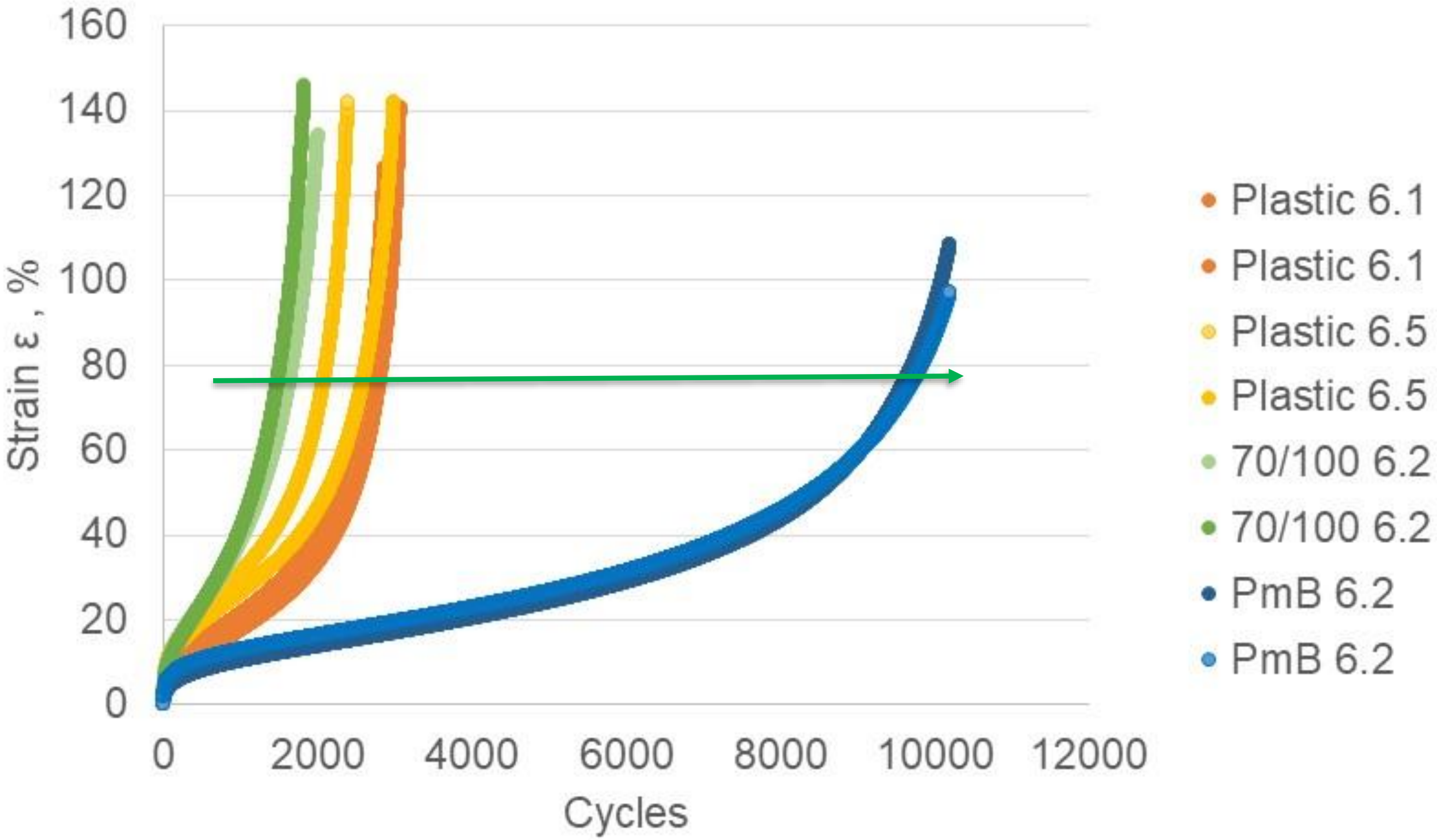
and 0.025 MPa

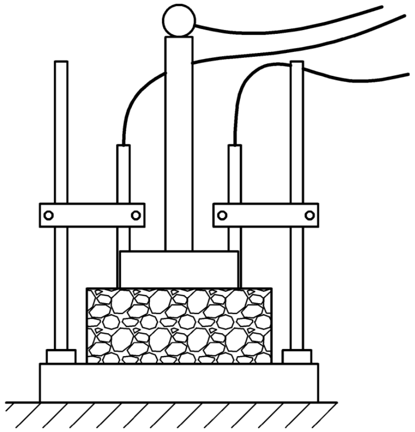




Plastic Modified Mixture: Cyclic Compression

50°C



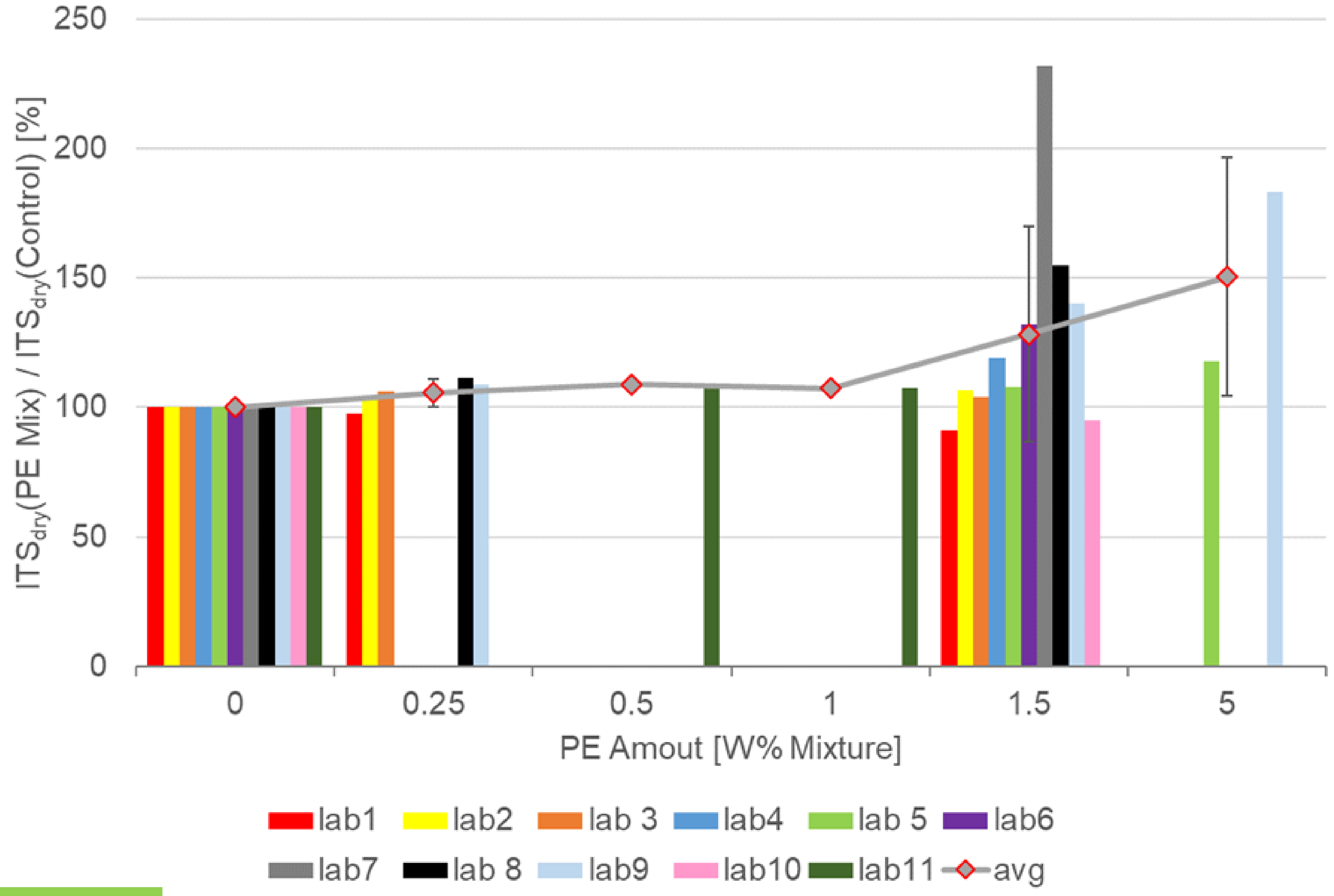


Kakar Rafiq, M., Mikhailenko, P., Piao, Z., Poulikakos, L.D. High and low temperature performance of polyethylene waste plastic modified low noise asphalt mixtures (2022) Construction and Building Materials, 348, art. no. 128633, DOI: 10.1016/j.conbuildmat.2022.128633

Indirect tensile strength wrt. ref. (Dry)

