Aalto University
School of Engineering

The role of bitumen in asphalt mixtures

The Finnish perspective

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Tallinn University of Technology, Tallinn, Estonia

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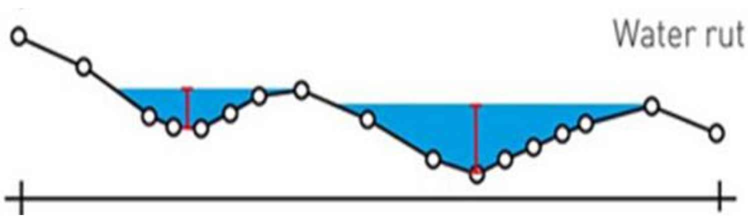
Outline

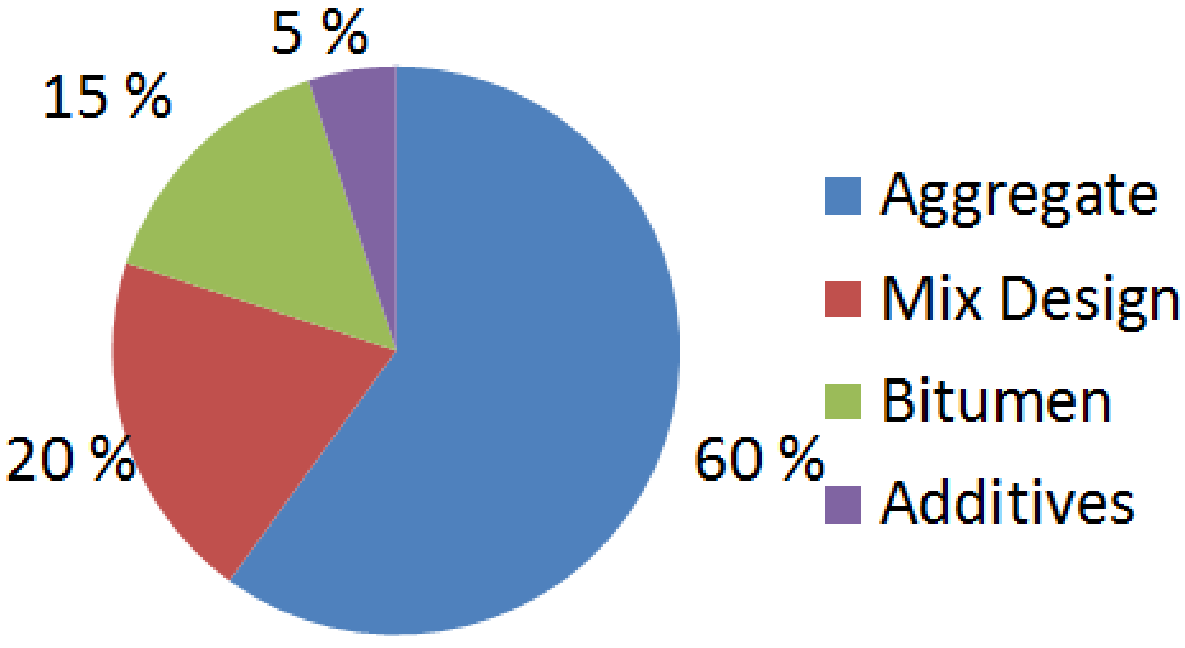
1. Studded tires – the necessary nuisance?
2. Review of changes in past 20+ years
3. Recent changes in Transport Agency's requirements
4. Case: Ring Road II – lessons learned
5. New ”REMIX” research program (2013-2017)
6. Evolution of asphalt mixtures from ASTO research days (1987-1992)
7. Concluding remarks

Rutting caused by abrasion of studs



ASTO Research 1987-1992:

Aggregate has the most impact on abrasion resistance



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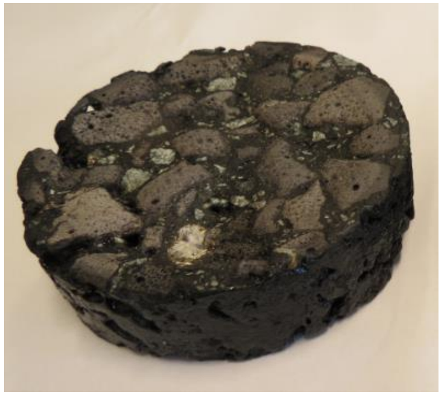
ASTO results: New abrasion tests

Nordic Ball Mill test

Pavement Wear Test
Sivurullakulutuslaite
(SRK)

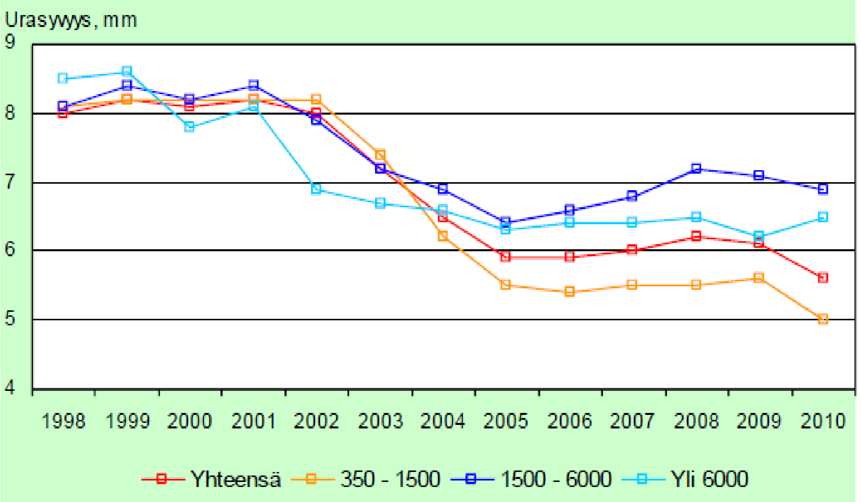
New Prall method for abrasion (2008)

Water +5°C



How to overcome negative impact of studded tires?

- Restrictions for studded tires:
  - 1992: lighter studs
  - 2009: number of studs reduced
- Use of man-made slag aggregates
- Restrictions of usage (cities)

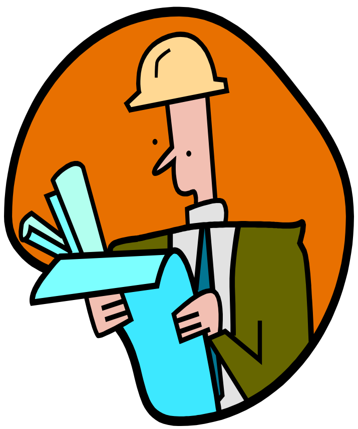


Kuva 3. Urasyvyyden kehittyminen Suomen tieverkolla 1998-2010. (Liikennevirasto 2011a).

Hot-in-place Recycling:
The Finnish solution for studded tire abrasion and declining maintenance funding

(Kuva: Pirkanmaan ELY / Tinnu Salonen)

Major changes over the past 20+ years



Contracting methods
Specifications
QA practices
QC practices

We want more asphalt with less money!

Rehabilitation strategies and work methods - HOT-IN-PLACE RECYCLING

Materials

Quality requirements
Test methods/equipment

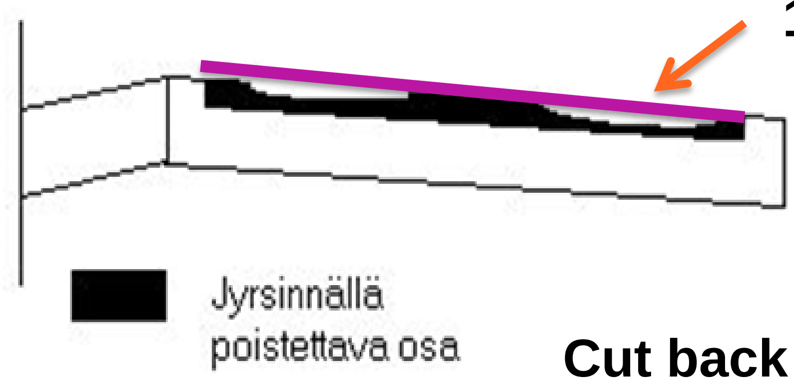
Recipes

Thick overlays have been replaced by thin surfacing with recycled mixtures

Preparation of old surface

- **Cod milling**
- **Heating & milling**
- **Heating and remixing**

18-25 kg/m²



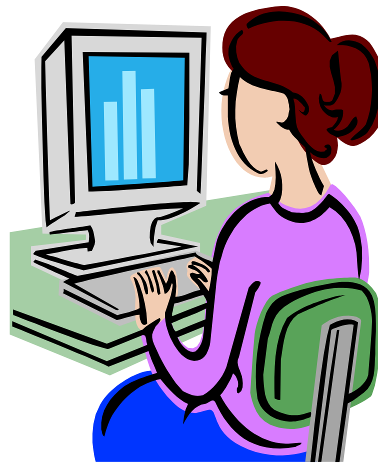
Cut back bitumen have been replaced by bitumen emulsions of 300-500 g/m²

Hot in-place recycling

Heating + scarifying existing layer + adding new mix ca. 18 kg/m^2

NDT testing has replaced conventional quality control testing in QC/QA

Implemented NDT test methods which are relative and need calibration



IRI
rut depths
in-situ air voids
segregation
surface texture

Faster computes, more storage space, smart phones, data clouds, Google Drive, storage of monitoring data.

From recipe MD and QA to end result/performance specifications

Rut depth has been the "only" performance requirement

- initial rut depth

- rut depth increase per year

Kuva 23. Varsin ohut SMA16/70 -päällyste on purkautunut valtatiellä 25 Hyvinkäällä.

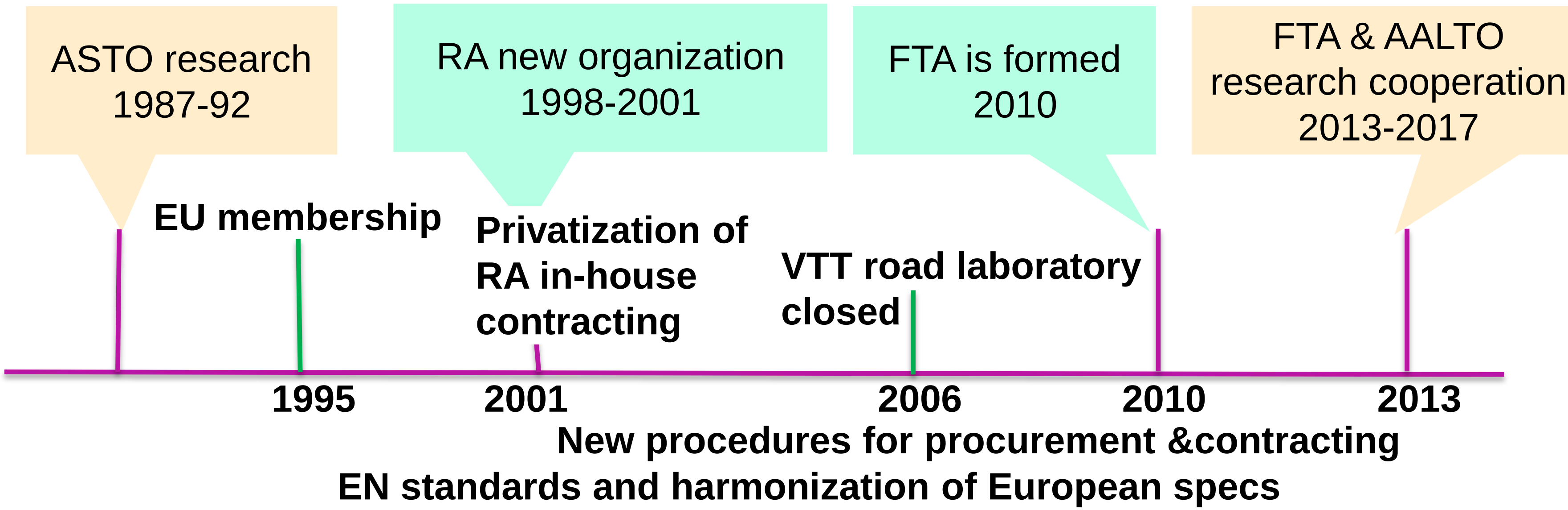
In 2002 modelled rut depth and LCC was the only criterion for the performance in the End results bidding.

Increase of vehicle gross weights and heights in 2014

In Finland axle load is 10 t (AASHTO 80 t)

Gradual change from dual tires to super singles

Goss weight 60 t → 76 t



- New types of maintenance contracts and DB contracts
- Termination of own laboratory QA testing for mixture quality
- Use of rut depth as the “only” quality requirement
- Use of monitoring vehicles for road surface QA measurements
- Use of NDT methods for density QA assessment
- Relaxing of material specs in 2000 for Fly Ash and Limestone filler


What were the consequences?

2007-2008 joints stated to open up and deteriorate

2007-2008 rapid development of potholes and raveling

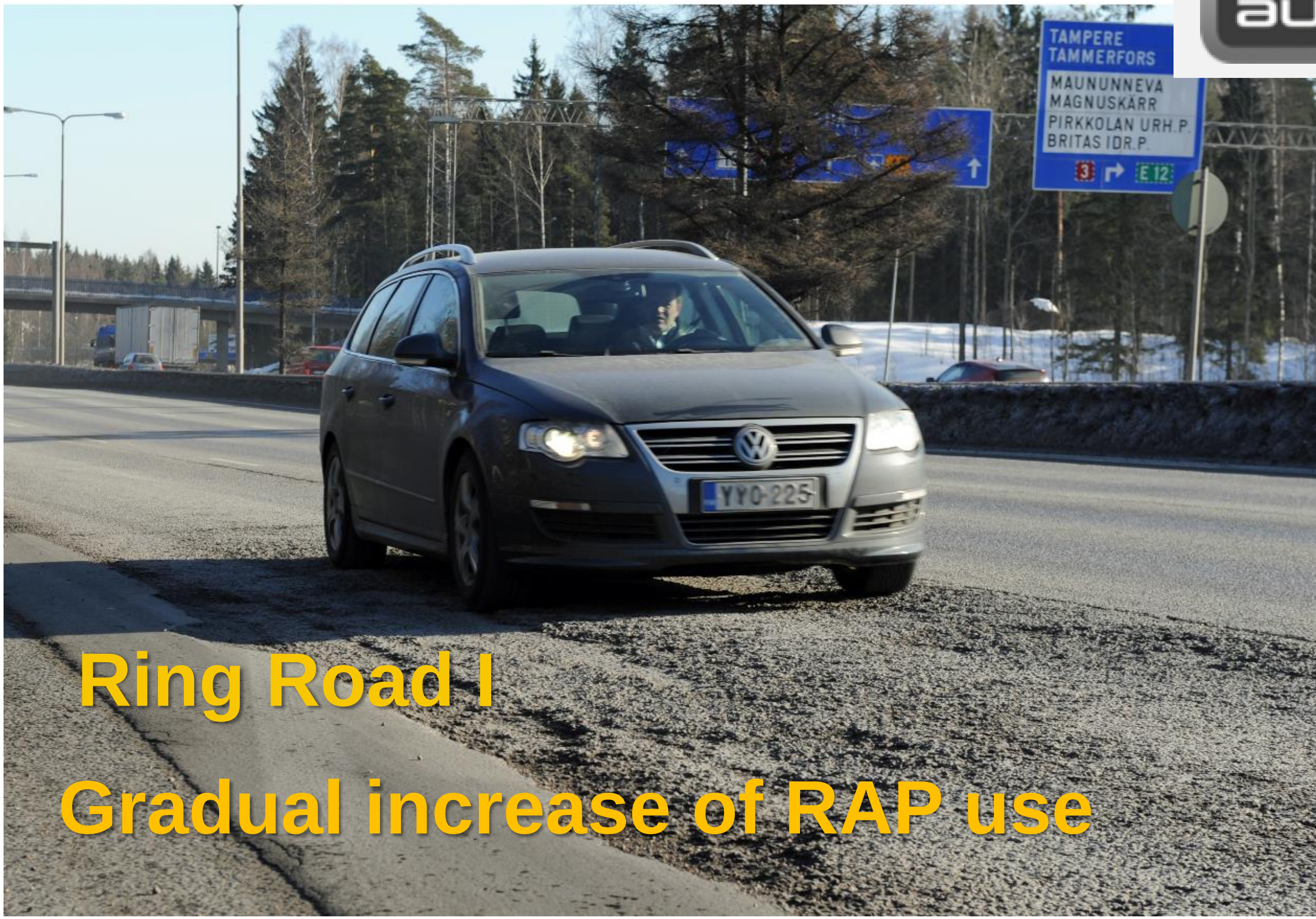
Layer separation

Ring Road II (2011)

Reduction of amounts of glue between lifts

Tienpitäjällä korvausvastuu: Suomen tiet surkeassa kunnossa

20.3.2012



Ring Road I

Gradual increase of RAP use

E18 motorway: damages appeared suddenly overnight (30.3.2011)


FFJ-328

Road Administration's Response:

Changes for Contracting Documents

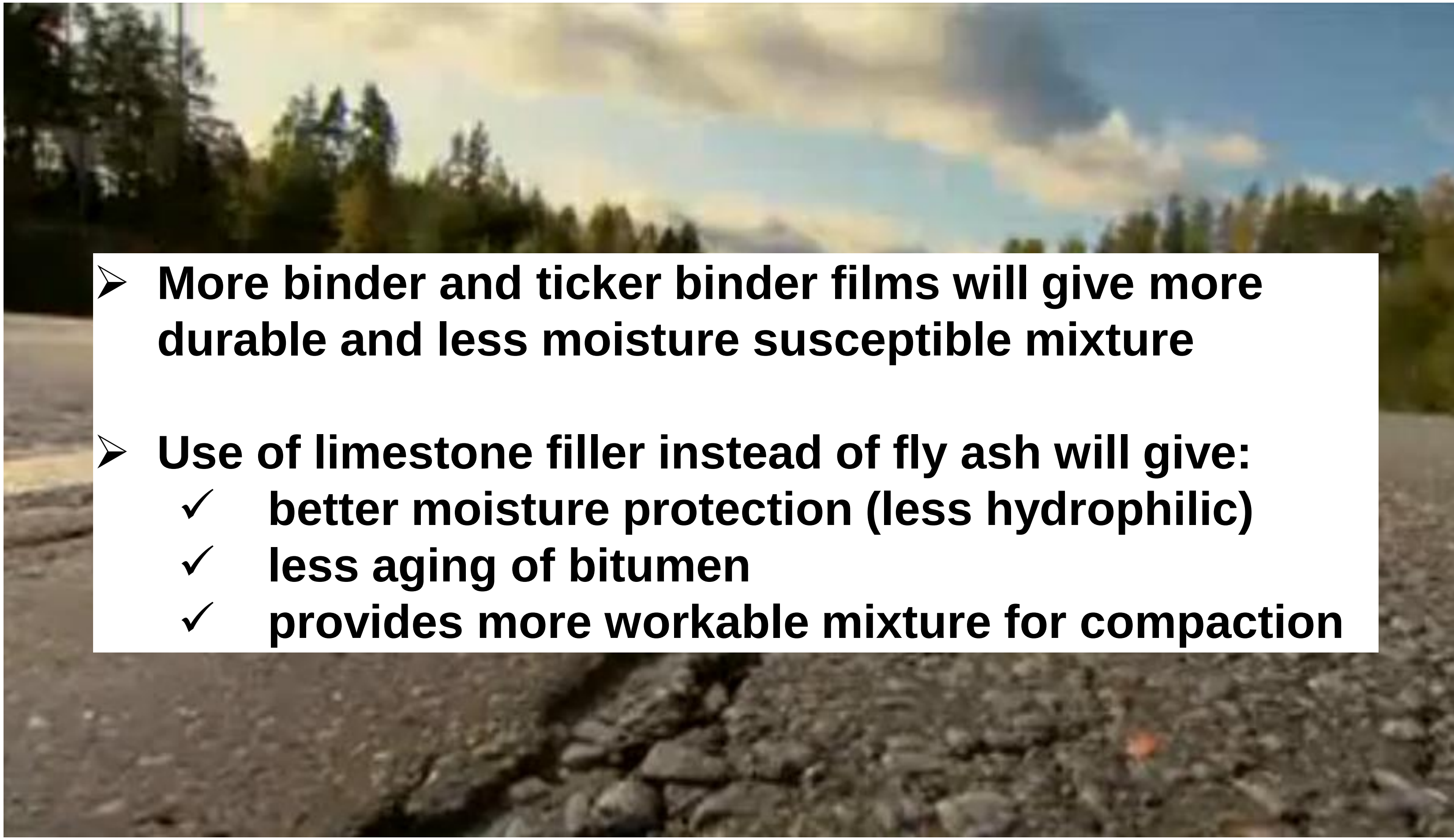
2008:

- **for tenders minimum binder content (amount used is paid)**
- **not allowed to use Fly Ash in SMA**
- **mandatory use of Limestone filler 4%**
- **mandatory use of rejuvenator in hot in-place recycling (70/100 Pen binder was then used as rejuvenator)**

2013:

- **mandatory use of 650/900 Pen binder (150-250 g/m^2) as rejuvenator for hot in-place recycling**

Desired outcome?