25°C

AC16,
VC ≈ 4%

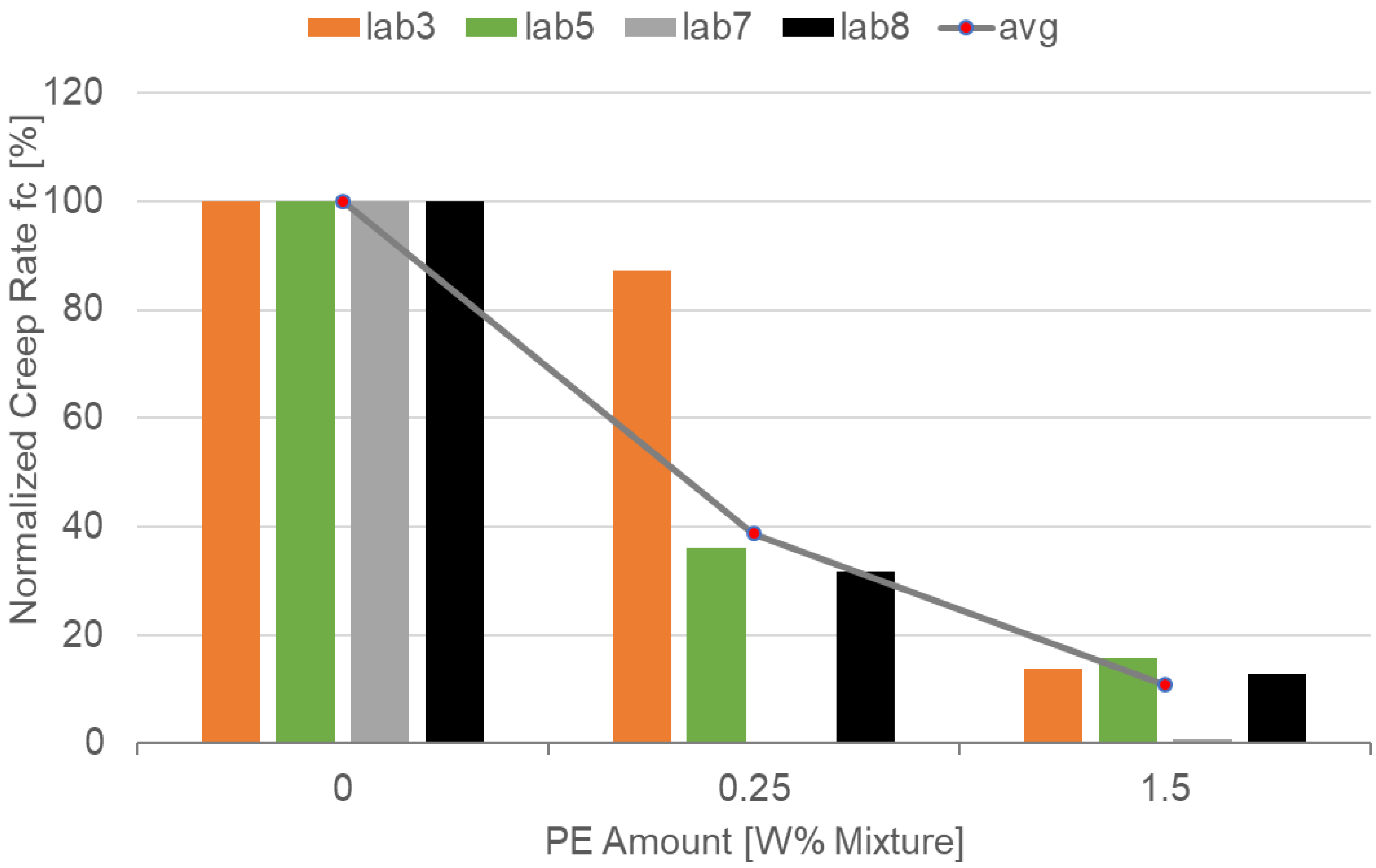


Poulikakos et al submitted

Cyclic Compression Test

50°C

AC16,
VC ≈ 4%



RCA in asphalt mixtures (Empa project)

Construction & Demolition Waste in Switzerland

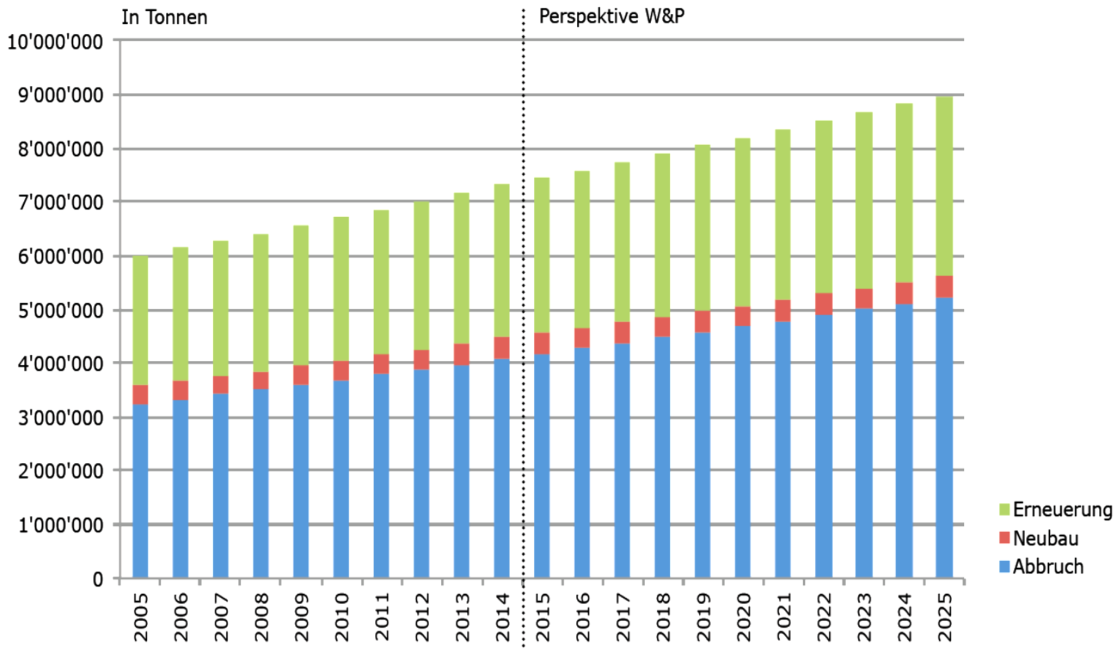


Abbildung 29: Entwicklung 2005-2025 der Bauabfälle nach baulichen Prozessen

Quelle: Gebäudemodell Wüest & Partner 2015

In Switzerland and the world, Construction and demolition waste (C&D) forms the largest part of waste produced

5 million tons of C&D Waste is landfilled or incinerated yearly in Switzerland

Construction & Demolition waste in Switzerland

- Most of C&D waste comes from Portland cement concrete, which can be re-used in the form of Recycled Concrete Aggregates (RCA).

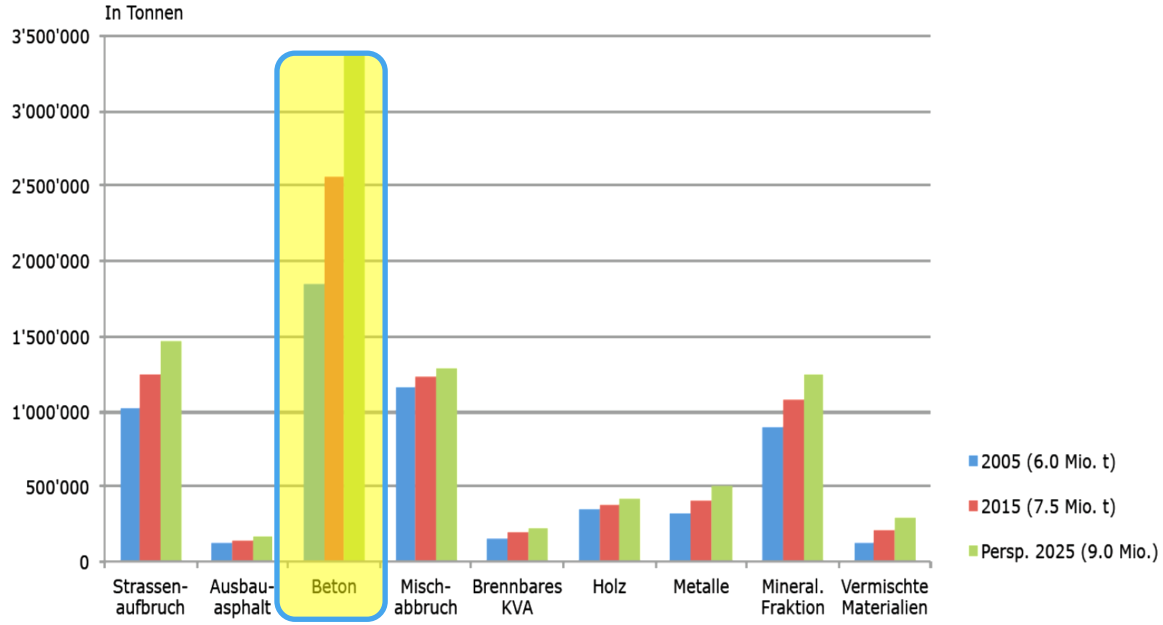


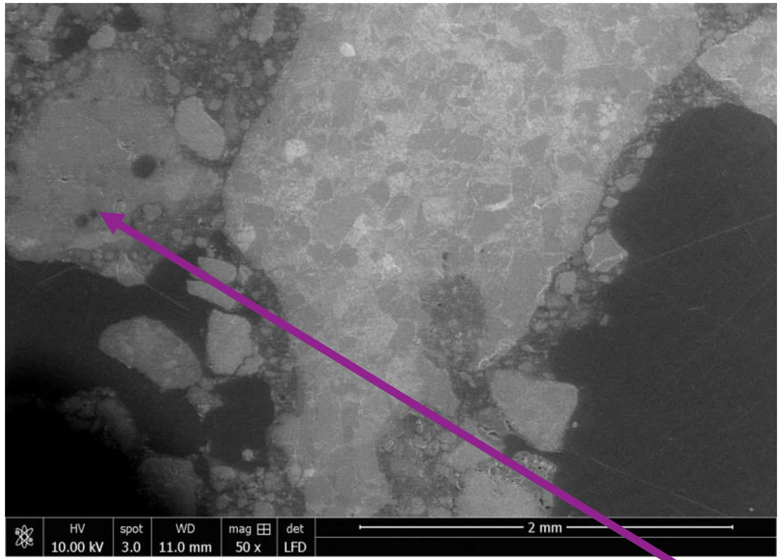
Abbildung 30: Entwicklung 2005-2025 der Bauabfälle nach Materialgruppen
Quelle: Gebäudemodell Wüest & Partner 2015