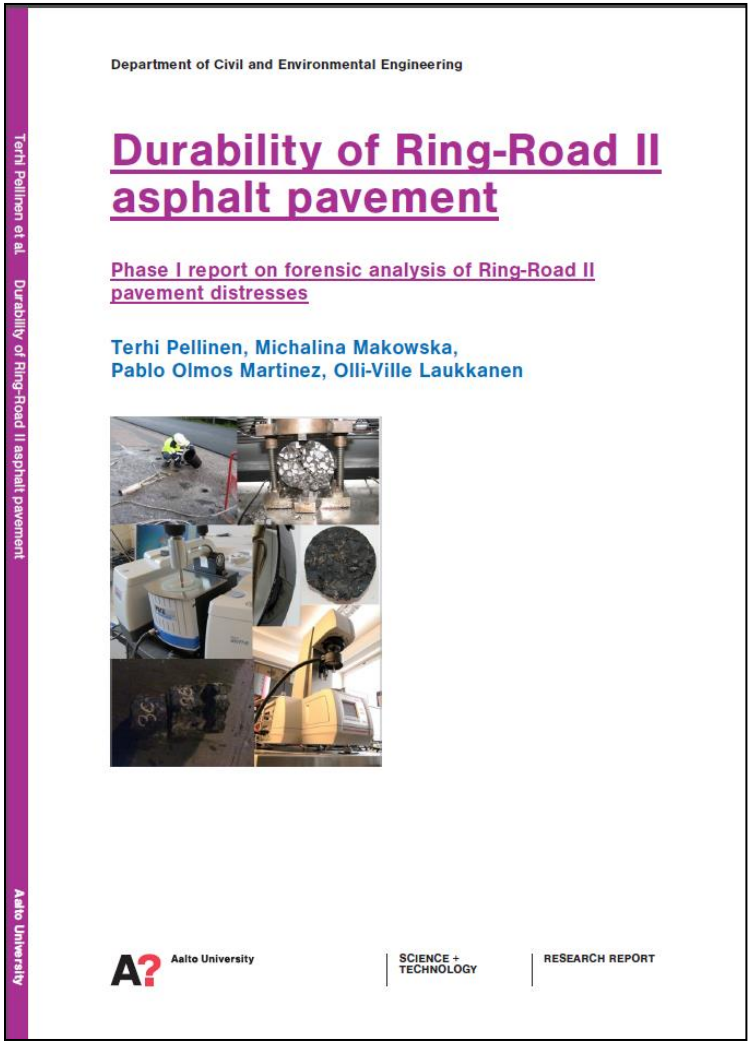
- **More binder and ticker binder films will give more durable and less moisture susceptible mixture**

- **Use of limestone filler instead of fly ash will give:**
  - ✓ **better moisture protection (less hydrophilic)**
  - ✓ **less aging of bitumen**
  - ✓ **provides more workable mixture for compaction**

Surface deterioration and poor driving comfort

CASE

Ring Road II (2011)



Department of Civil and Environmental Engineering

Durability of Ring-Road II asphalt pavement

Phase I report on forensic analysis of Ring-Road II pavement distresses

Terhi Pellinen, Michalina Makowska, Pablo Olmos Martinez, Olli-Ville Laukkanen

Aalto University

SCIENCE + TECHNOLOGY

RESEARCH REPORT

Terhi Pellinen et al. Durability of Ring-Road II asphalt pavement

Aalto University

Ice and odd brown color

- **Slabs were taken in spring 2012 from RRII after it was overlaid**
  - Layers were separated and there were ice between them
  - SMA 16 slab was brown in color and asphalt could be broken by hands

Advanced Material Characterization

Binder studies

- Dynamic Shear Rheometer (DSR)
- SARA – factions

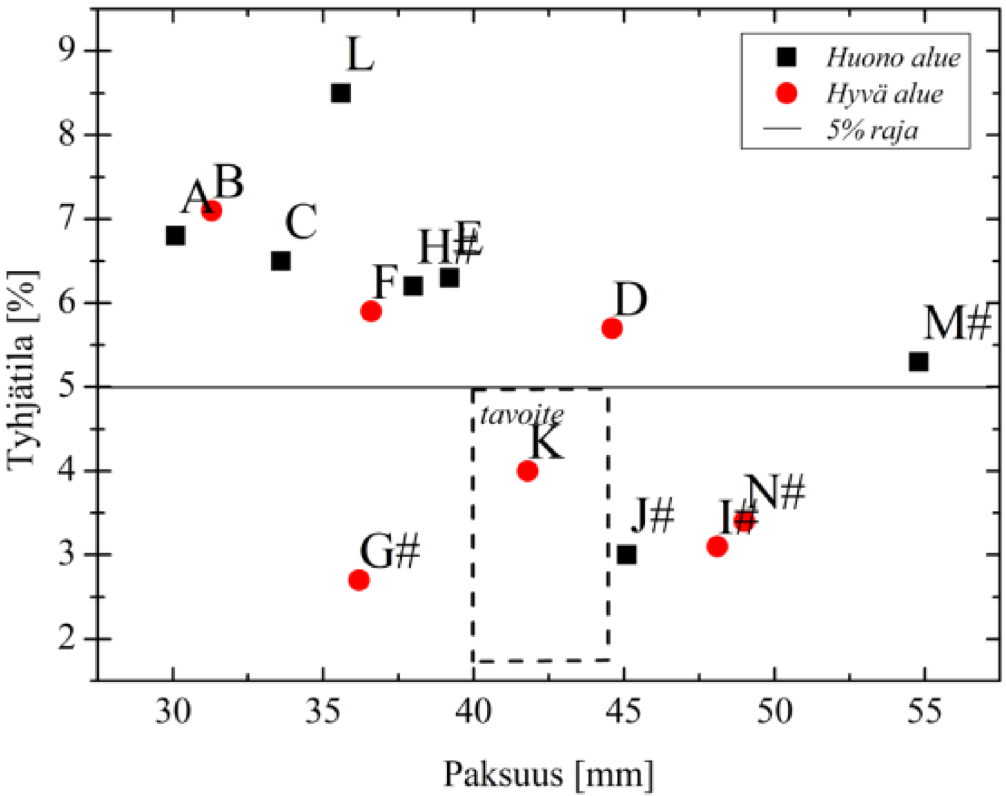
Filler/fines studies

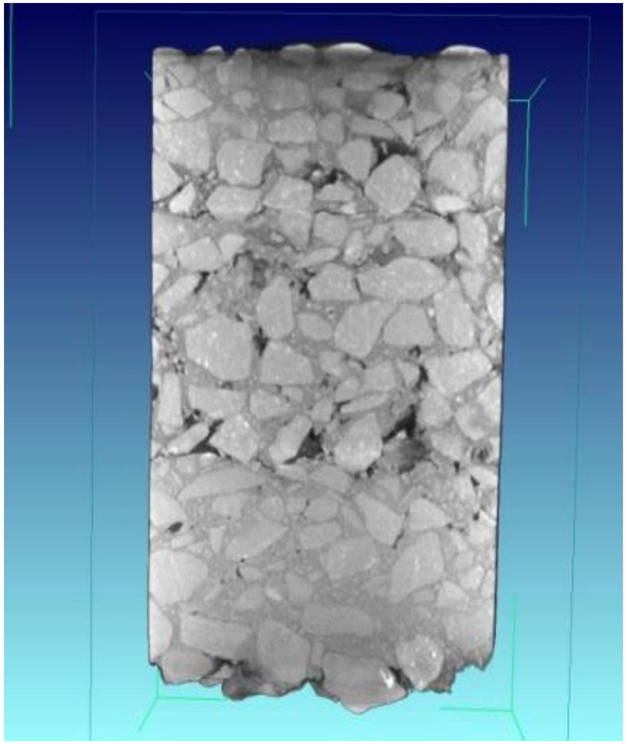
- Thermogravimetric analysis (TGA)
- X-ray Diffraction (XRD)
- Scanning Electron Microscopy (SEM)
- Fourier transform infrared spectroscopy (FT-IR)
- BET-surface analysis
- Hydrochloride acid solubility testing (HAST)

Mechanical properties

- Stiffness and Strength
- X-Ray Computed Tomography (CT)

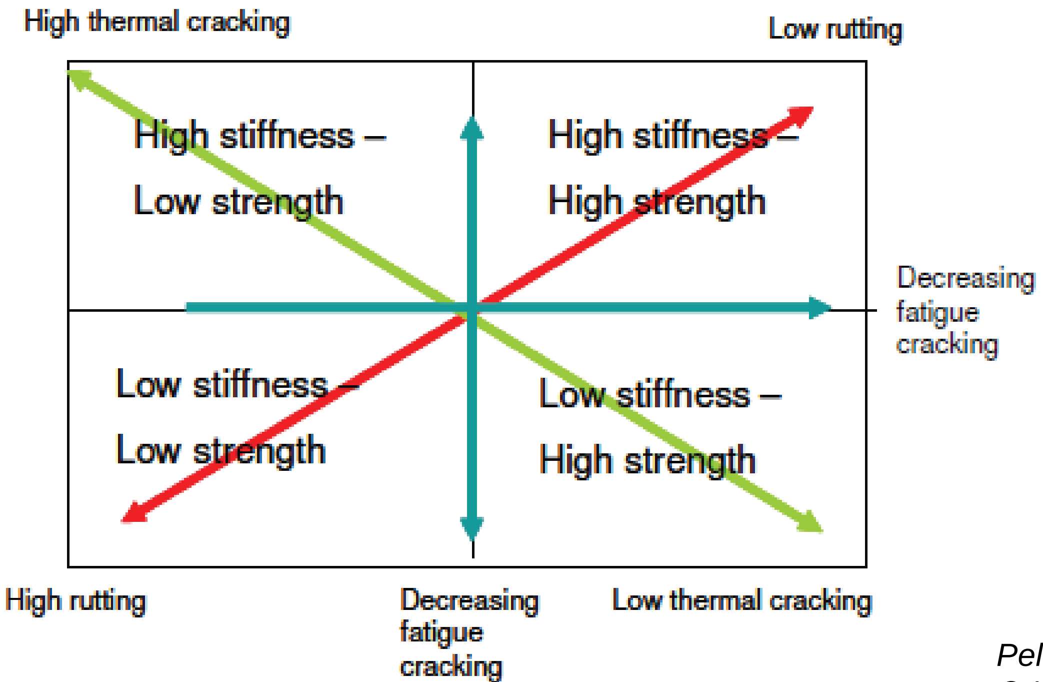
Quality deficiencies

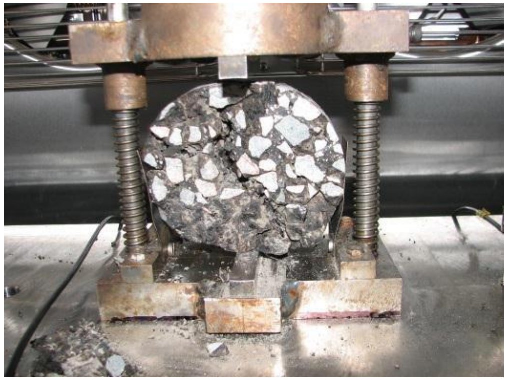


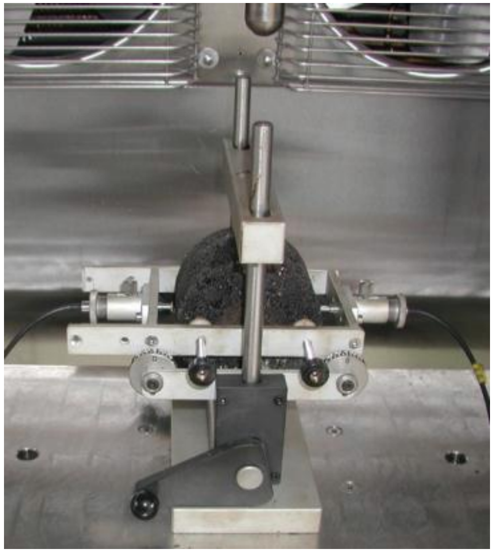


X-ray CT Scan at KTH

Stiffness-strength Performance Criteria

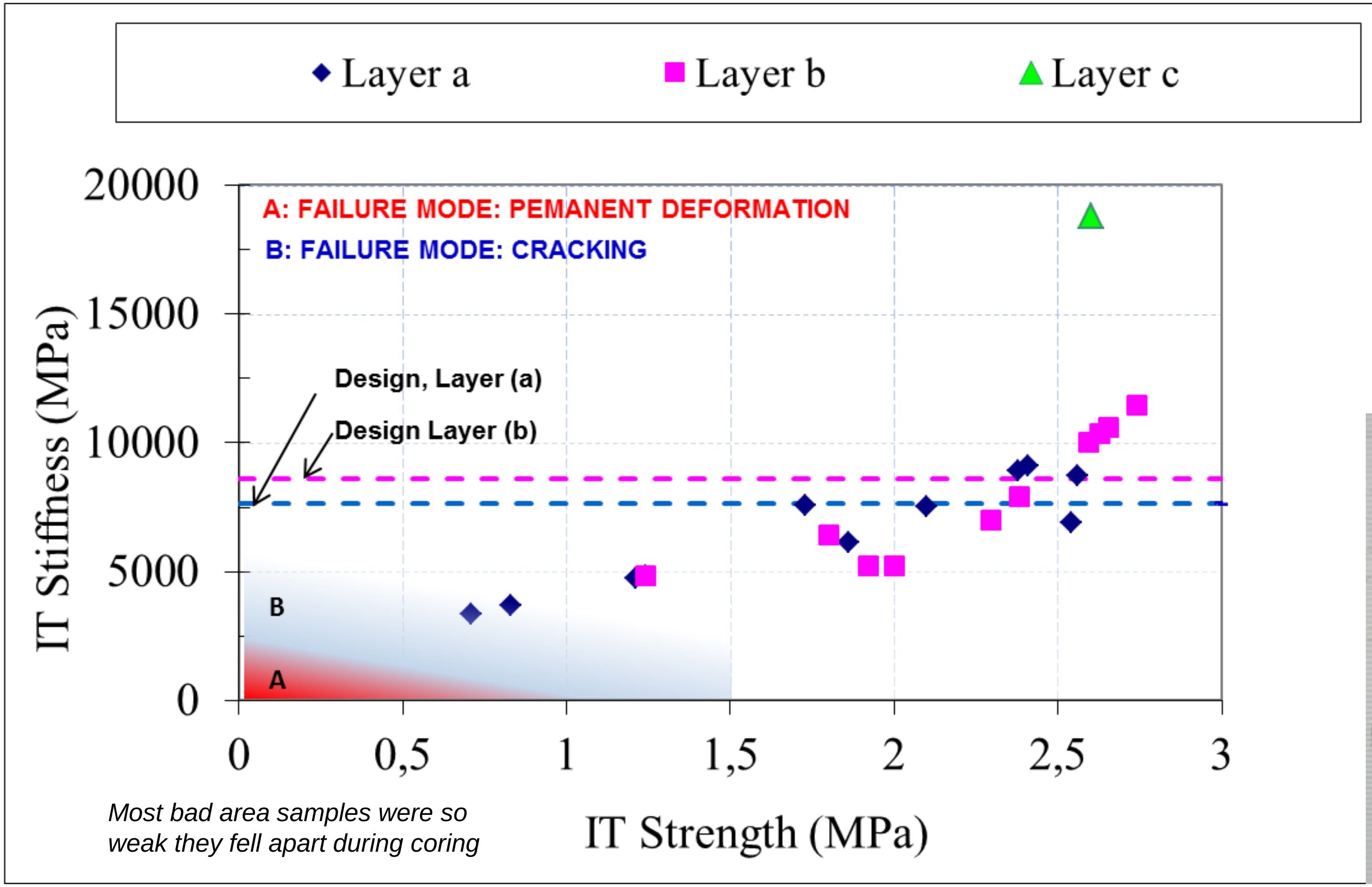




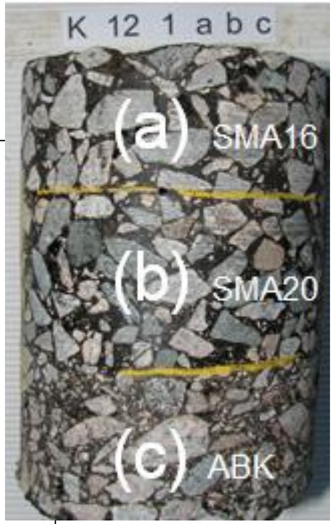


Pellinen T. K., "Conceptual Performance Criteria for Asphalt Mixtures", Journal of the Association of Asphalt Paving Technologists, Volume 73, 2004, pp. 337-366.