Fig. 1 Control sandstone aggregate fractions

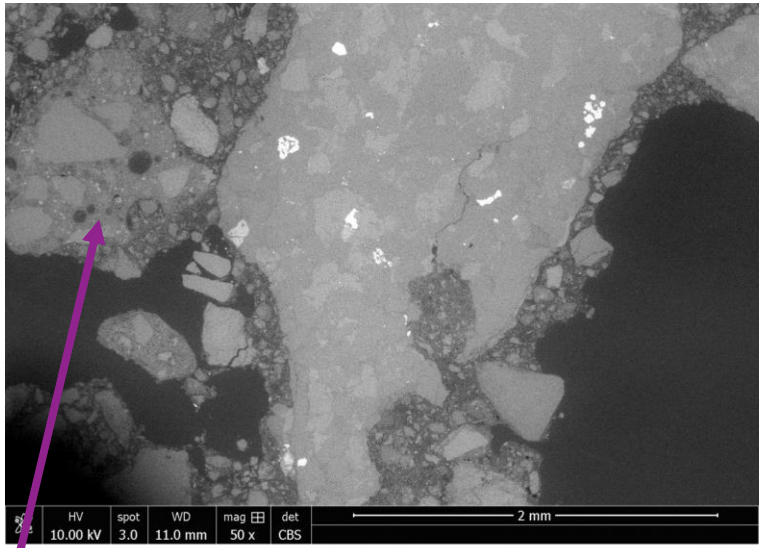
Fig. 2 RCA aggregate fractions

Mikhailenko, P., Kakar, M.R., Piao, Z., Bueno, M., Poulikakos, L. Improving the Sustainability of Semi-Dense Asphalt Pavements by Replacement of Recycled Concrete Aggregate Fractions (2020) Lecture Notes in Civil Engineering, 76, pp. 343-351. DOI: 10.1007/978-3-030-48679-2_33

ESEM Micrograph RCA Mixtures



Topography

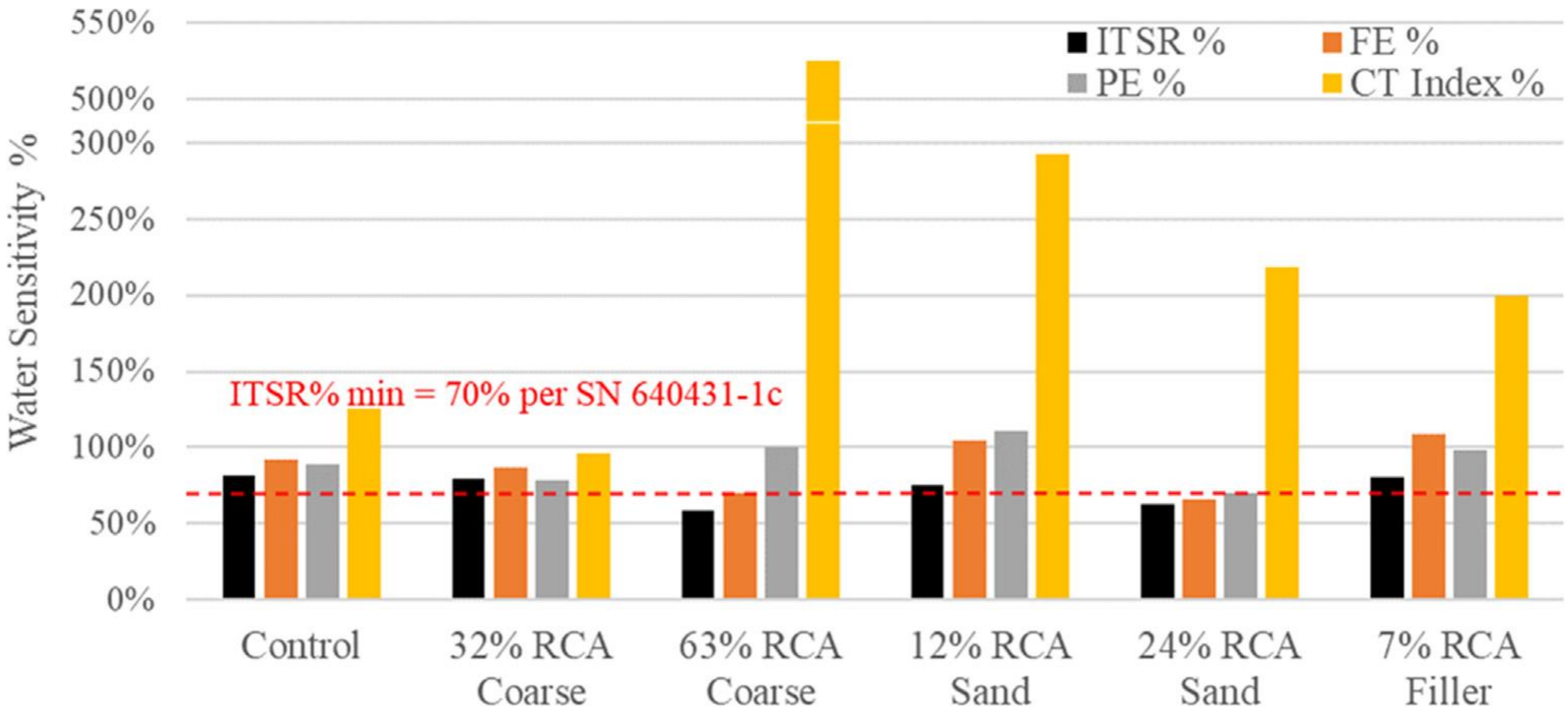


Chemistry

RCA

Sample RCA 12B
RCA particles visible in mixture

Water sensitivity based on different criteria

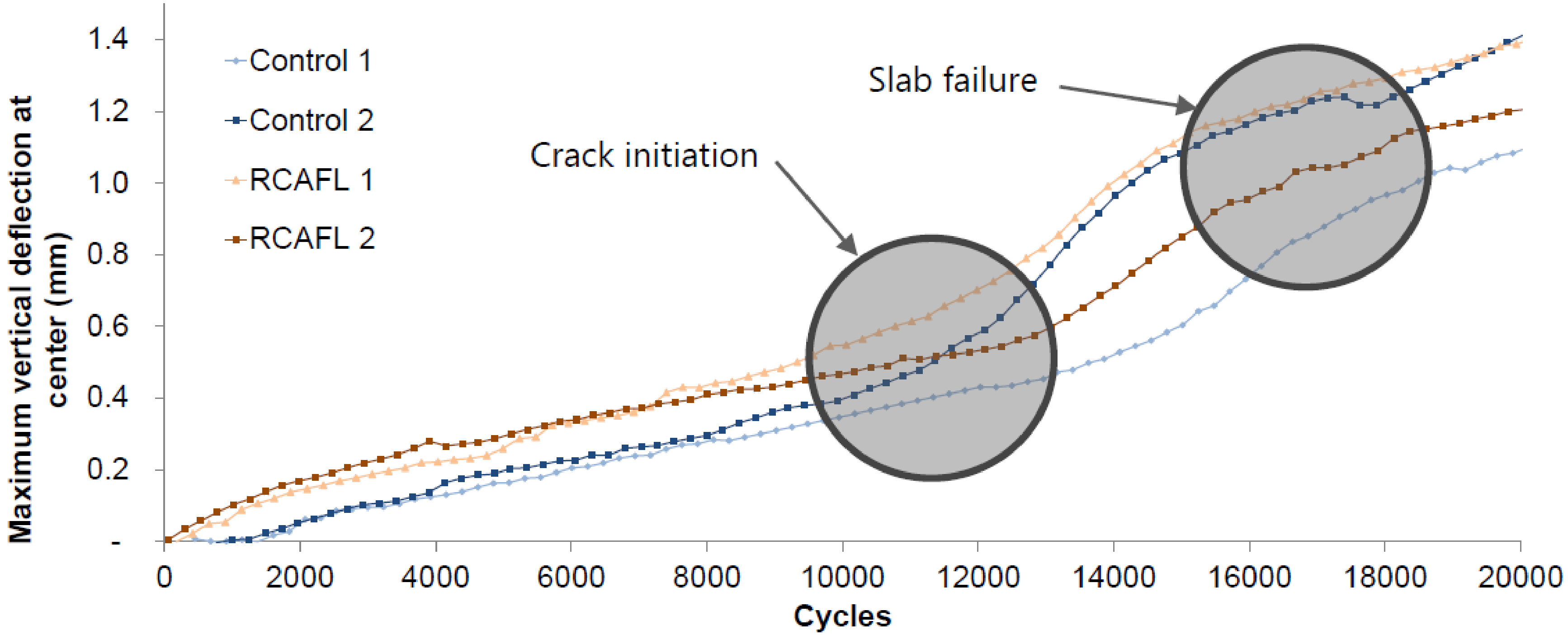


$$CT_{index} = \frac{t}{62} \times \frac{G_f}{|m_{75}|} \times \frac{l_{75}}{D}$$

P Mikhailenko, M R Kakar, Z Piao, M Bueno, L Poulikakos, Incorporation of Recycled Concrete Aggregate (RCA) Fractions in Semi-Dense Asphalt (SDA) Pavements: Volumetrics, Durability and Mechanical Properties, Construction and Building Materials 264 (2020)

MMLS3: m-Scale Mechanical Perfromance: RCA Modified Mixture

30°C



Use of RCA filler did not pose a significant disadvantage

Mikhailenko, P, Arraigada, M, Piao Z, Poulikakos, L D., Multiscale Laboratory Mechanical Performance of SDA Mixtures with Construction and Demolition Waste Filler J. Mater. Civ. Eng., 2022, 34(6): 04022106, DOI: 10.1061/(ASCE)MT.1943-5533.0004244

Quiz 3 why do we need round robin (multi lab) studies

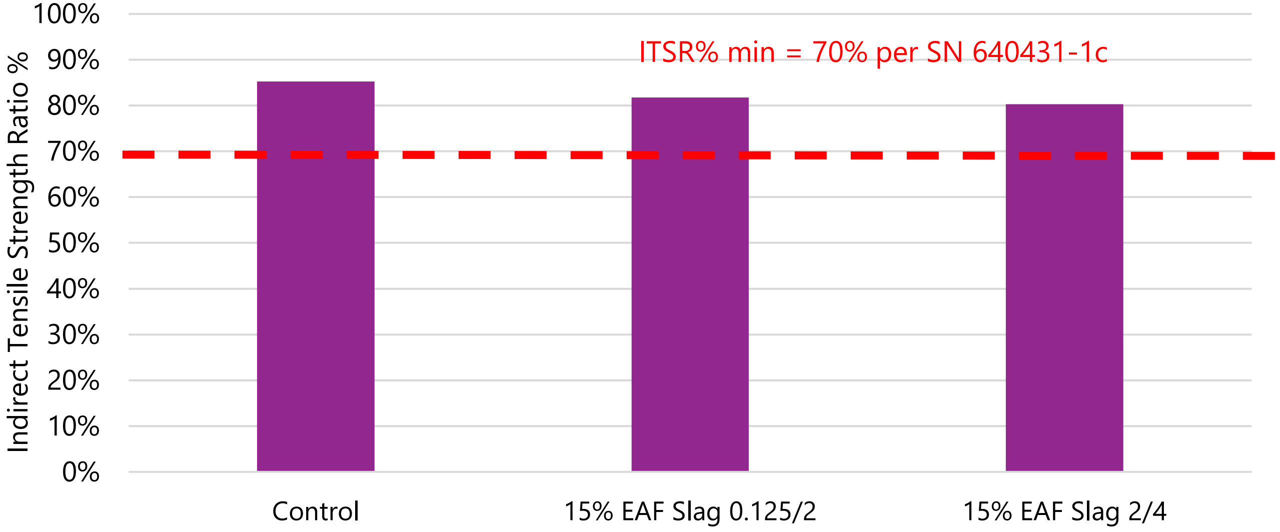
1. **To determine reproducibility of results**

2. **To collaborate with others**

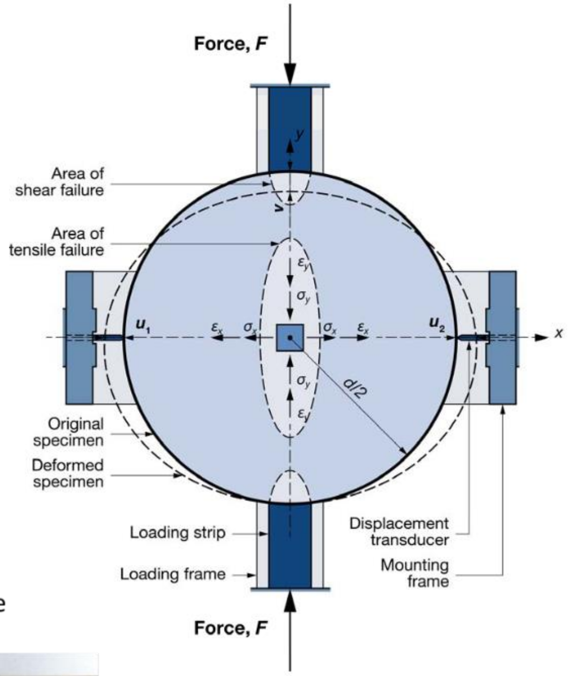
Steel slags in asphalt mixtures (Empa project, Peter Mikhailenko)

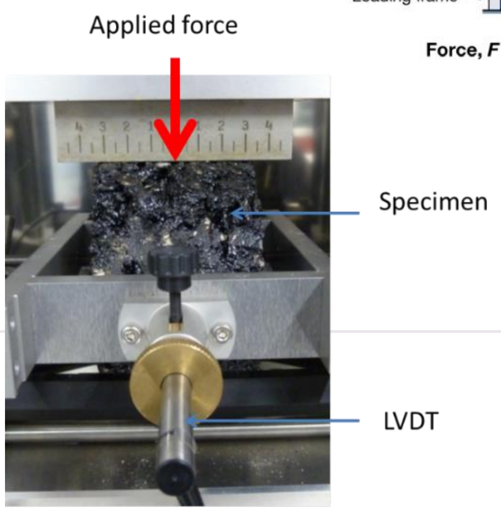
Water Sensitivity

- Similar to control with slag



(Miljković and Radenberg, 2014)





Mechanical Performance by Indirect Tensile Loading

- Stiffness Modulus (EN 12697-24)
- Fatigue resistance (EN 12697-26)

➢ Sinusoidal, stress-controlled loading

➢ 3 loading amplitudes for each mixture, with 3 100 mm ø samples tested at each amplitude (3x3)

➢ Stress (σ) calculated based on:

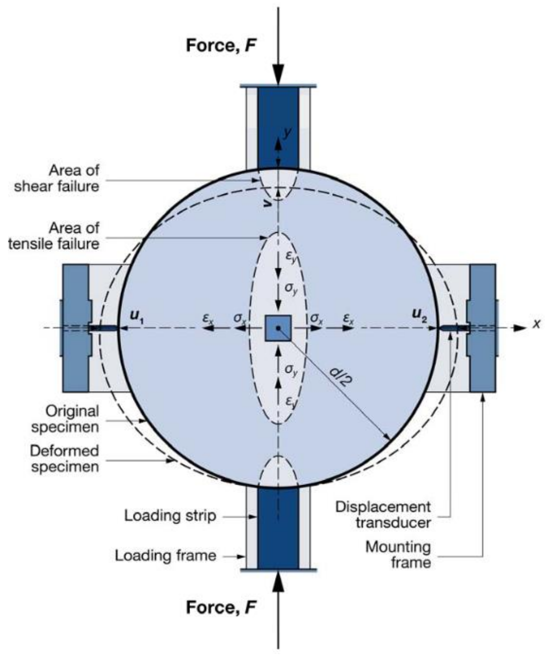
$$\sigma = \frac{2F}{\pi \times d \times h}$$

F is the vertical force

h is the sample height

d is the sample diameter

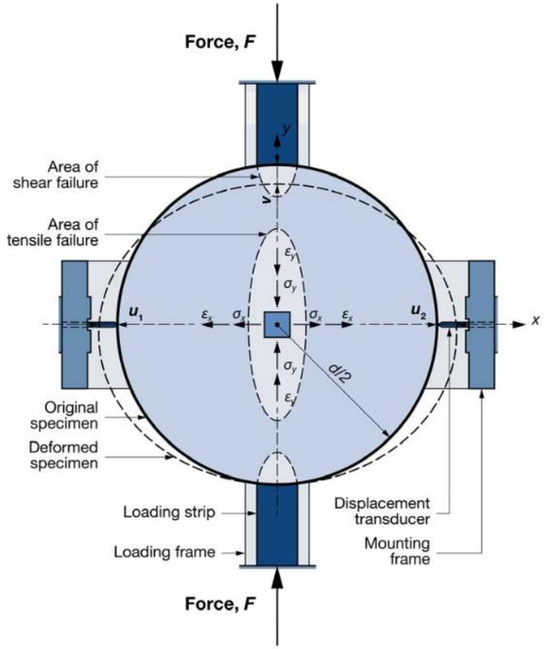
(Miljković and Radenberg, 2014)



Mechanical Performance by Indirect Tensile Loading

- Stiffness modulus |E| calculated based on:

(Miljković and Radenberg, 2014)



$$|E| = \frac{\Delta F \times (0.274 + \mu)}{\mathrm{h} \times \Delta \mathrm{u}}$$

ΔF is the difference between maximal and minimal force

μ is the poison ratio (0.239 at 10°C)