Stiffness vs. strength at 10°C



Most bad area samples were so weak they fell apart during coring



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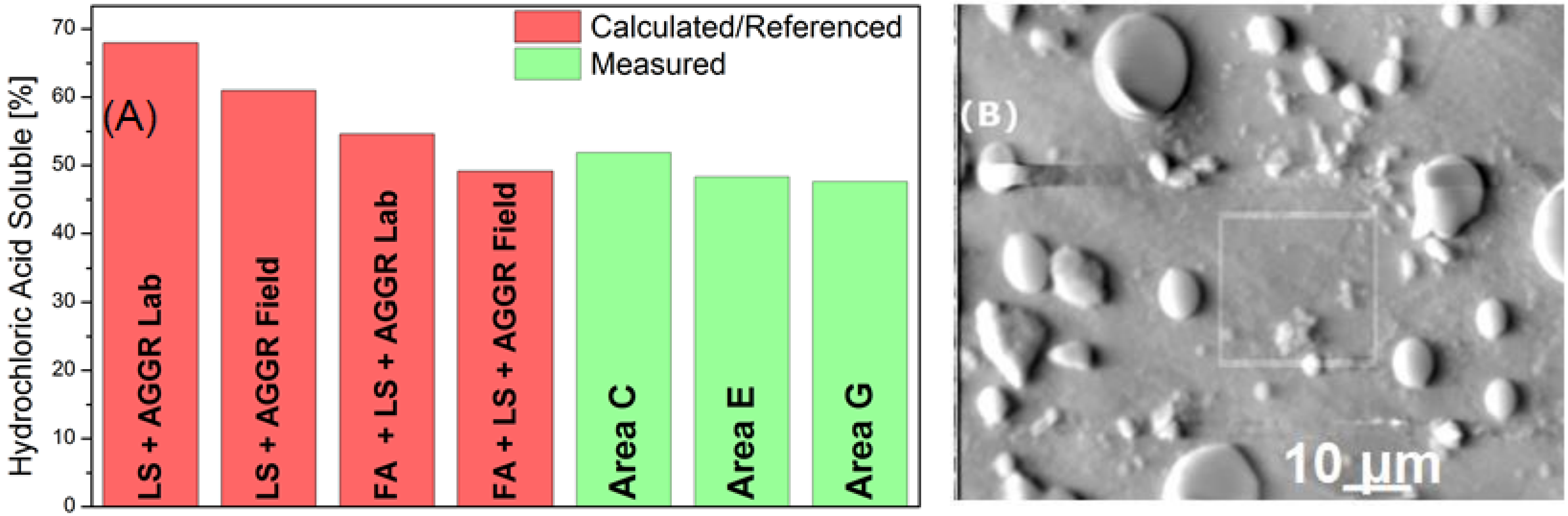
HAST and SEM



(A) Solubility in hydrochloric acid (HAST). (B) Scanning Electron Microscope (SEM) images

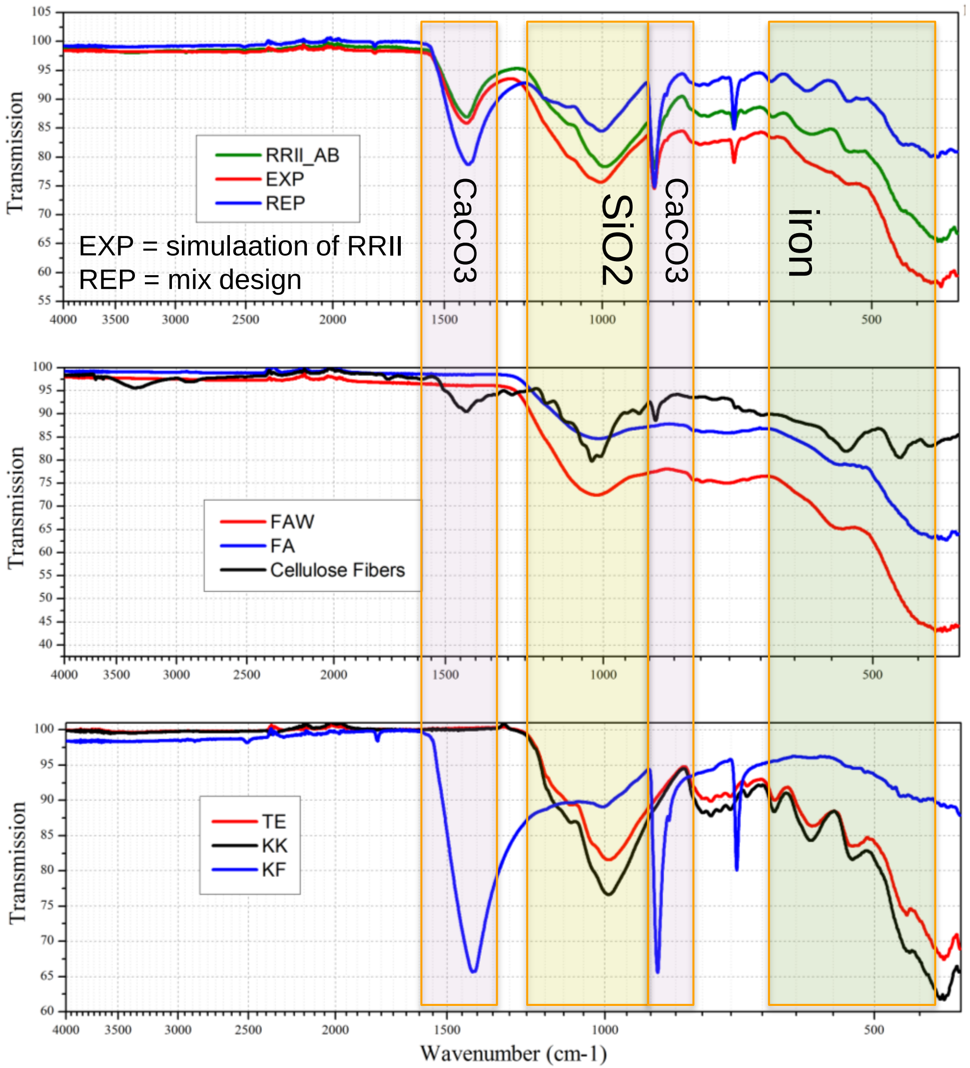
FT-IR inorganic analysis of pavement

We used the FT-IR-ATR, without conversions for forensic analysis.

Both granites (KK, TE), limestone (KF), fly ash (FA, FAW) and cellulose give signals that are characteristic and distinguishable.

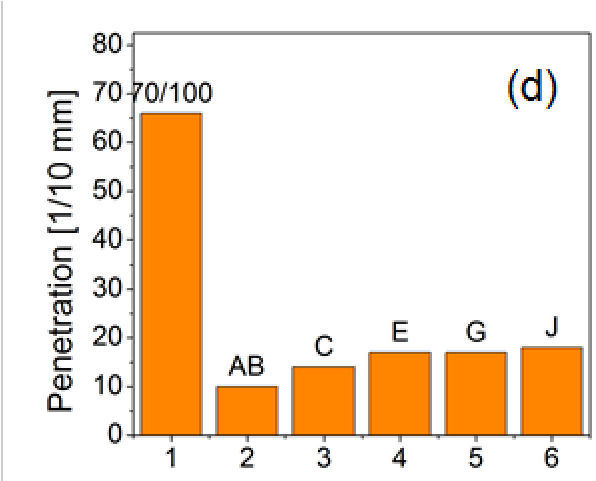
Because of the quantitative properties of this technique it is also possible to determine composition of blends (RRII, EXP, REP).

This helped us to prove that reconstructed fines were almost identical to those obtained from the field and differed from the fines specified in the mix design.



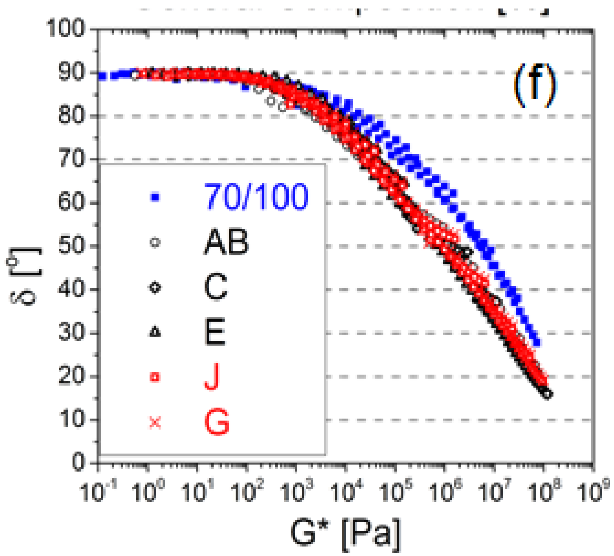
Makowska, M., Pellinen, T., Olmos Martinez, P., Laukkanen, O.-V., (2014). Analytical methodology to determine the composition of filler used in HMA: Case study, Research Record: 2445, TRB, ISSN: 0361-1981, pp 12–20.

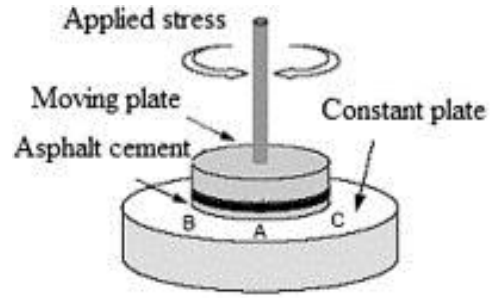
Conventional tests for bitume

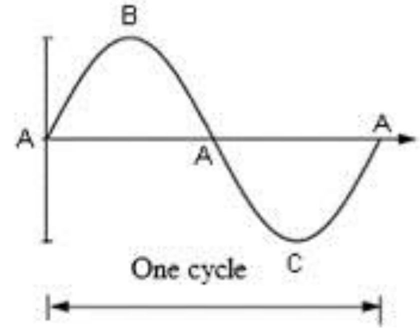


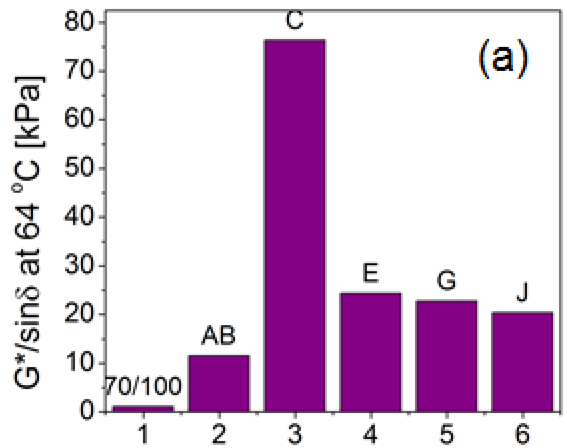
Property	**PANK 70/100**	**70/100**	**AB**	**C**	**E**	**G**	**J**
Penetration 1/10 mm at 25°C	70-100	66,5	9,8	13,7	28,0	16,5	17,7
R&B Softening point, °C	43,0-51,0	47,5	73,6	66,9	-	64,8	65,0
Fraass breaking point, °C	≤ -10	-18	-2	-4	-	-4	-4

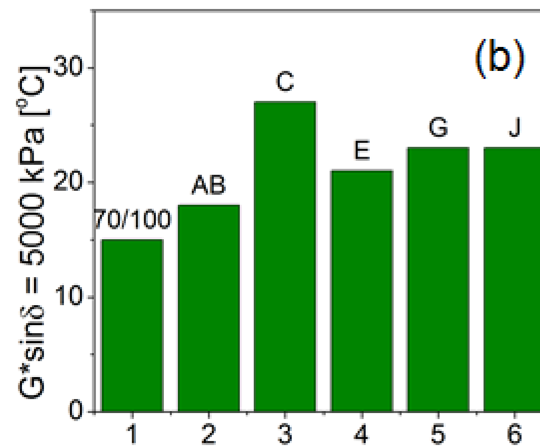
Dynamic Shear Rheometer (DSR)



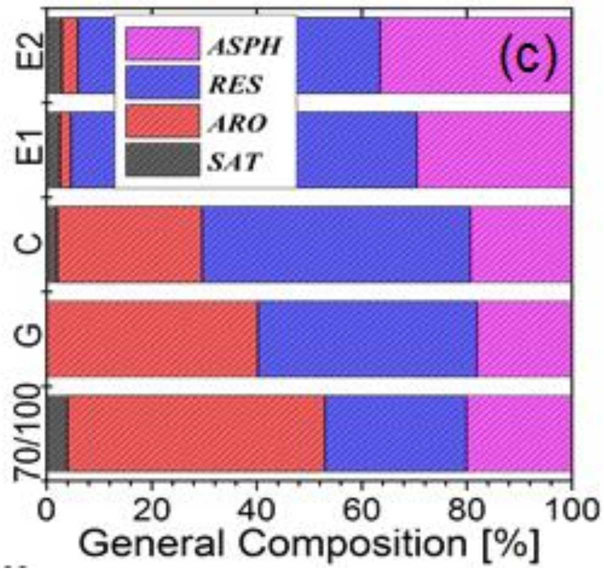


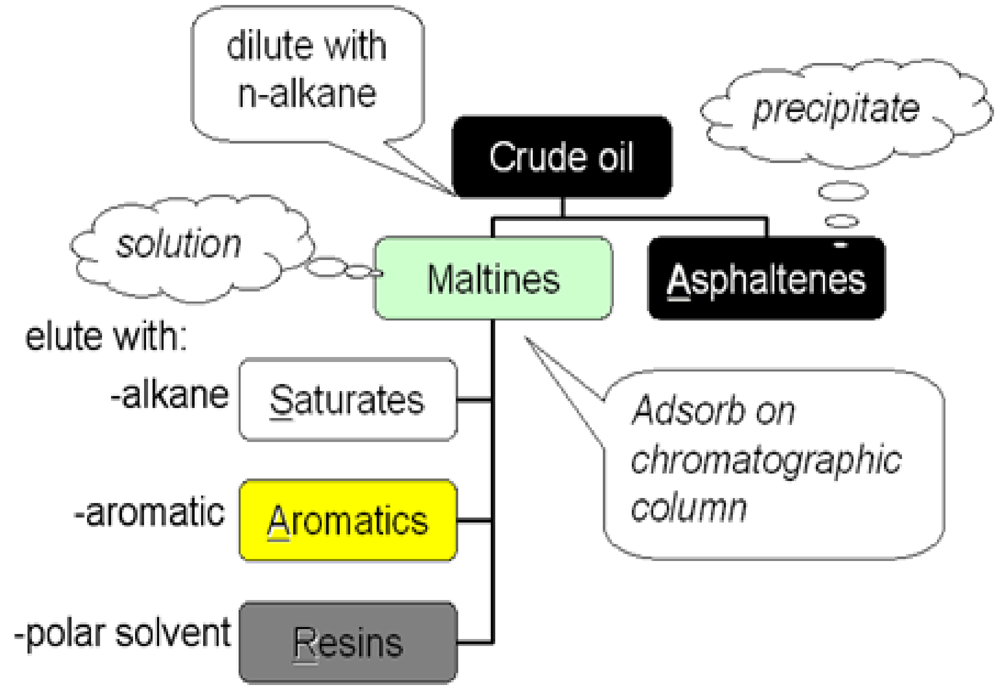






SARA fractions

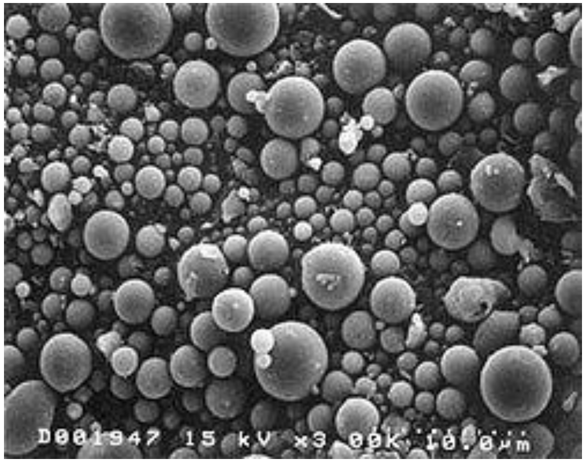




- **Transformation of aromatic fraction into resins stays in agreement with knowledge of bitumen aging**
- **Areas G and C express similar levels of asphalthenes compared to the original bitumen. Similar observations were not found from literature for aged bitumen.**
- **Area E resulted in extraordinary readings because there were no saturates or aromatics. Similar observations were not found from literature.**

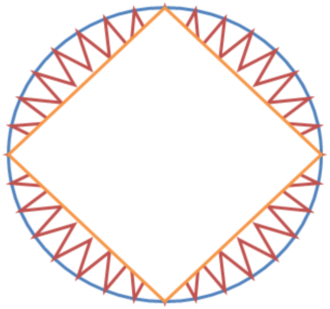
Problems with Fly Ash

Round shape

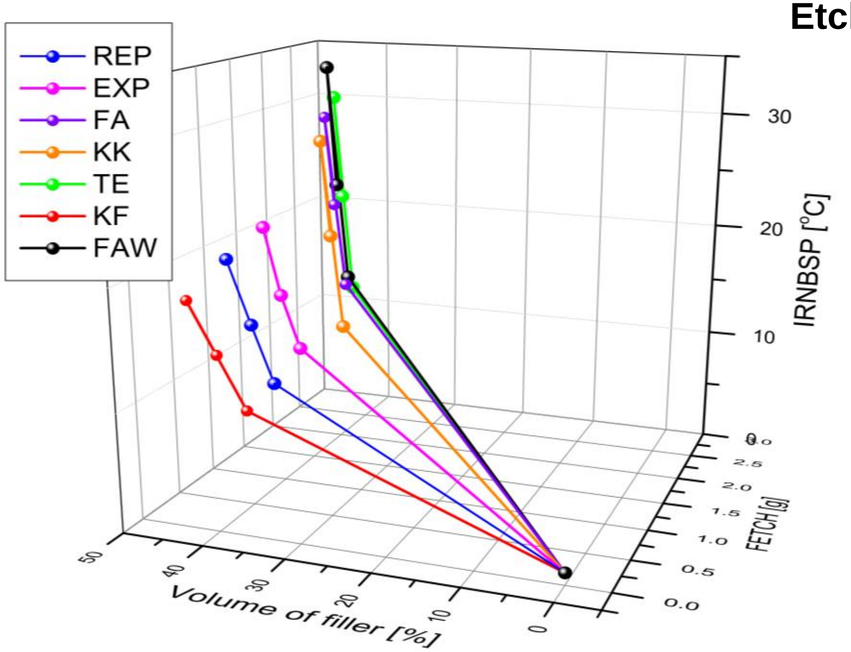


- **Surface area is high**
- **Unburned carbon**
- **Chemical composition**
  - *Silica, calcium, iron, aluminum*
  - *Heavy metals, Kalium (K), acidic anions (Cl-, SO42-)*
- **More silica in mixture increases moisture susceptibility, i.e. moisture damage**
- **Iron stiffens the mastic (compare: asphaltenes are precipitating during crude oil transport) i.e., aging increases**