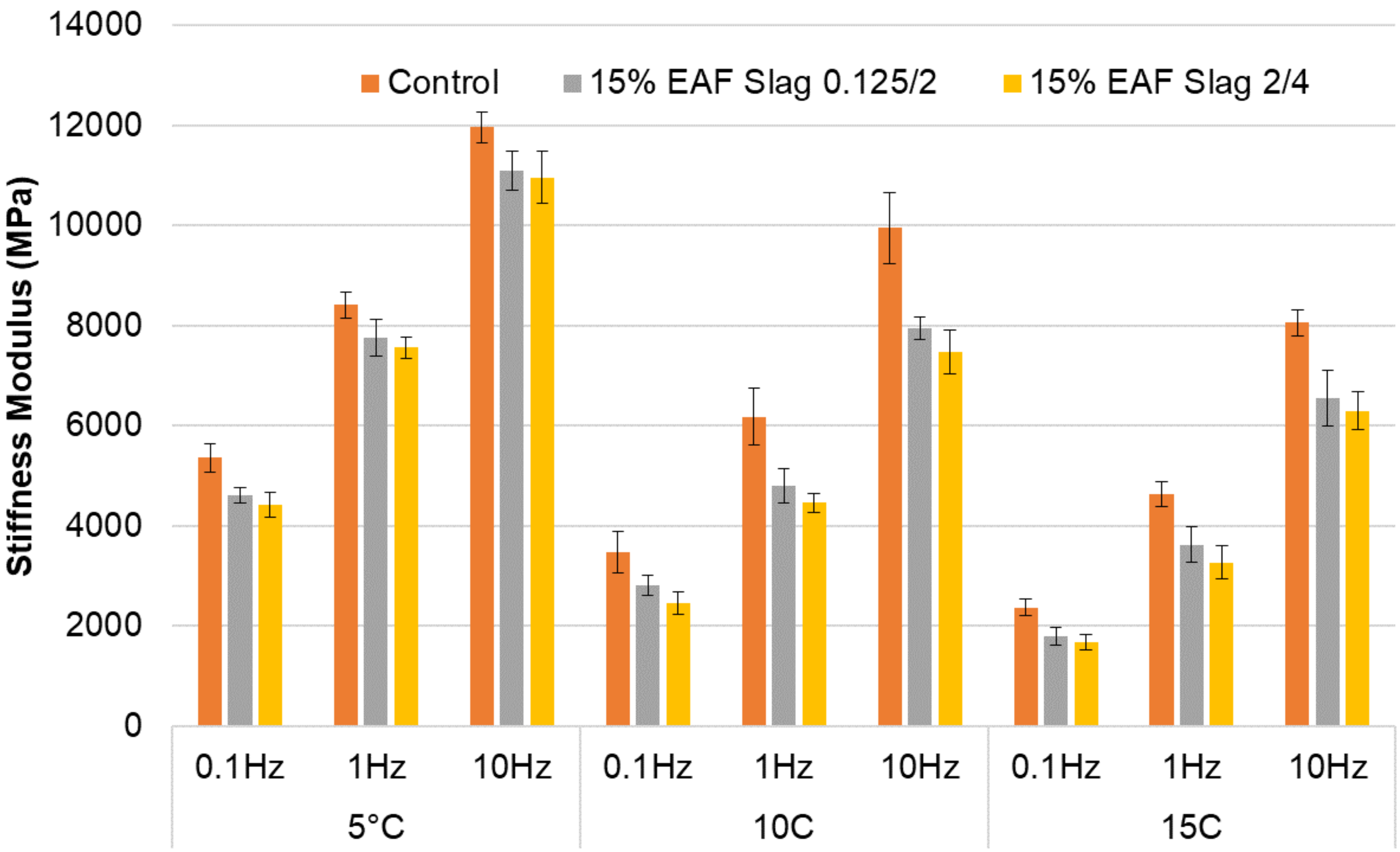
h is the sample height

Δu the difference between the maximal and minimal displacement

Stiffness Modulus

- Stiffness modulus loading in linear-elastic
- 3 temperatures (5, 10, 15°C)
- 3 frequencies (0.1, 1, 10 Hz)

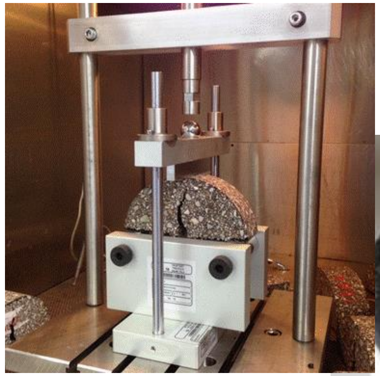
➢ Stiffness somewhat lower for higher binder %

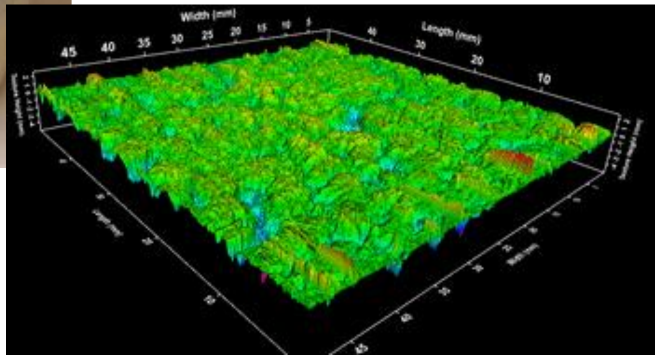


Environmental assessment + LCA (Empa projects)

- Bueno, M., Haag, R., Heeb, N. et al. Functional and environmental performance of plant-produced crumb rubber asphalt mixtures using the dry process. Mater Struct 54, 194 (2021). https://doi.org/10.1617/s11527-021-01790-y
- Piao, Z.; Bueno, M.; Poulikakos, L. D.; Hellweg, S., Life cycle assessment of rubberized semi-dense asphalt pavements; A hybrid comparative approach. Resources, Conservation and Recycling 2022, 176, 105950. https://doi.org/10.1016/j.resconrec.2021.105950

Mixtures-Noise Reduction

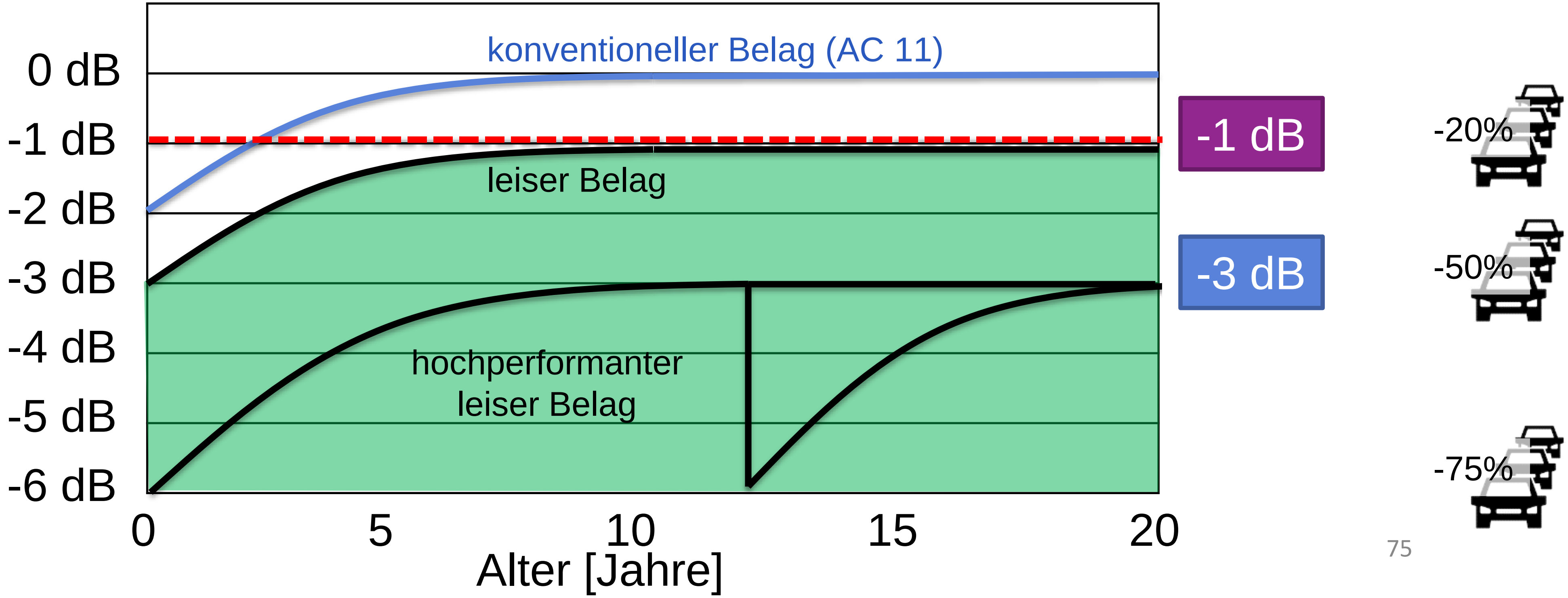




What is a low noise pavementerwarten

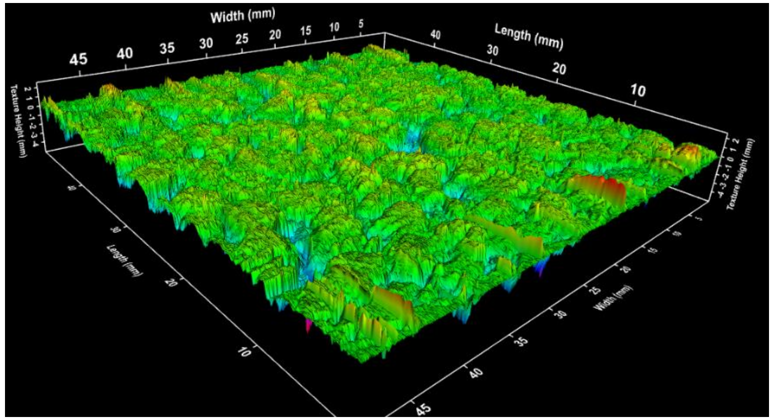
++G+P INGENIEURE

"A low noise pavement should reduce the traffic noise emissions considerably in comparison to a conventional pavement."



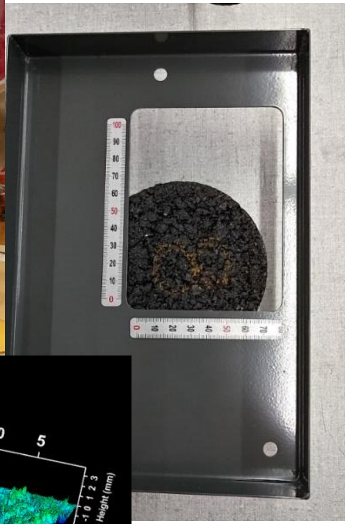
Low Noise Pavements

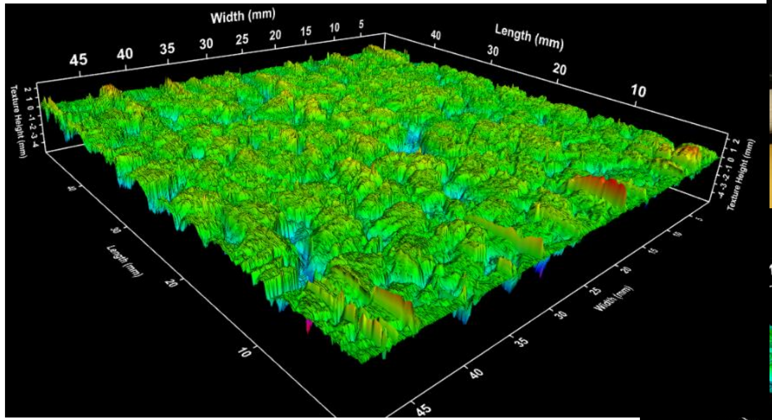
- Porosity
- Surface texture
- Conectivity of pores
- …….