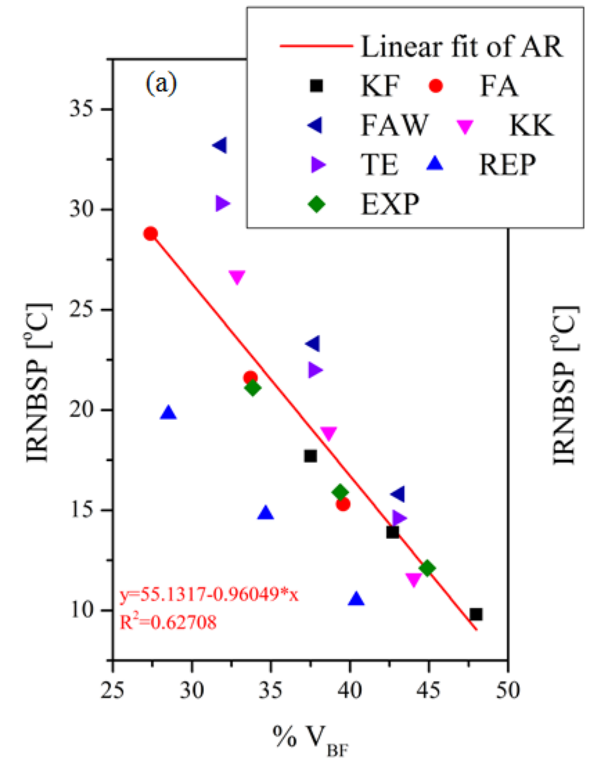
Variable surface areas



Influence of the FETCH on the Increase in Ring and Ball Softening Pointt

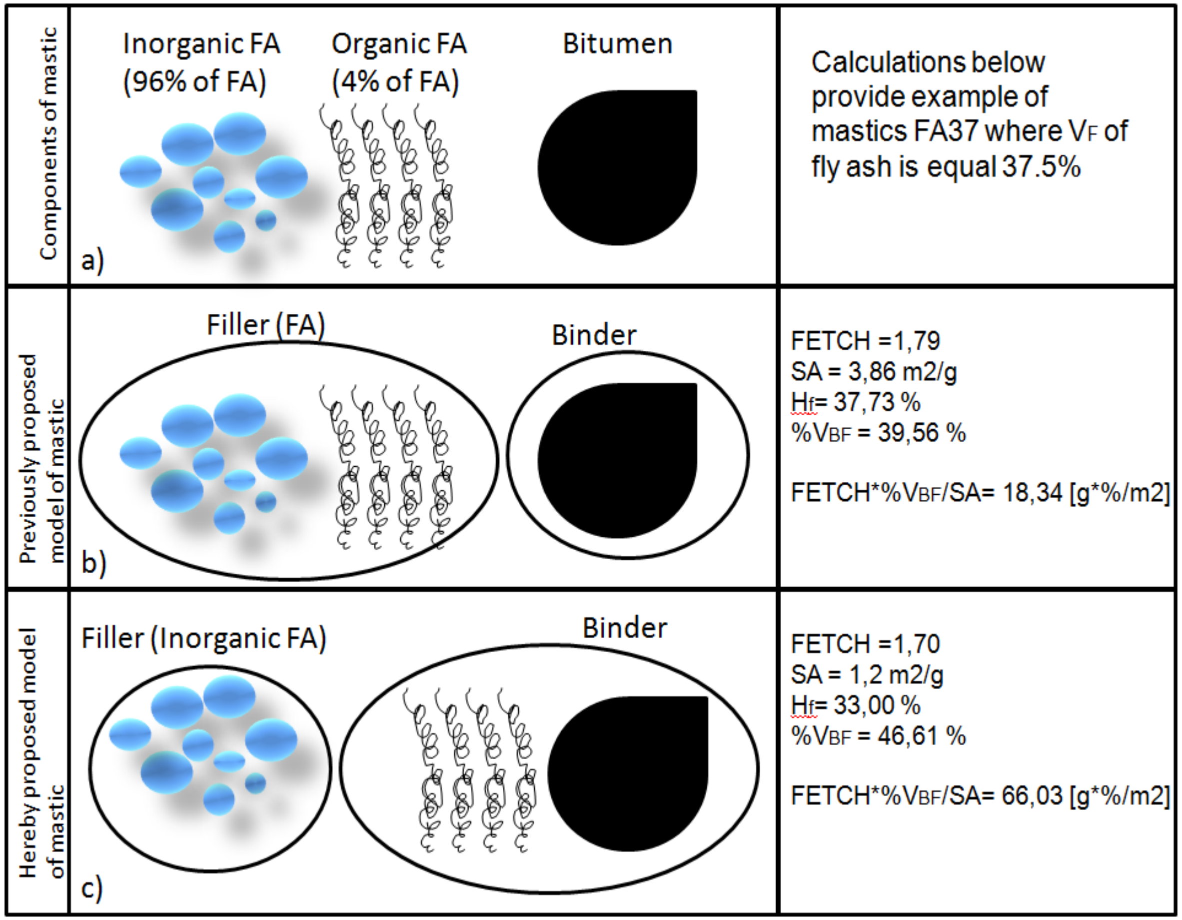


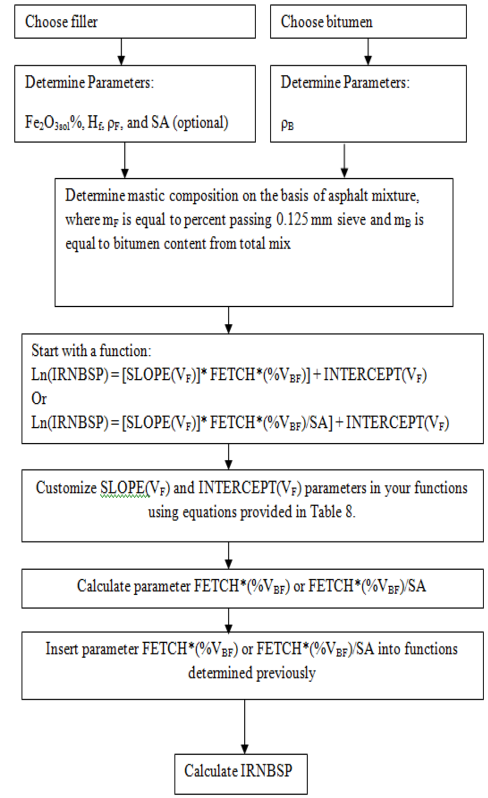
Etchable iron (III) oxide content (Fe_2O_{3sol}%)



Makowska. M., Pellinen, T., (2015) Etchable iron content (FETCH) proposed as the missing parameter for the better prediction of asphalt mastic stiffening, Construction & Building Materials, Accepted

Schematic representation of a novel mastic composition concept demonstrated on the example of FA37; a) definition of mastic components, b) current understanding of mastic, c) proposed understanding of mastic incorporating fly ashes.

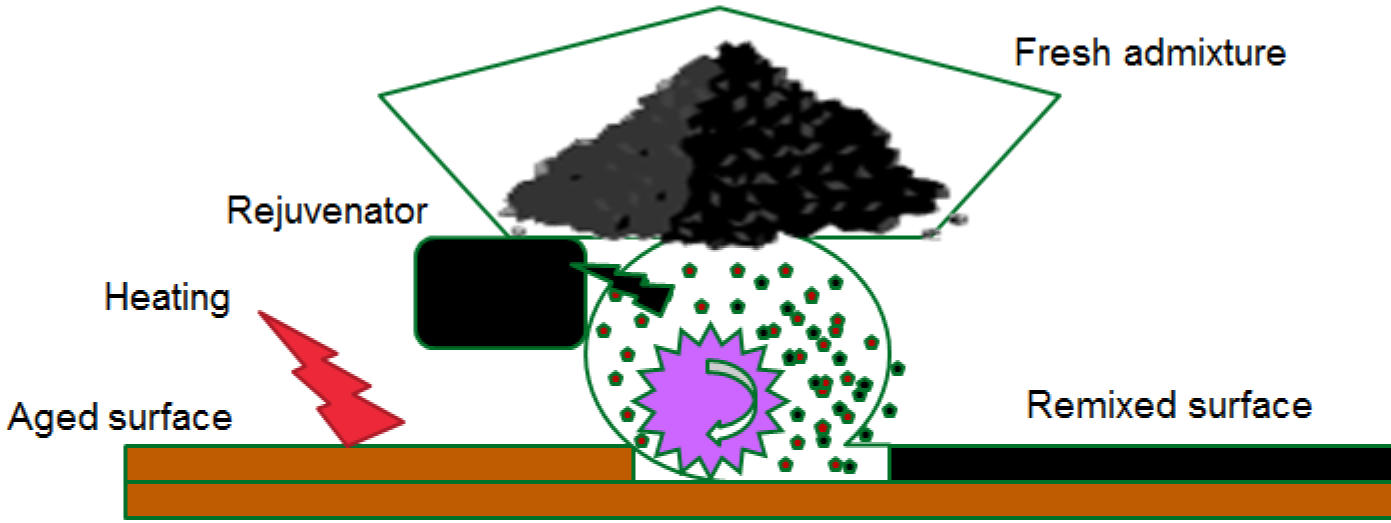




"REMIX" (Hot in-place recycling)

Ongoing joint study by Finnish Transport Agency and AALTO University, 2013-2017

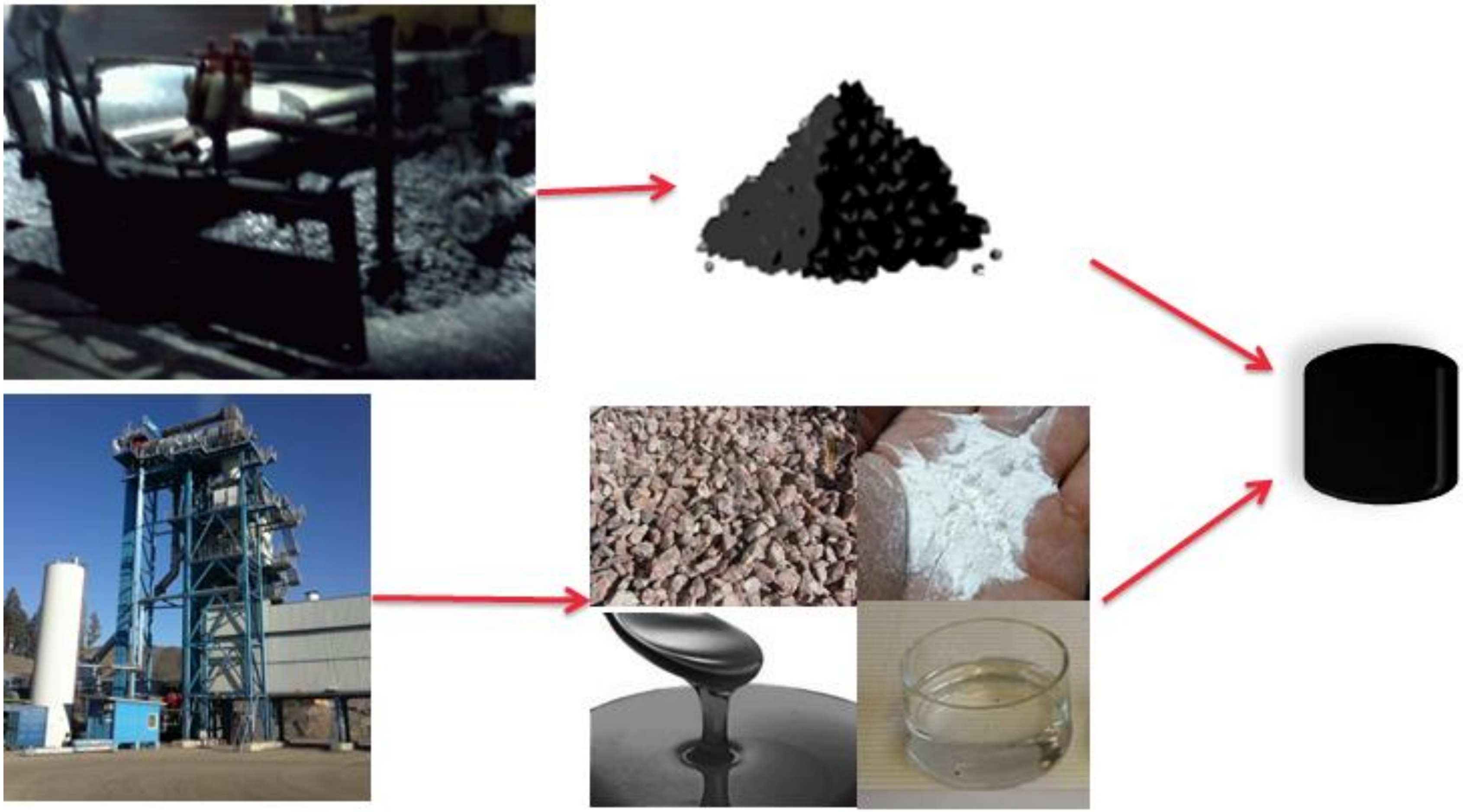
Liikennevirasto



Makowska, M., Pellinen, T., (2015) Development of specifications and guidelines for hot in-place recycling in Finland, 8th International RILEM SIB Symposium, Testing and Characterization of Sustainable & Innovative Bituminous Materials, October 7-9, 2015 – Ancona, Italy, submitted

Test Road VT1: Core Analysis

Rejuvenation and Admixtures



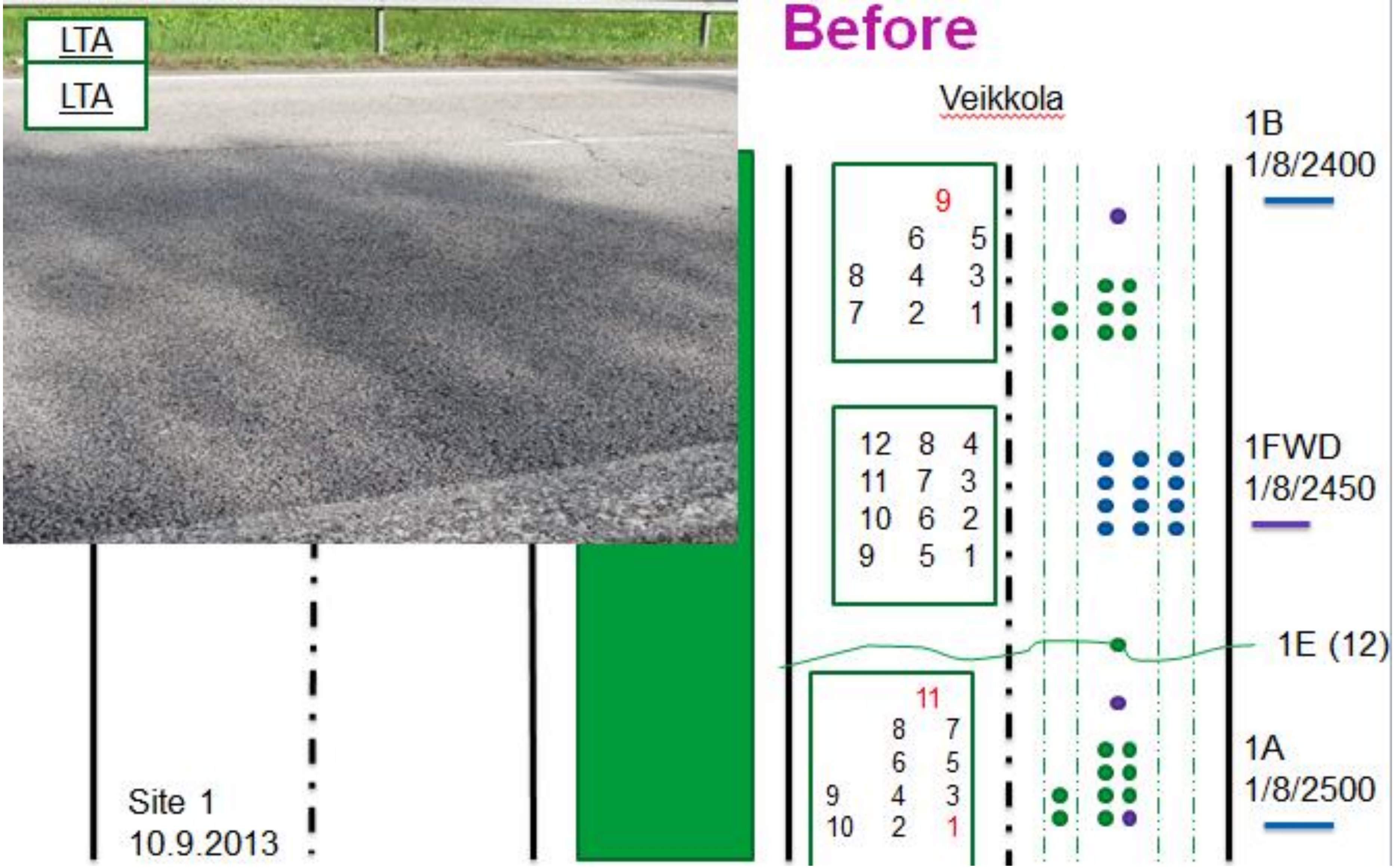
"REMIX"

Objective: How to select optimal rejuvenator and admixture for best performance?

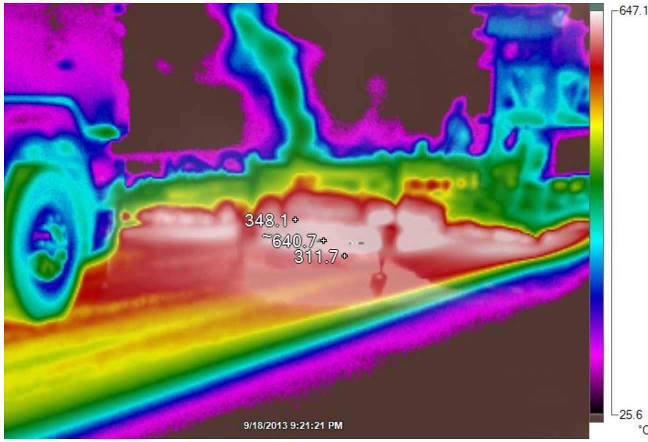
Types of tests	Test Method	QTY	Ready%
Conventional QC/QA work	Bulk density	157	100
	Maximum density	133	100
	IDT stiffness and strength	55+55	100
	Prall ja SRK abrasion	12+12	100
	Binder content and gradation	80+80	90
	Extraction and bitumen recovery	38	90
	Density of aggregate and filler	36+36	67+0
	Penetration	38	90
	Fraass	38	50
Rheology	DSR-testing for bitumen	38	70
Chemical analysis	SARA-fractions for bitumen	32	0
	BET surface area of filler	36	30
	HAST (solubility)	36	36
	XRF	18	0
	FT-IR filler and bitumen	80+38	70+60

TEST ROAD VT1

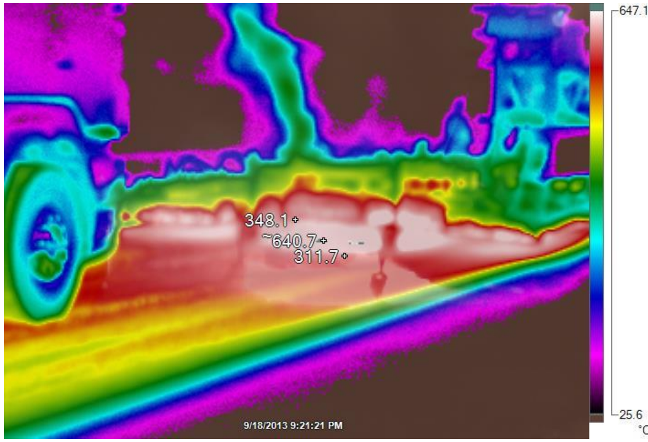
Before


LTA
LTA
Veikkola
1B
1/8/2400
9
6 5
8 4 3
7 2 1
12 8 4
11 7 3
10 6 2
9 5 1
1FWD
1/8/2450
1E (12)
11
8 7
6 5
9 4 3
10 2 1
1A
1/8/2500
Site 1
10.9.2013

After



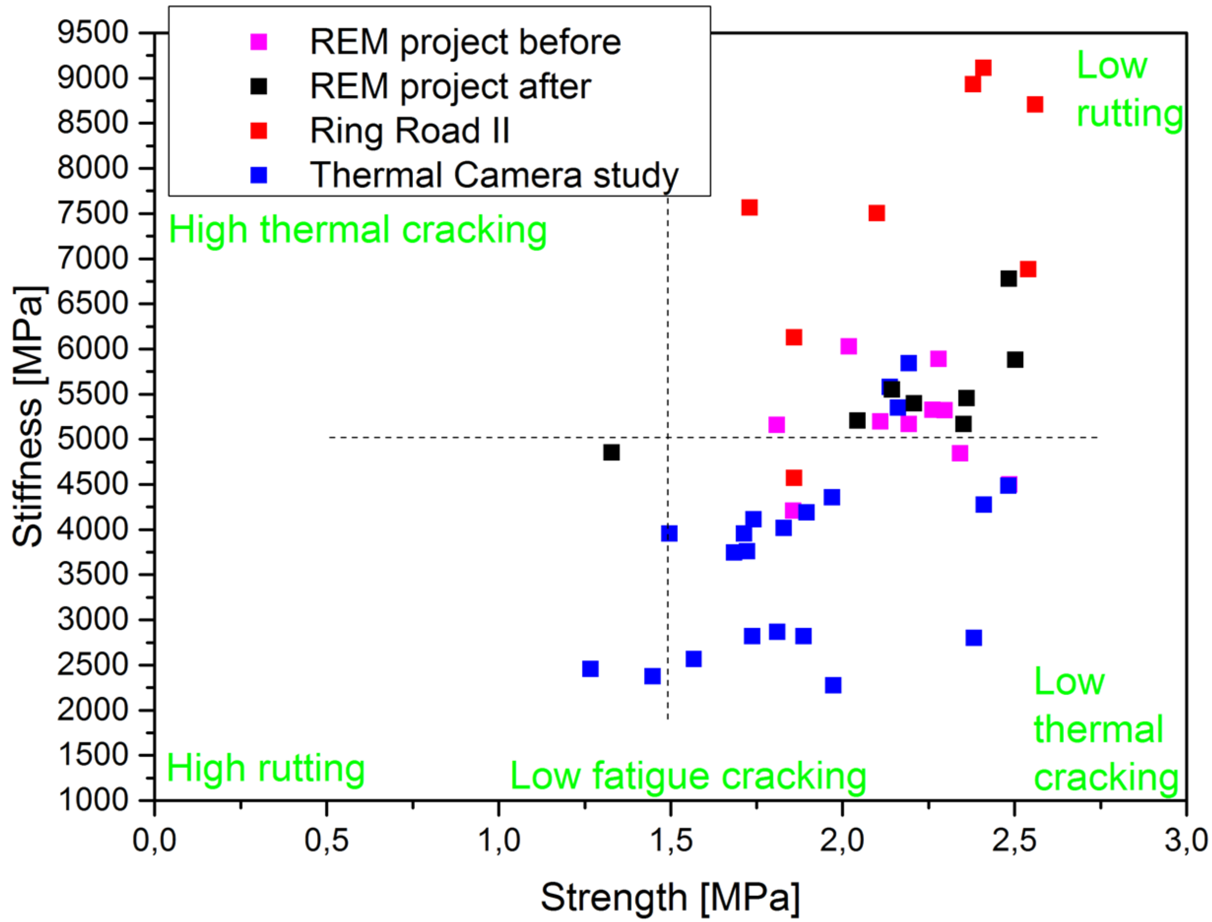
After



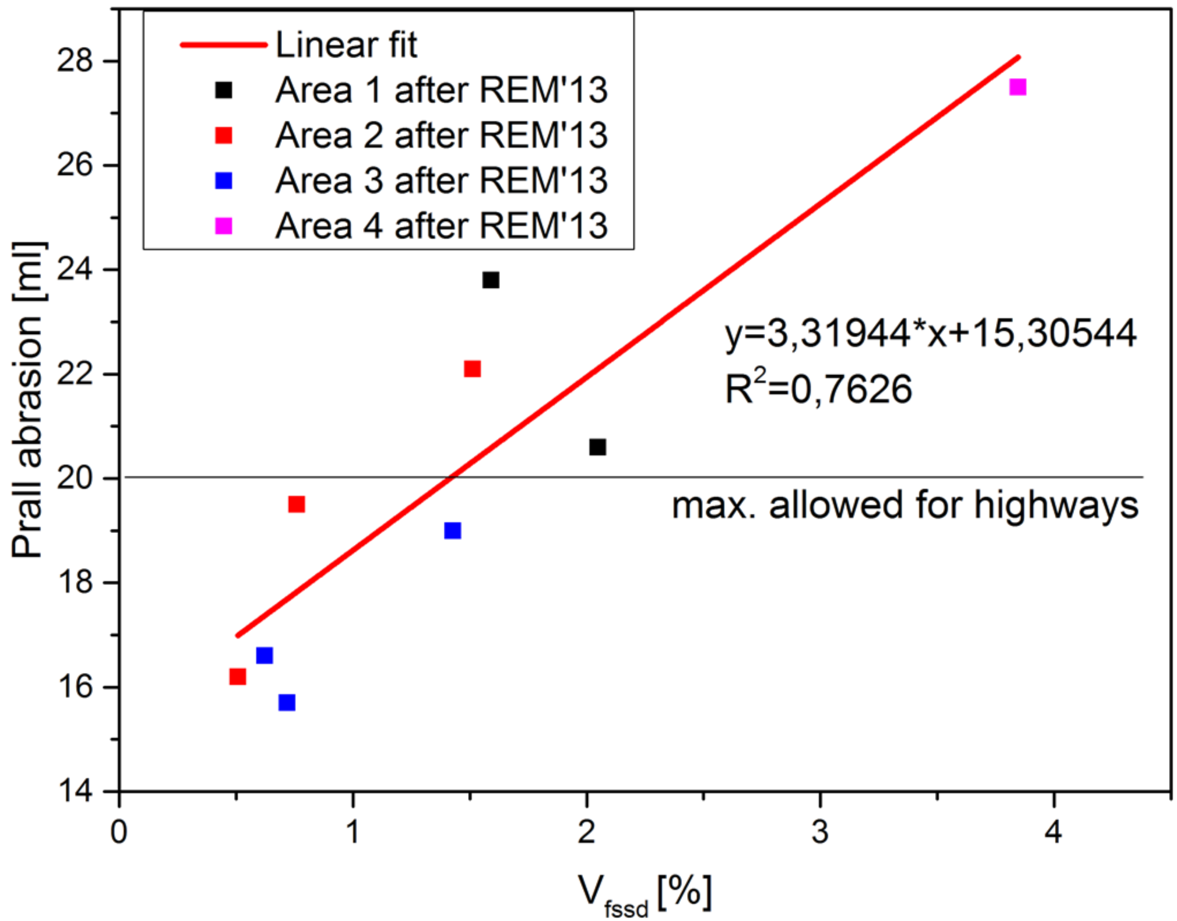
Before

After

Stiffness vs. strength at 10°C

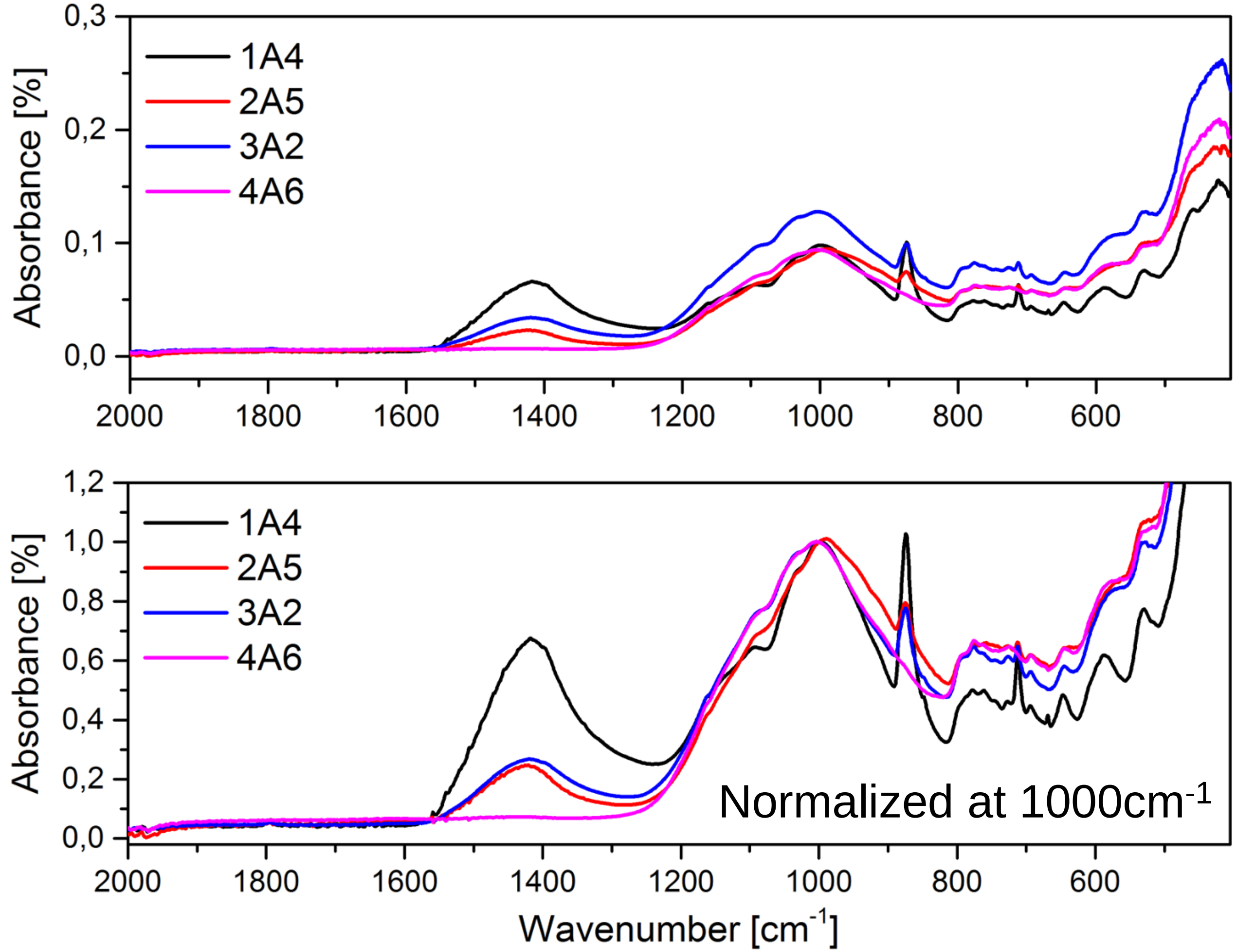


Prall abrasion



Qualitative FT-IR of fines

Area 4 = no limestone filler
Area 3 = limestone filler
Area 2 = limestone filler
Area 1 = lot of limestone



Exact amounts of $CaCO_3$ and Etchable iron to be confirmed with wet chemistry

Quantitative FT-IR as a result of this study

Bitumen studies

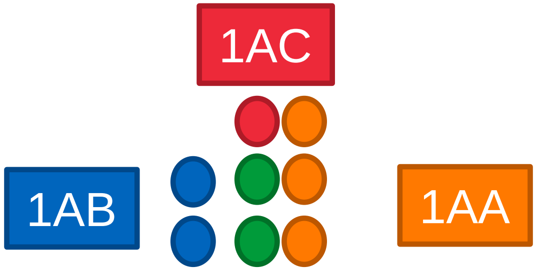
- How to choose a rejuvenator with the optimal properties (facilitating blending)?
  - Hansen Solubility Parameters
  - FT-IR
  - SARA

Example from a full series

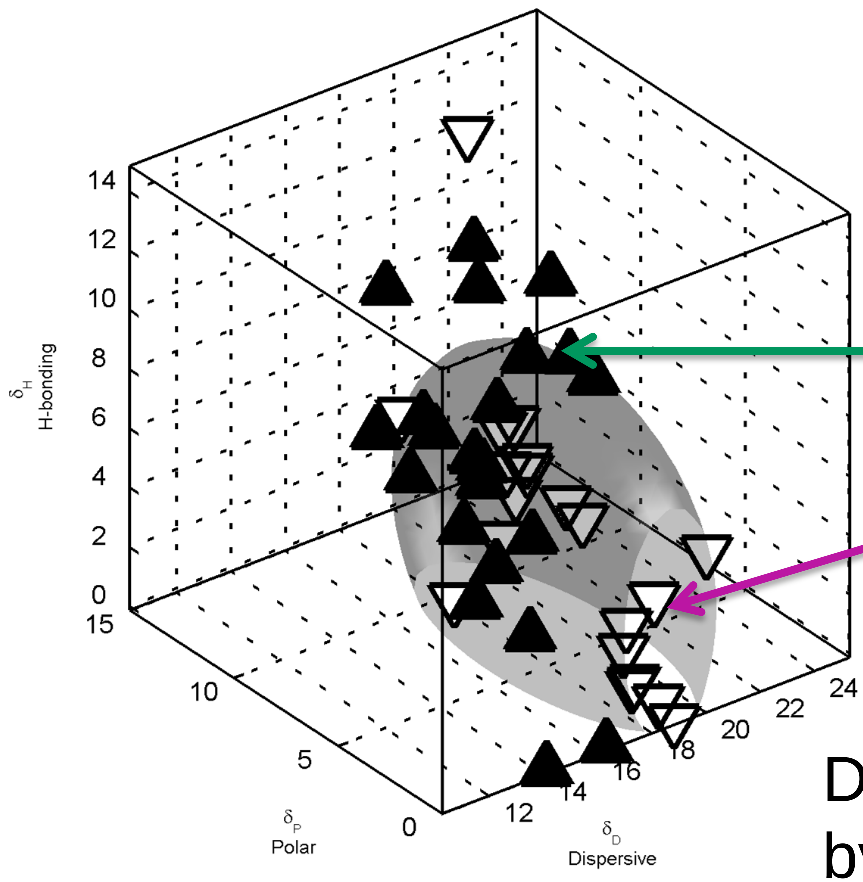
1FA Pen 33

1FB Pen 35

1FC Pen 40



Hansen Solubility Parameters (sphere)



- 42 solvents tested against each bitumen
- Plotted
- Sphere fitted

Developed in Nynas AB Sweden by Per Redelius and WRI

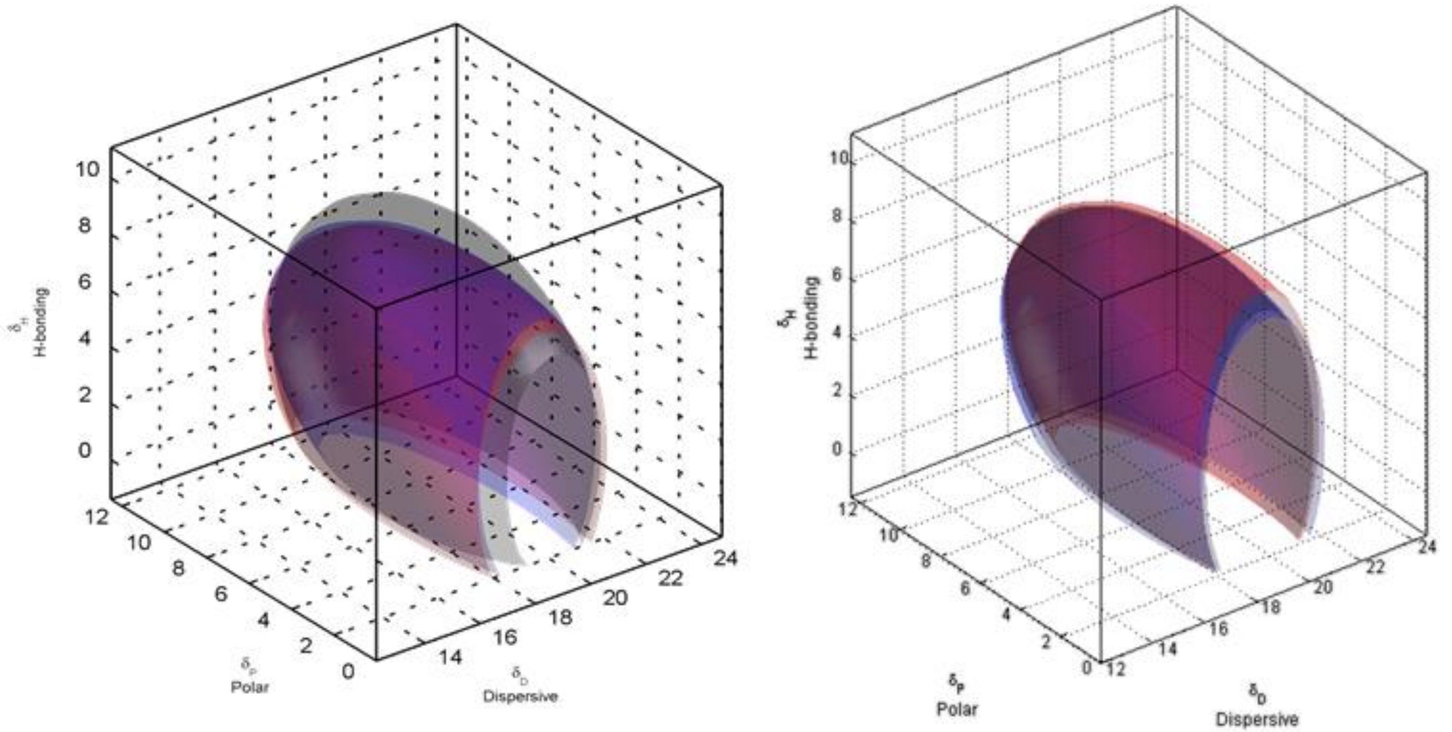
Bisom Titration – what is?