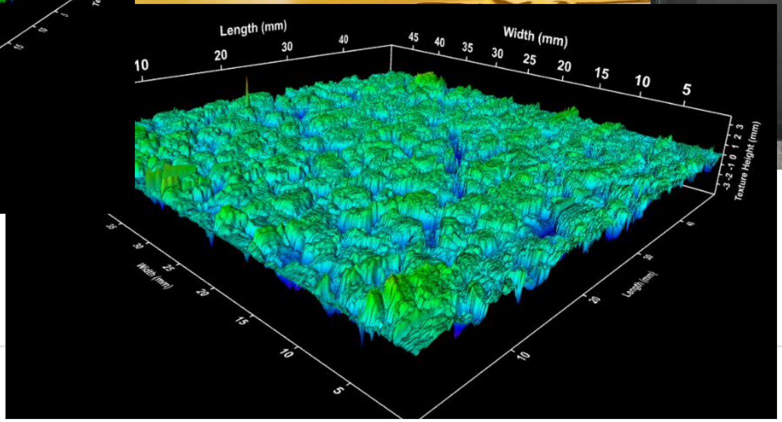
Texture Scanning

3D Laser Scanner (Ames Engineering 9400HD)





(SDA 4)



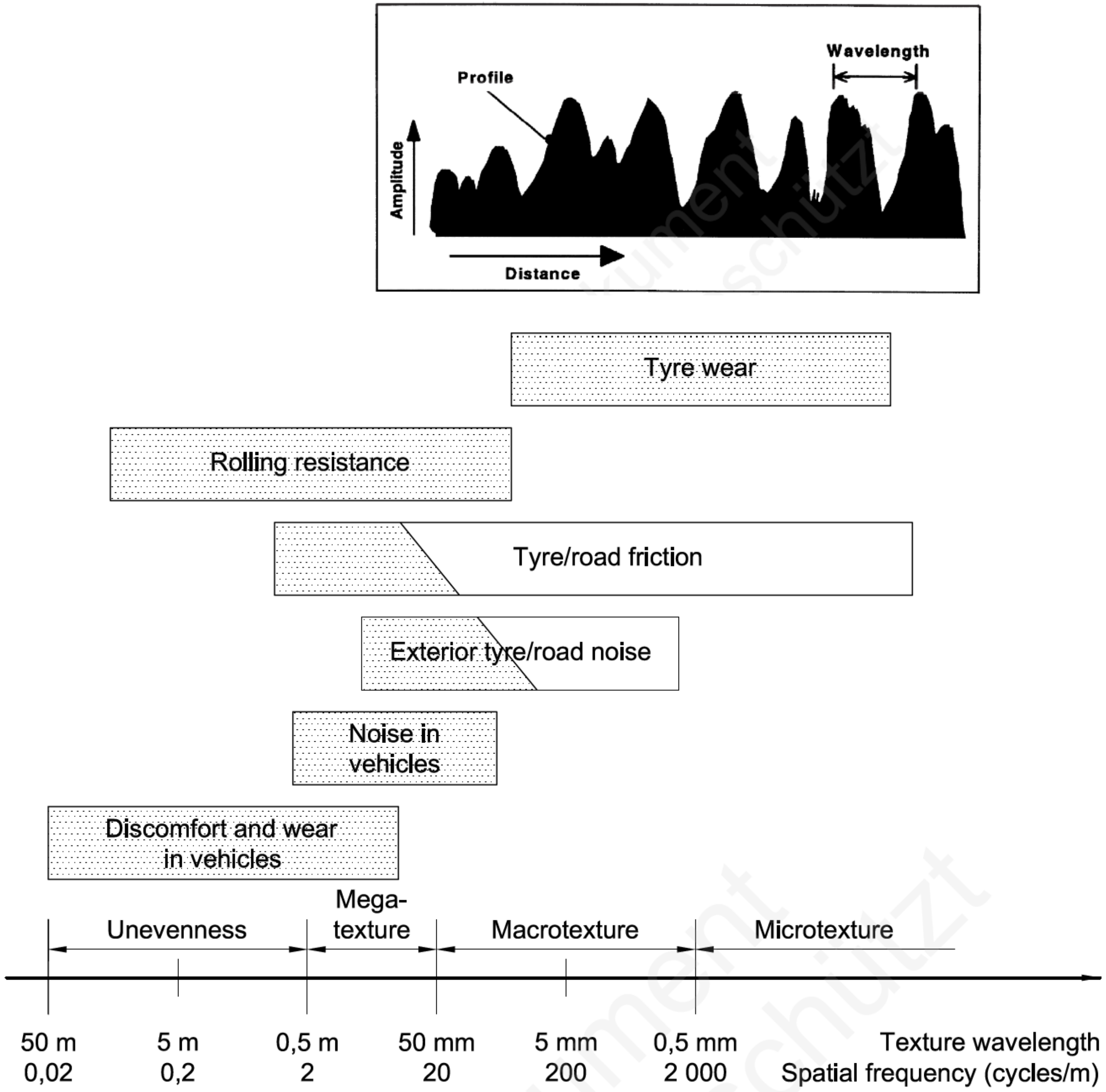
(SDA 4 with 30% RCA Coarse)

Texture Scanning

- Texture Wavelengths

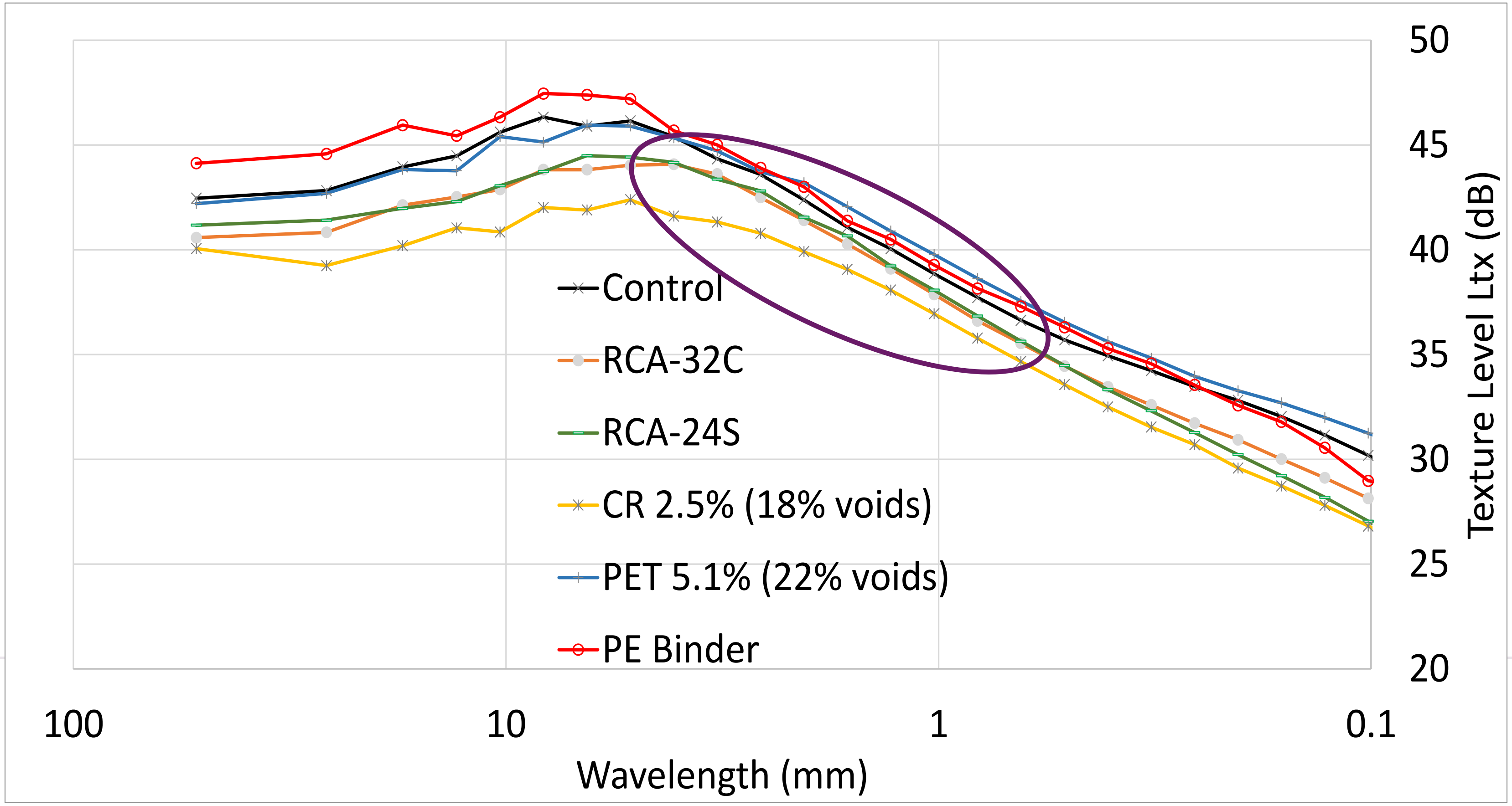
(ISO 13473-2)