- Method developed in Nynas AB in Sweden by Per Redelius and co-workers

- It evaluates
  - Stability of the bitumen
  - Quality of the bitumen
  - Usability of the bitumen

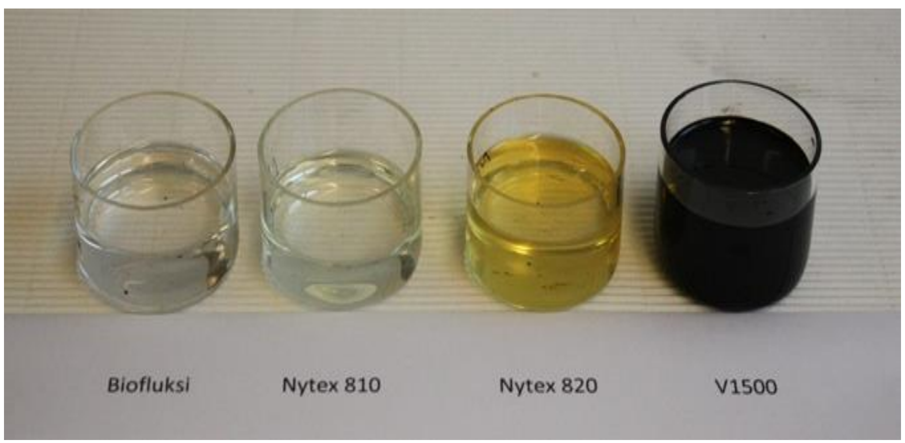
- The results are correlated to the rheological behavior of the bitumen

Best rejuvenator – soft binder



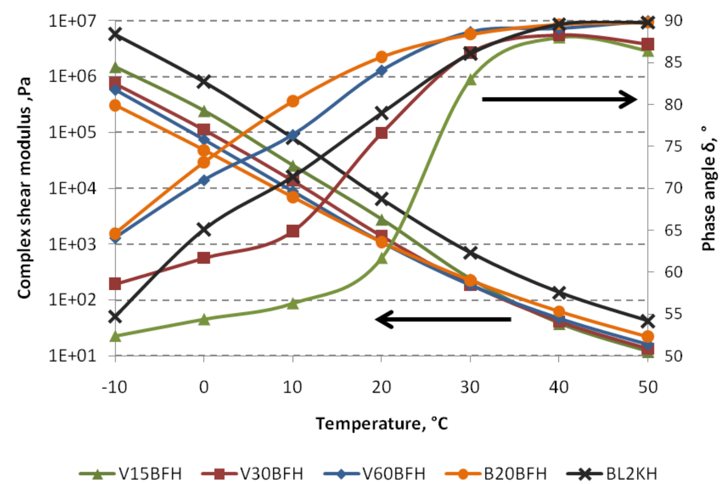
a) Solubility parameters of recovered bitumens indicating minuscule changes in solubility between the materials; b) Bitumens recovered from the cycles 1 (black) and cycles 2 (blue) and an example of soft solubility parameter for soft bitumen (red)

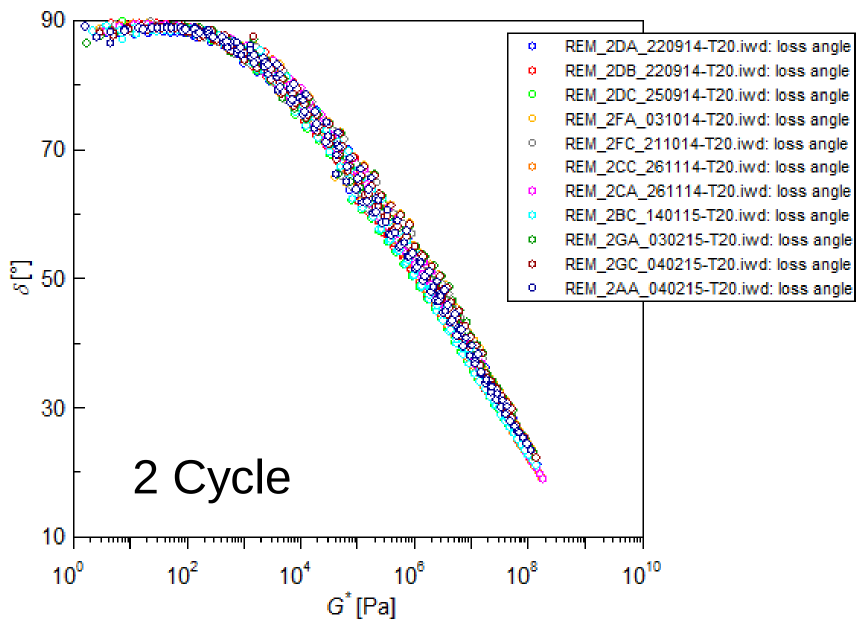
Rejuvenation of bitumen with bio-based oils

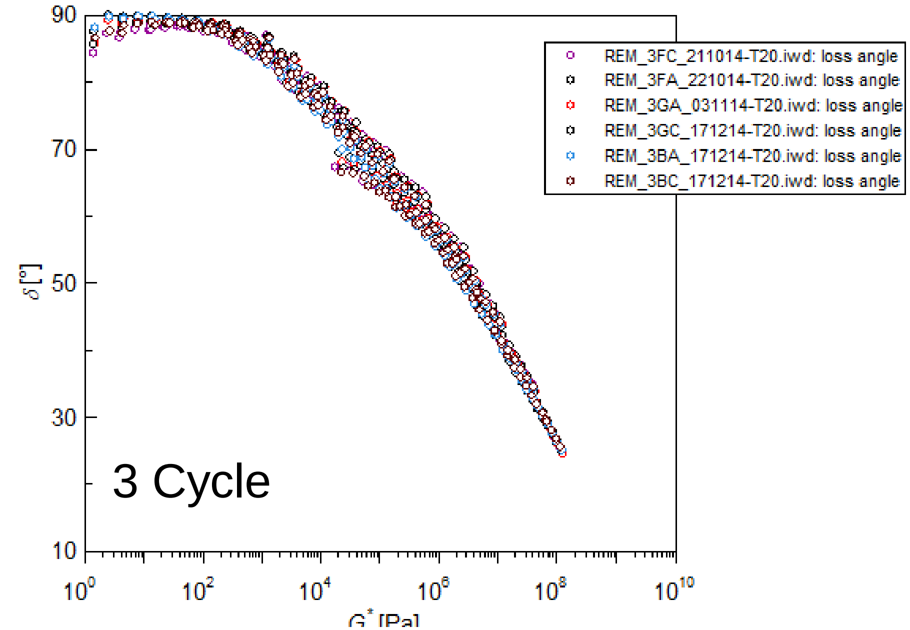


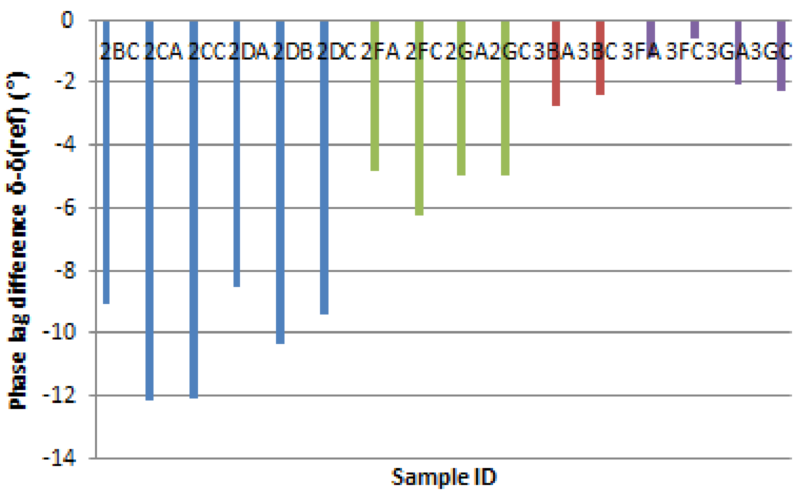
Lehtomäki, H. ”Asfalttirouheen elvyttäminen keveillä öljytuotteilla (Lightweight oil products as rejuvenators for reclaimed asphalt pavement)”. Diplomityö, Aalto-yliopisto, 2012.

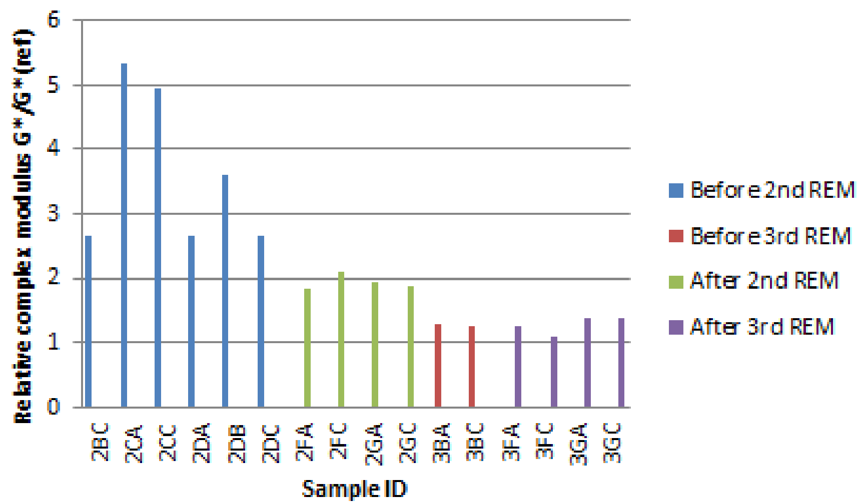
Simonen, M., Blomberg, T., Pellinen, T., Valtonen, J. (2013): Physico-chemical Properties of Bitumens Modified with Bioflux. International Journal of Road Materials and Pavement Design, Vol. 14, Issue No. 1, pp. 36-48.









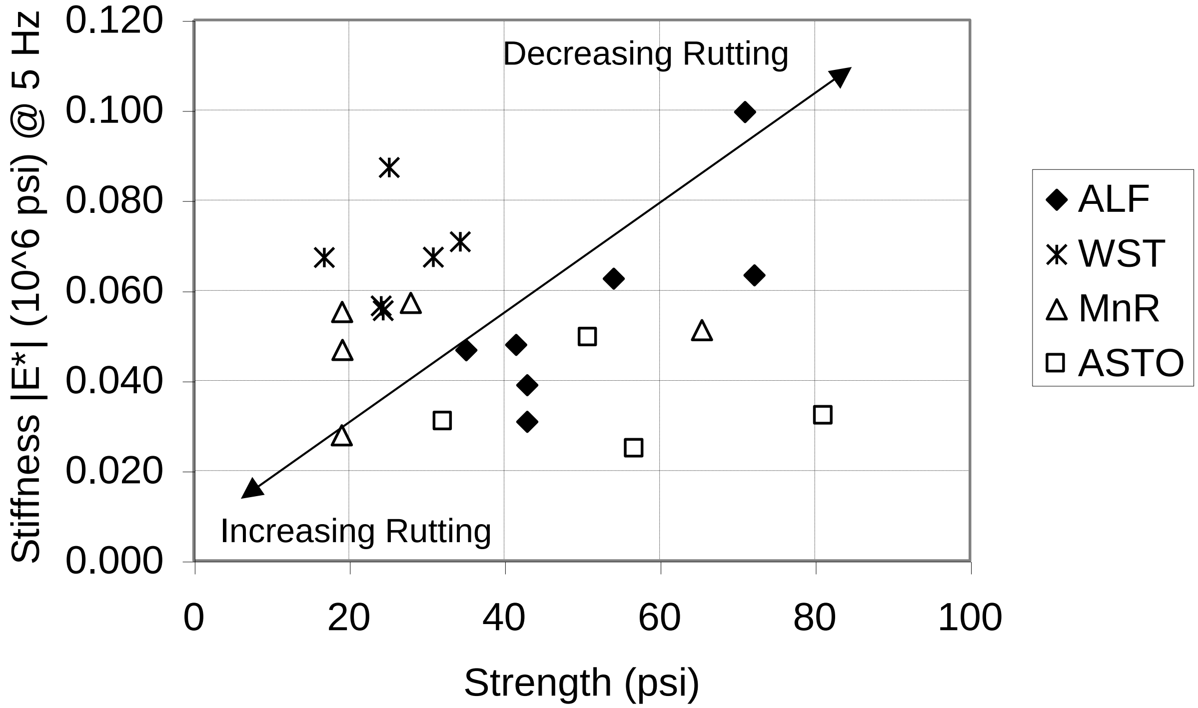


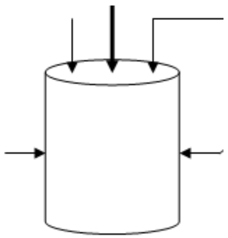
DSR: Angular Frequency: 10 rad/s
Temperature: 40 °C

Initial conclusions

- REMIX can be used to improve damaged areas
- The success of REMIX is not determined by the number of cycles
- Success of REMIX depends on the:
  - Quality of the initial materials
  - Added materials
  - Successful rejuvenation
  - Temperature control during resurfacing
  - Compaction effort

Performance of ASTO Mixtures tested at 54,4°C





Pellinen, T. Investigation of the use of dynamic modulus as an indicator of hot-mix asphalt performance. Thesis (PhD), Arizona State University, USA, 2001.