➢ 0.5-5 mm wavelengths correlated with noise reduction

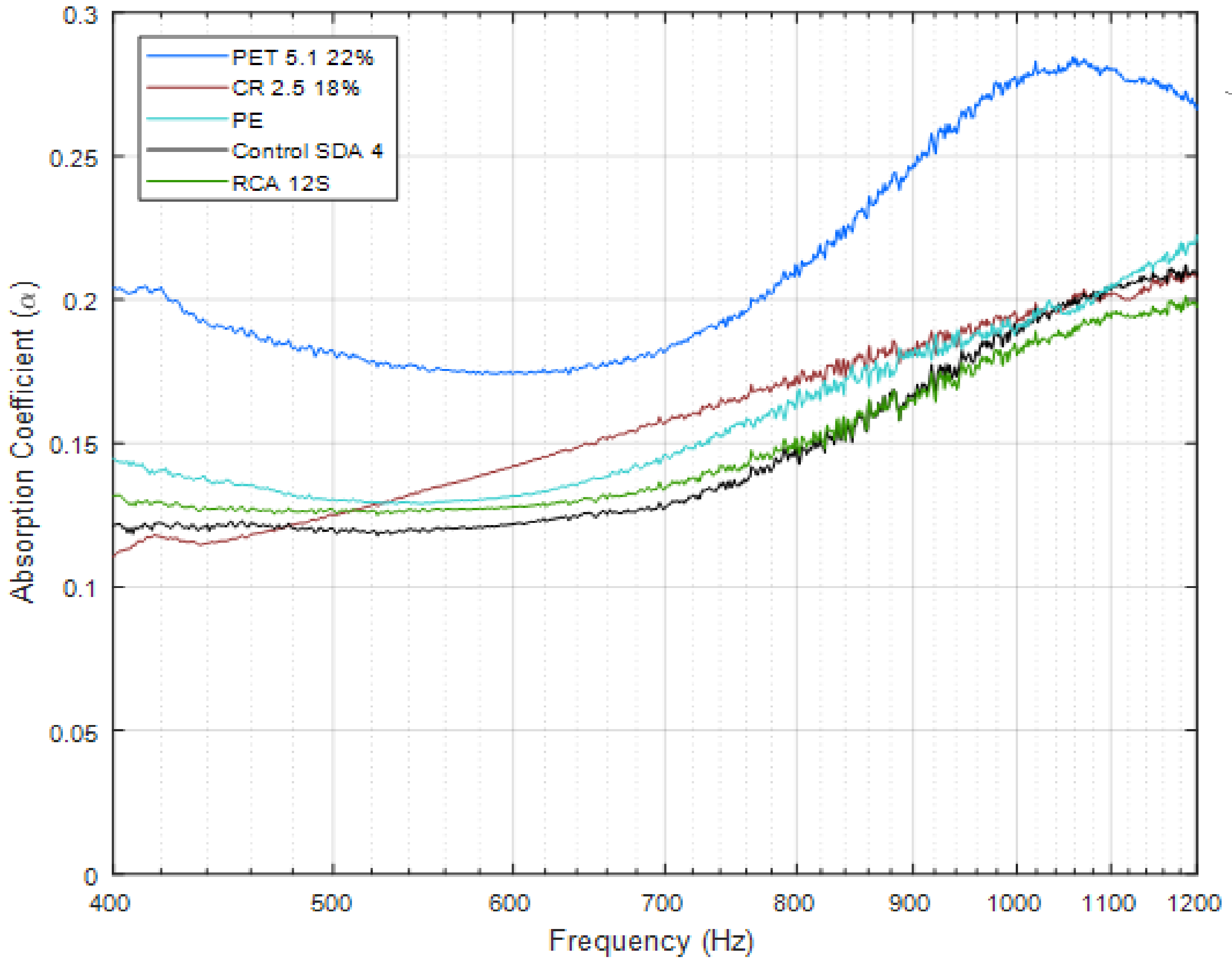


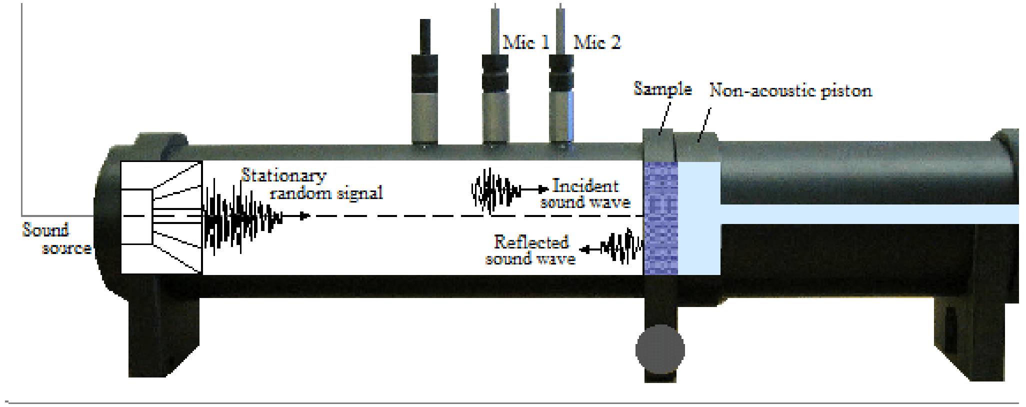
Texture Level (dB)

- PE, PET, No significant change in macro and microtexture (noise reduction and skid resistance)
- CR, RCA reduction in microtexture



Noise Absorption

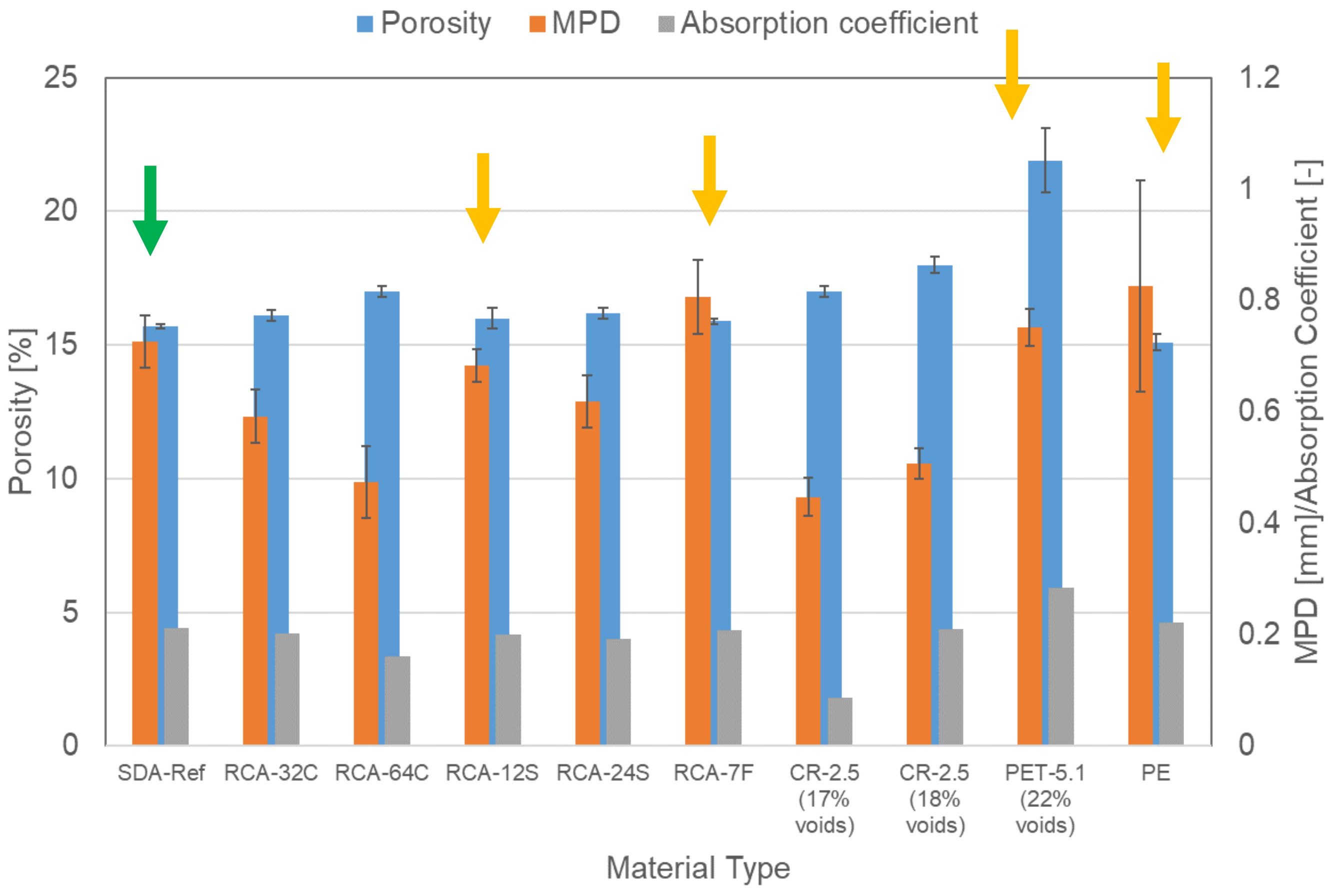




No significant change in noise absorption

Porosity, MPD and sound Absorption for the materials investigated

Possible to have similar or better noise reduction parameter with waste materials



Source: Poulikakos, LD, Athari, S, Mikhailenko, P, Kakar, MR, Bueno, M, Piao, Z, Pieren, R, Heutschi, K
Effect of waste materials on acoustical properties of semi dense asphalt, Transportation Research Part D 102 (2022) 103154

Leaching Tests

- Based on the Batch Method (US EPA TCLP Method 1311)
  - designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes.
- Performed on samples:
  - CR
  - SDA
  - SDA+CR

Lab. procedure

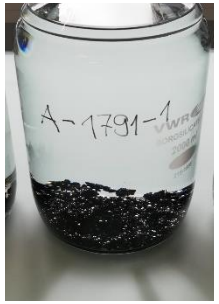
100 g sample extraction
- 2.5 L bottles with acidic water → **S/L ratio= 1:20**
- 18-24 h
- Re-extraction