US and ASTO mixtures

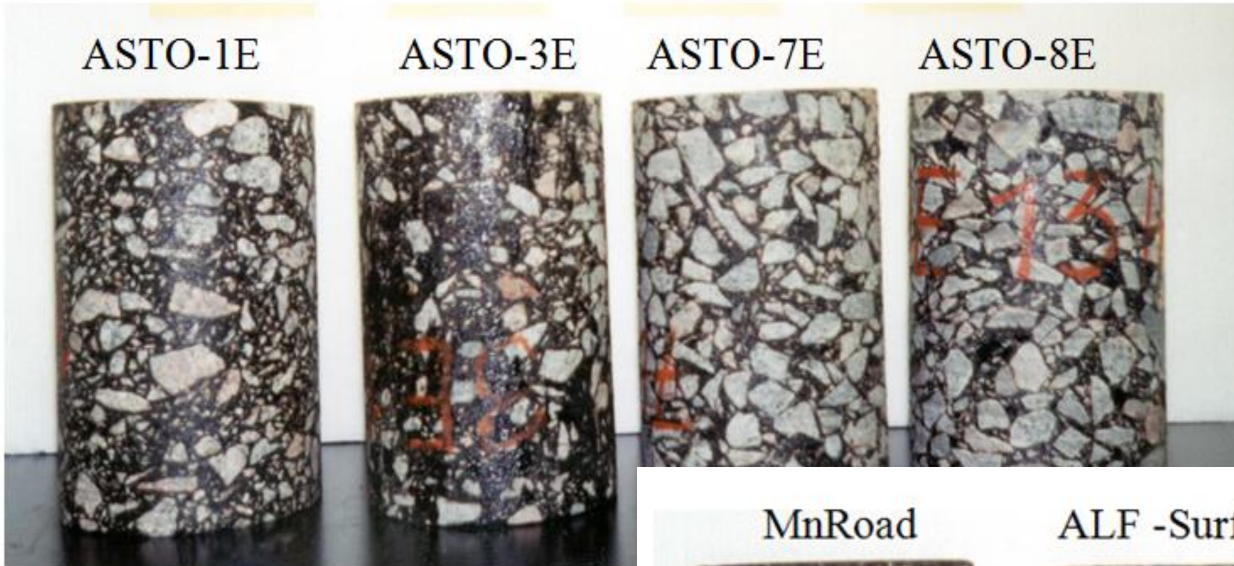
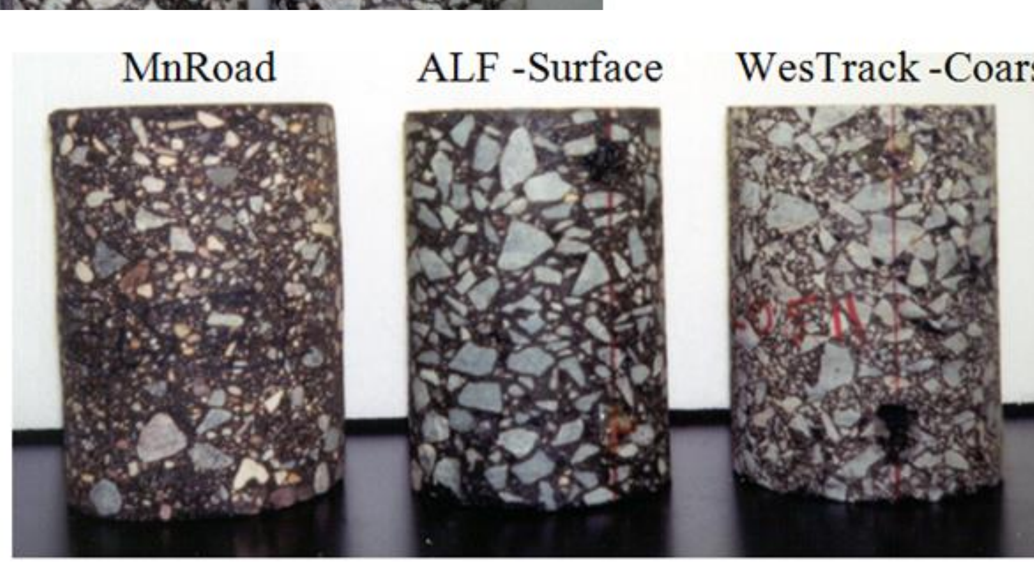
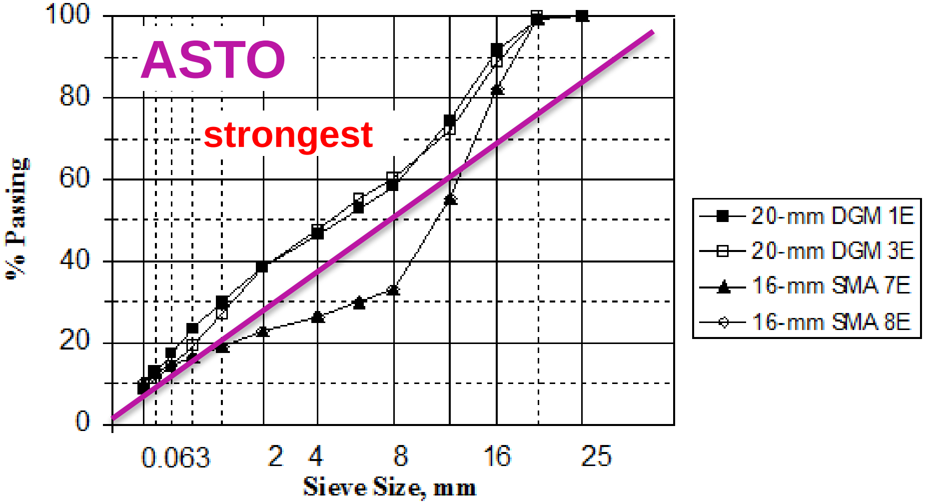
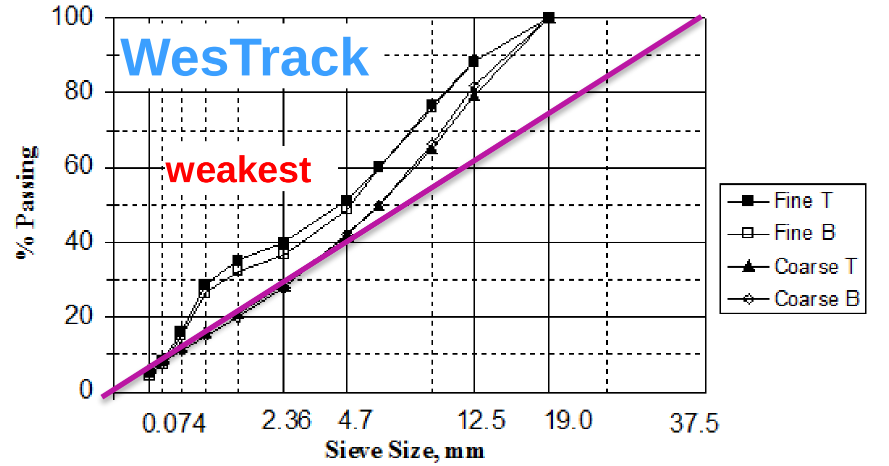
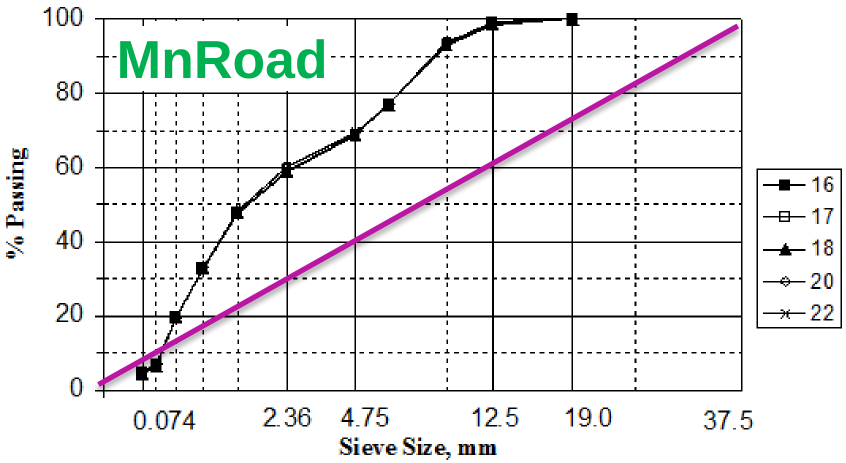


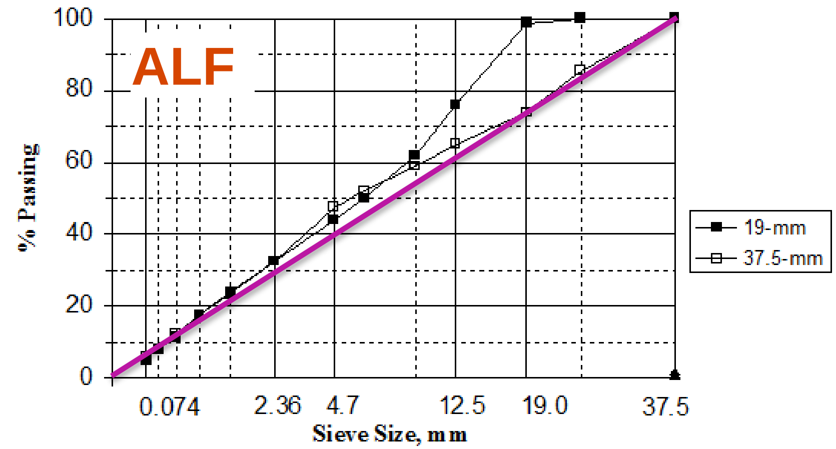
Figure 5.37. A



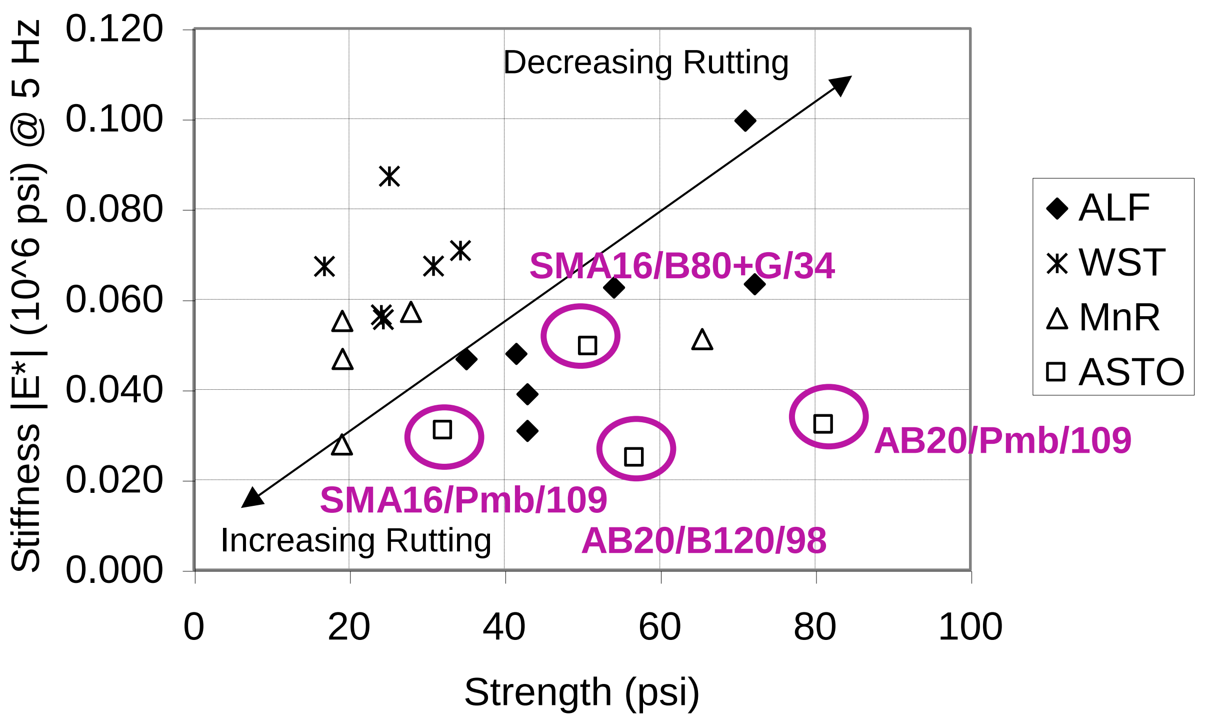

ASTO
strongest
% Passing
Sieve Size, mm
100
80
60
40
20
0
0.063
2
4
8
16
25
20-mm DGM 1E
20-mm DGM 3E
16-mm SMA 7E
16-mm SMA 8E


WesTrack
weakest
% Passing
Sieve Size, mm
100
80
60
40
20
0
0.074
2.36
4.7
12.5
19.0
37.5
Fine T
Fine B
Coarse T
Coarse B

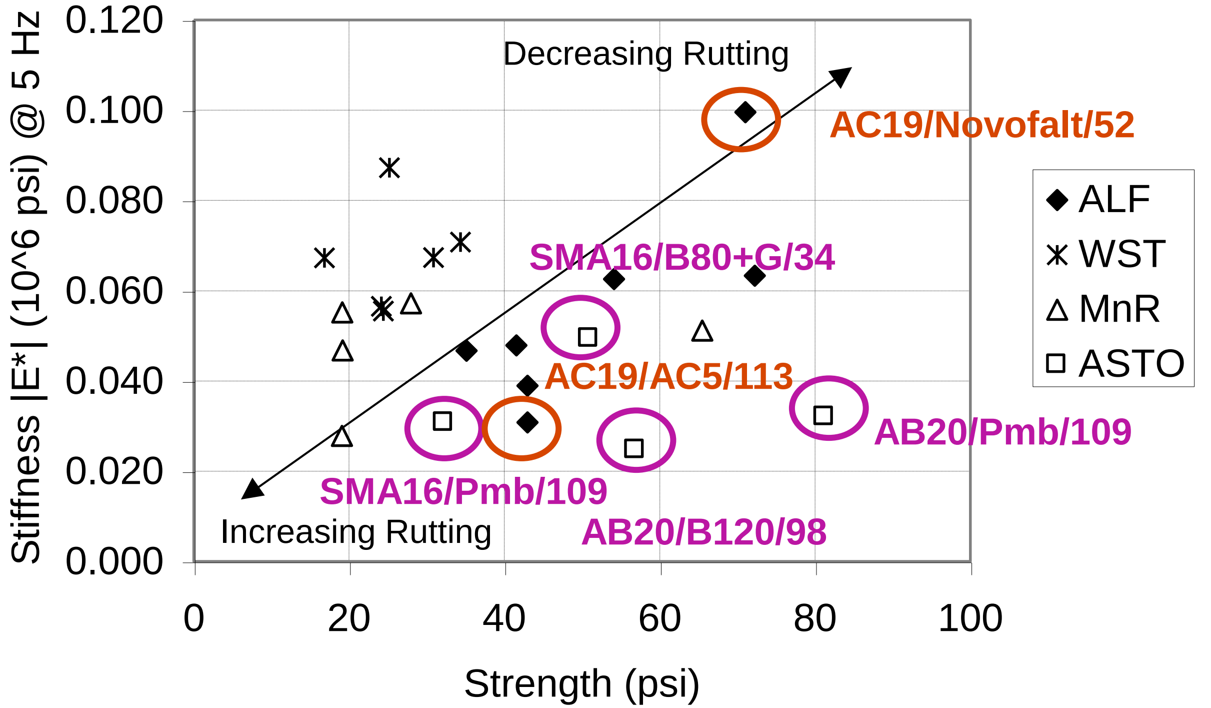

MnRoad
% Passing
Sieve Size, mm
100
80
60
40
20
0
0.074
2.36
4.75
12.5
19.0
37.5
16
17
18
20
22


ALF
% Passing
Sieve Size, mm
100
80
60
40
20
0
0.074
2.36
4.7
12.5
19.0
37.5
19-mm
37.5-mm