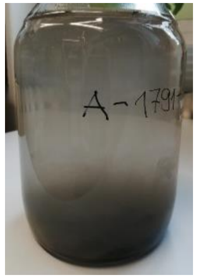
L/L extraction with DCM/ENV Disks and volume reduction

PAH and metal analyses following the standardized methods

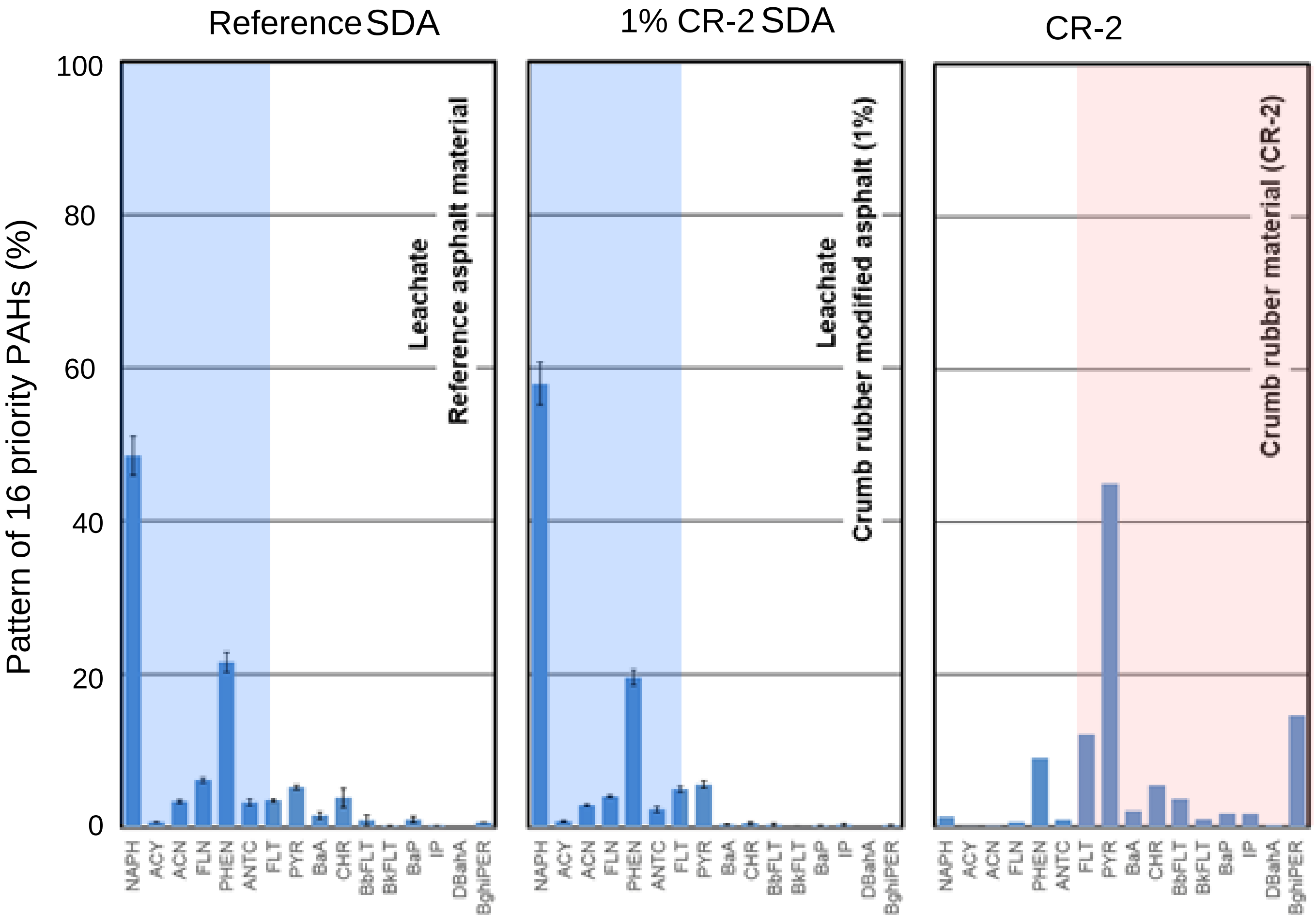
Norbert Heeb, Empa

Comparison of PAH pattern in leachates and crumb rubber





Pattern of 16 priority PAHs in leachates and CR-2 material



- Soluble 2-3-ring PAHs like naphthalene dominate in leachates
- Less soluble 4-6-ring PAHs dominate in CR-2
- Leaching of PAHs is asphalt-related

Norbert Heeb, Empa

LCA of rubberized SDA vs. non rubberzied SDA

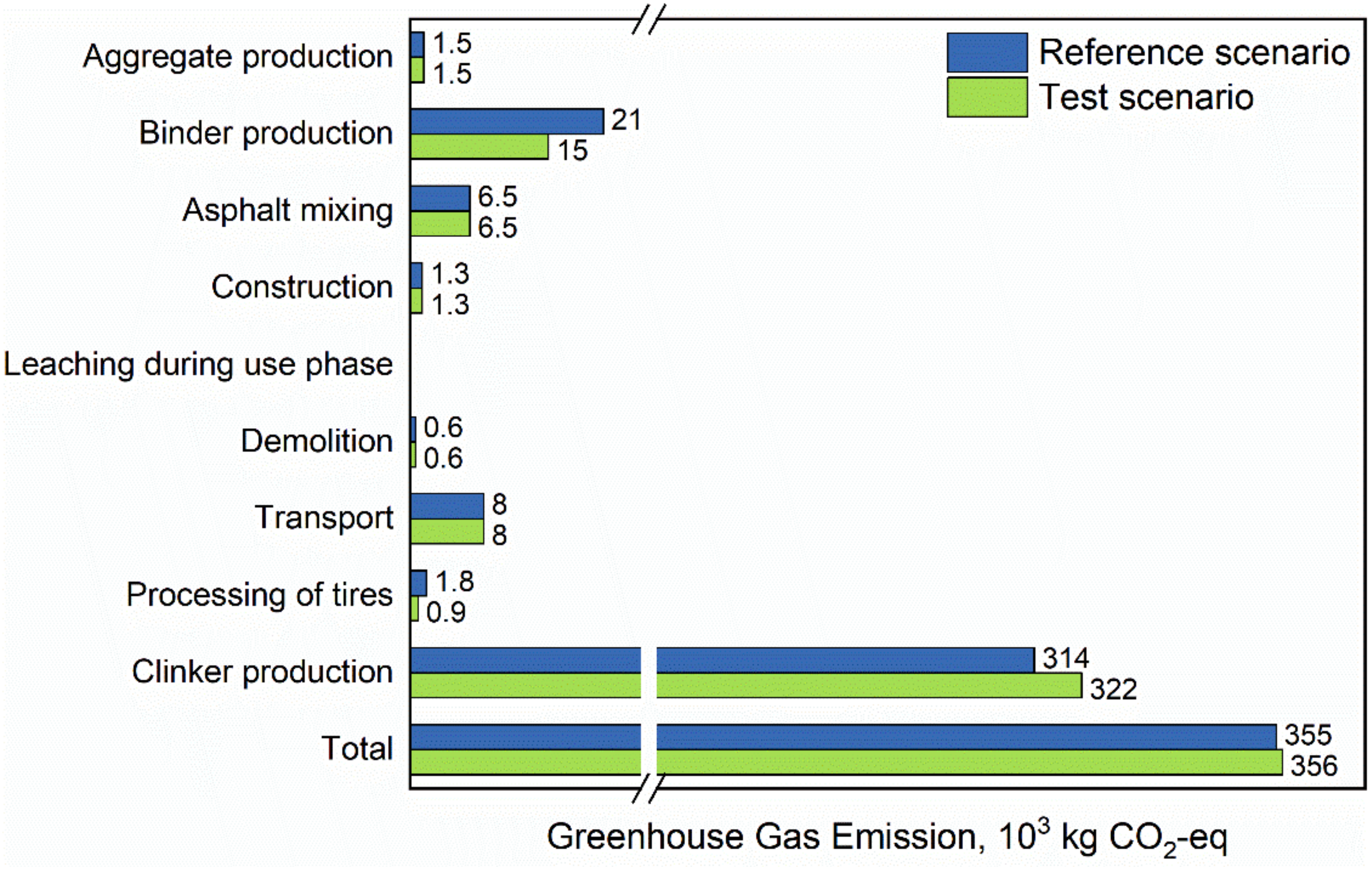
The LCA was carried out considering two scenarios:

(1) The reference scenario focuses on standard SDA produced of only virgin materials; CR used as fuel for clinker production-current waste management situation in Switzerland

(2) The test scenario refers to rubberized SDA using crumb rubber- waste tires used for SDA and primary fuels were used for clinker production

Piao et al Life Cycle Assessment of Rubberized Semi-Dense Asphalt Pavements; A Hybrid Comparative Approach, Resources, Conservation & Recycling. Resources, Conservation & Recycling 176 (2022) 105950

LCA of rubberized SDA



From an environmental point of view in Switzerland, it is not recommended to promote rubberized SDA by reducing the waste tires used for clinker production. However, if there are waste tires used for MSWI or landfilled etc, the rubberized SDA is still an environmentally viable option.

Waste management strategy plays an important role

Conclusions

Waste and marginal materials can be a viable option for use in roads

Need to develop correct evaluation methods

- *Mechanical performance*
- *Life cycle assessment-consider local waste management strategies*
- *Environmental evaluation: leaching, heavy metals, mico plastics etc.*

Legislation/incentives can help to encourage use

Thank you for your attention

Dr. Lily Poulikakos, Empa, Switzerland
Lily.poulikakos@empa.ch