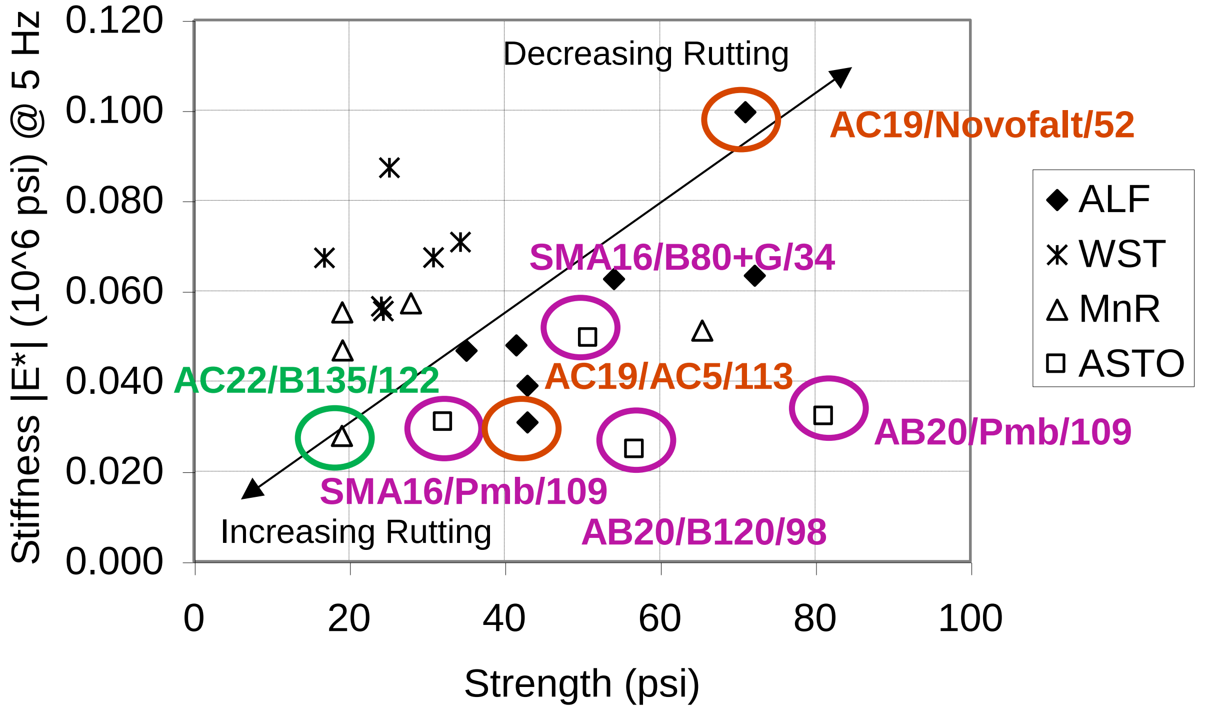
Performance of ASTO Mixtures



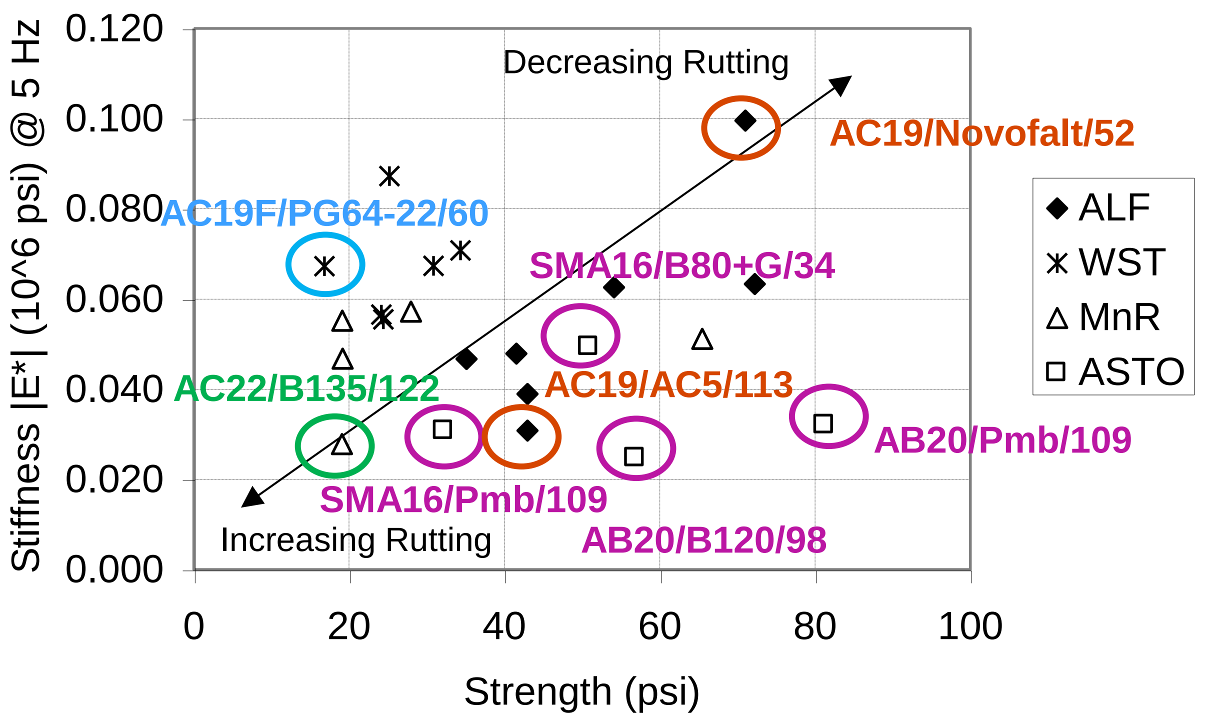
Performance of ASTO Mixtures



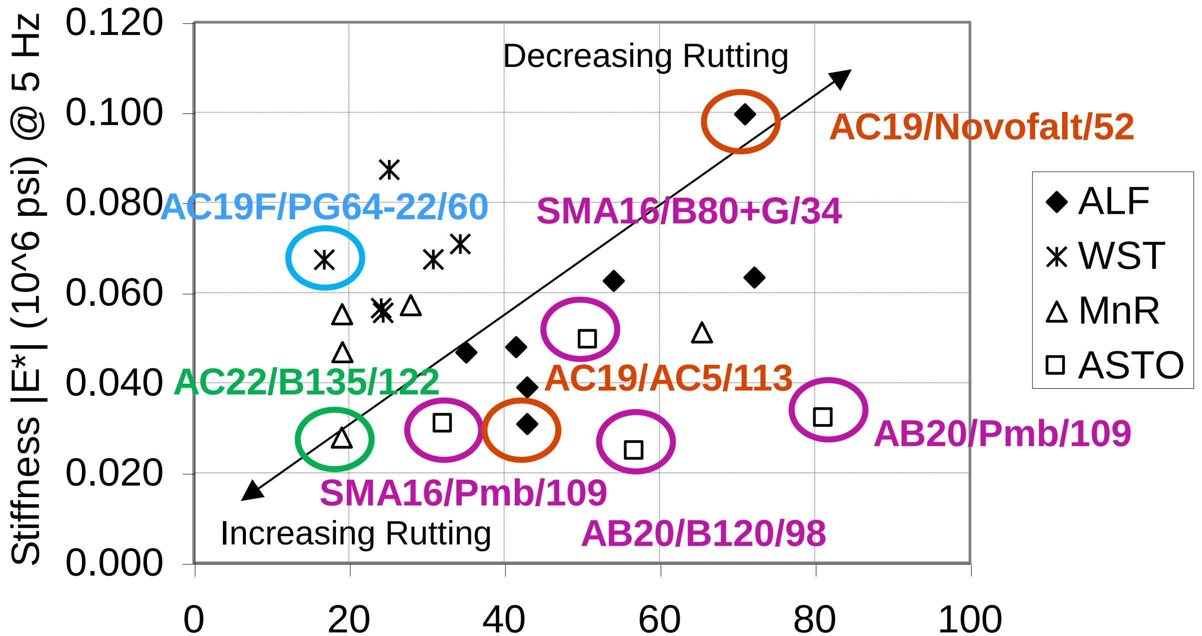
Performance of ASTO Mixtures



Performance of ASTO Mixtures

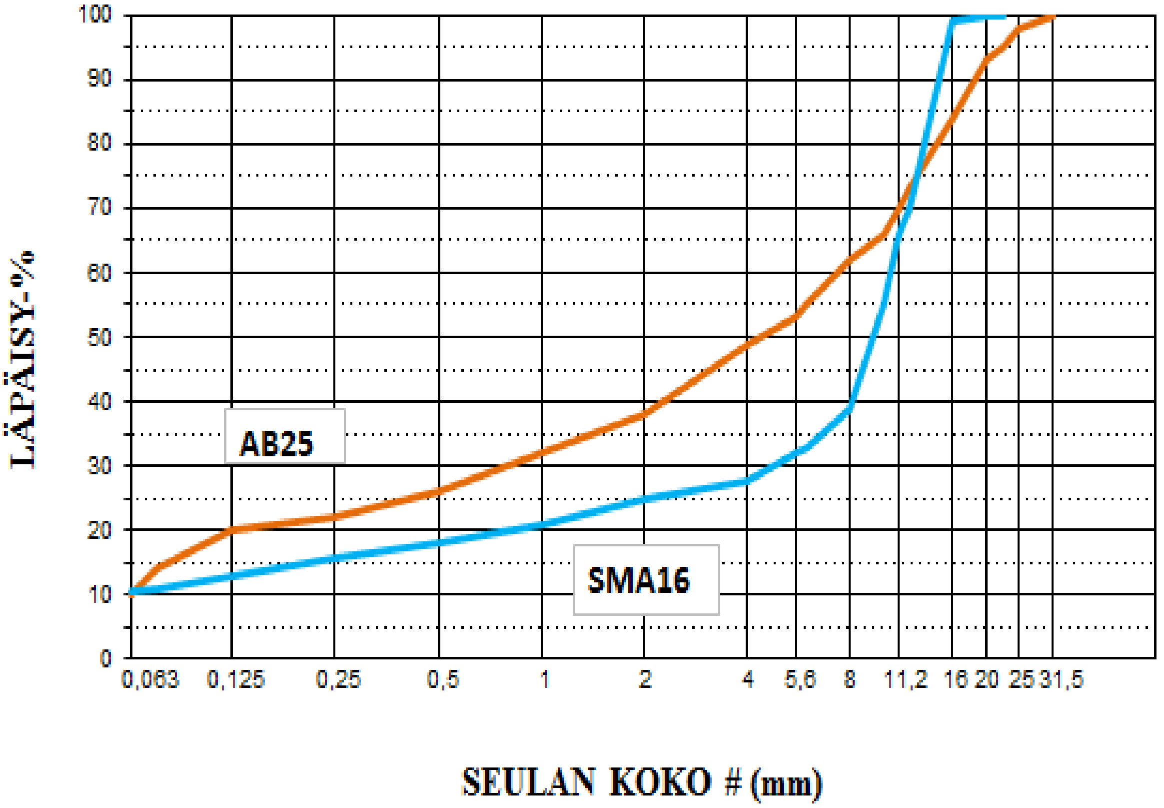


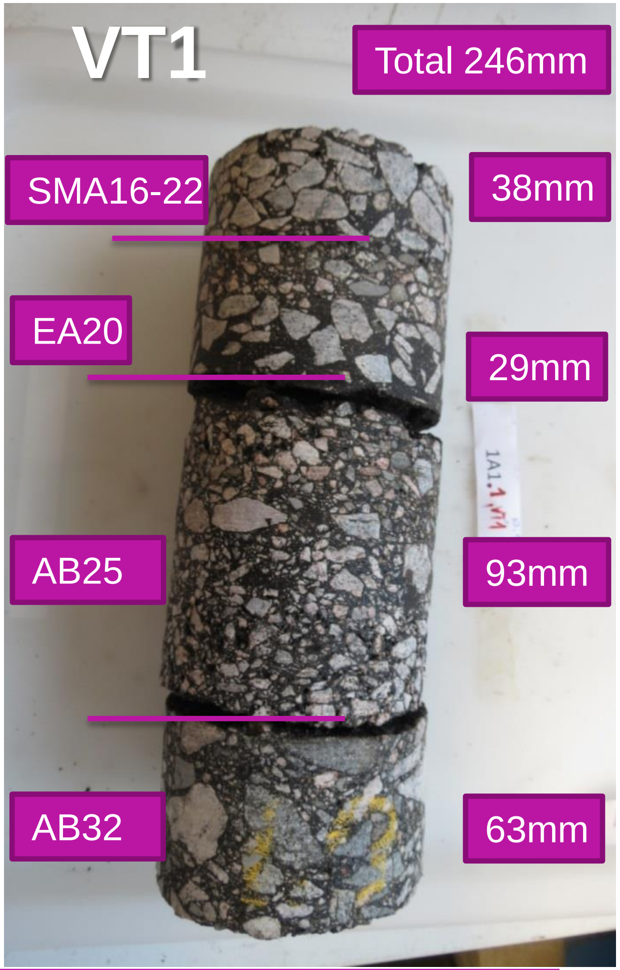
Performance of ASTO Mixtures



		Bit-m%	Bit Vol-%	Fines %	f/b (m) ratio	f/b (vol) ratio	VMA%	VFA%
ASTO	avg all	6,3	14,0	9,4	1,48	0,67	17,1	81,0
MnRoad	22	5,4	10,2	4,3	0,80	0,42	16,9	61,5
ALF	8	4,7	9,7	5,1	1,09	0,53	21,6	45,0
WesTrack	2	5,0	10,4	5,0	1,00	0,48	15,8	41,0

Todays asphalt mixtures are coarser





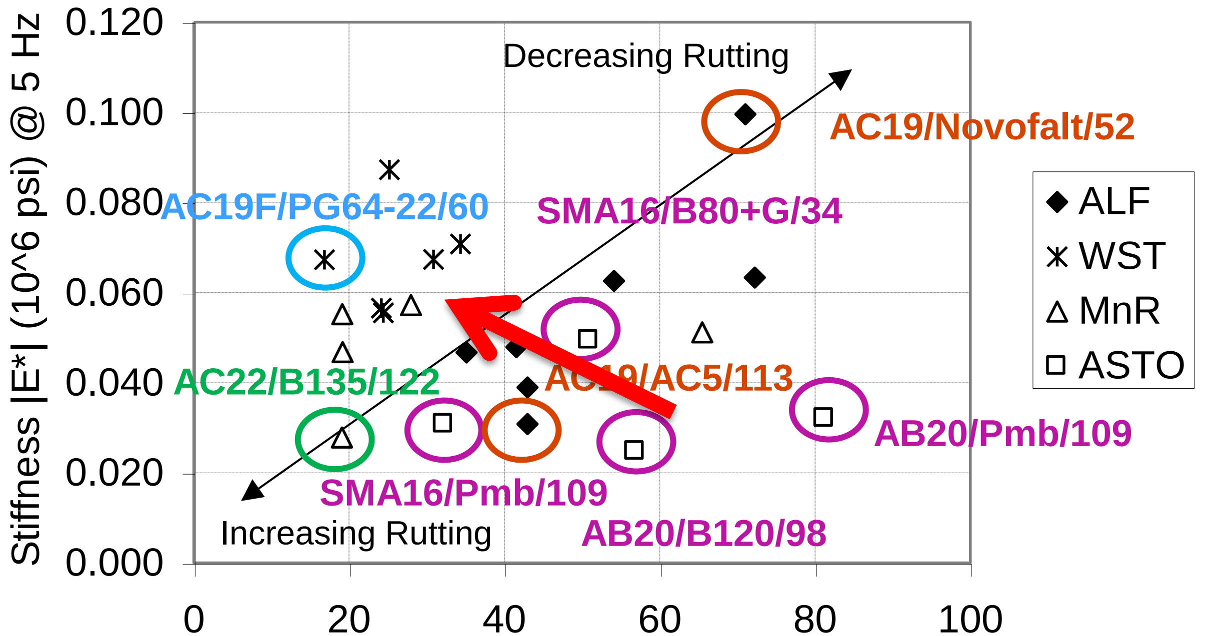
Today we use stiffer bitumen

1980's 100/145 →
1990's 70/100 →
2000's 50/70 (SMA)

AASHTO
Superpave Grade is PG 58-22

modified bitumen are used only for bridges etc.

Performance of ASTO Mixtures



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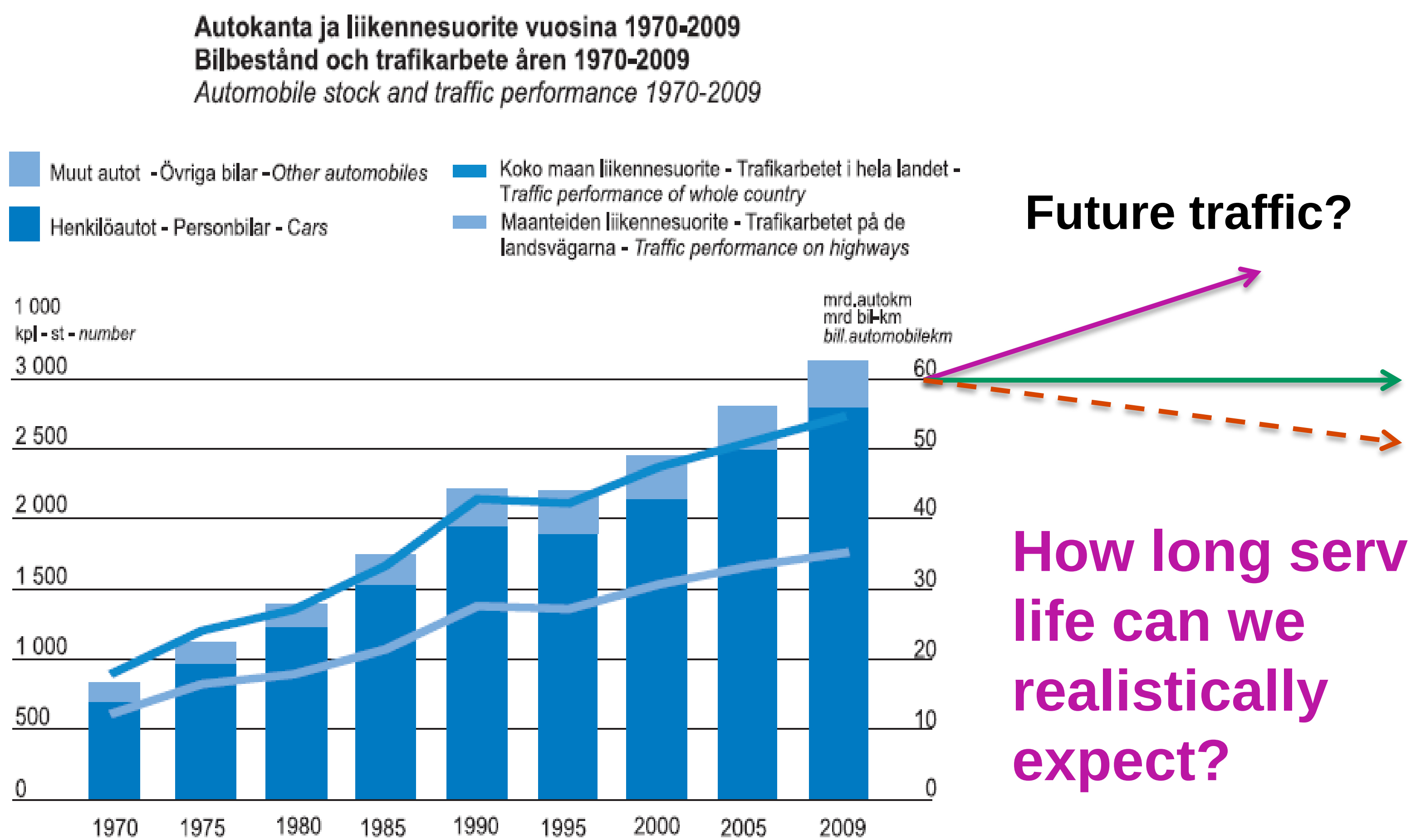
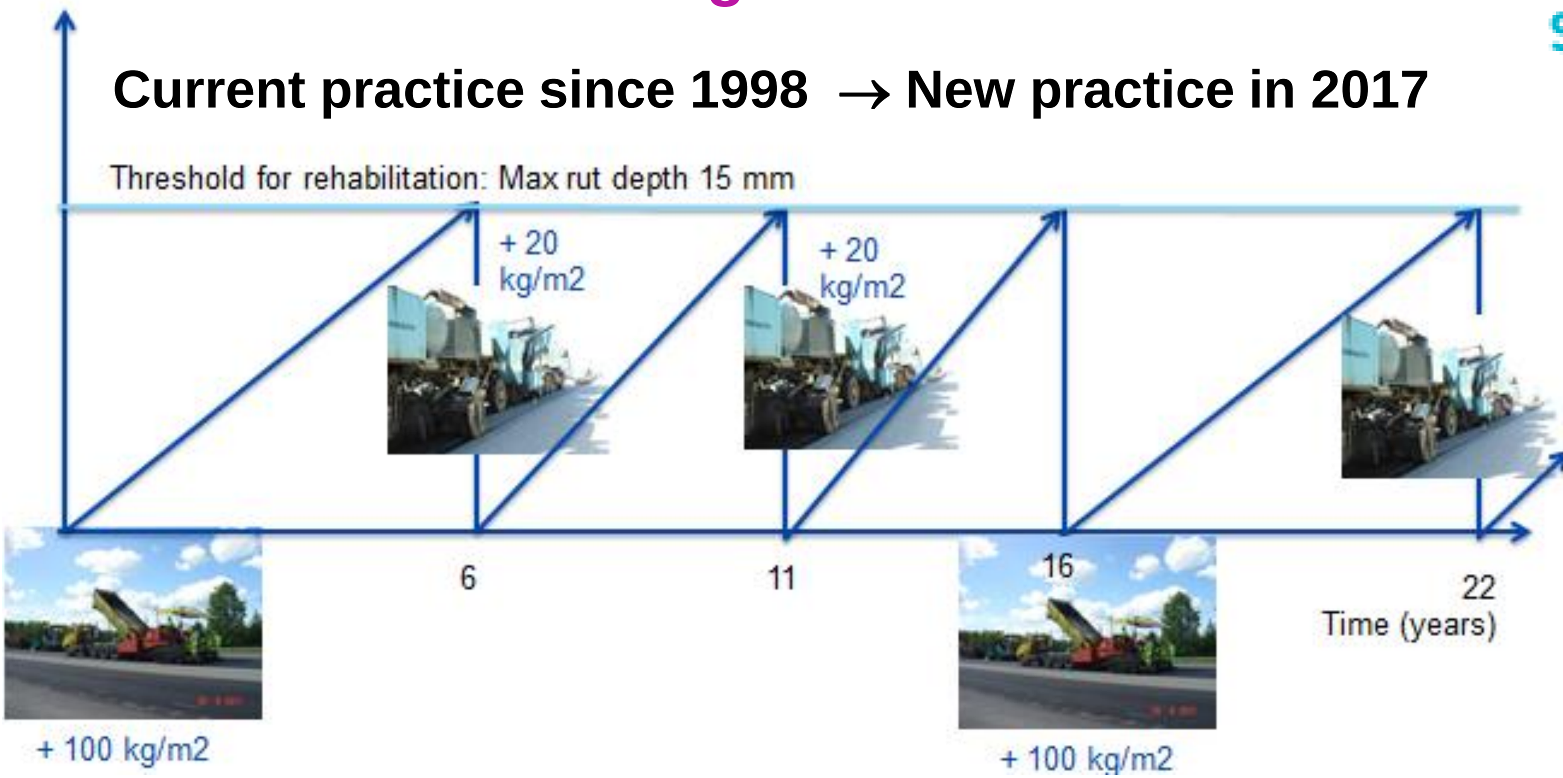
WesTrack	2	5,0	10,4	5,0	1,00	0,48	15,8	41,0

How to improve life span?



How long service life can we realistically expect?

- Adding one more year for pavement life will bring savings
- Adding one more Remix cycle will bring considerable savings



Concluding Remarks

- **Binder content – crucial for performance –optimum needed**
- **Air void content –current NDT methods need development**

- **Amount of filler and filler type important (FT-IR)**
  - Mastic/binder in-situ aging (FT-IR)
  - Mastic moisture susceptibility ?
- **Mastic stiffening important – if doubts use delta R&B → DSR?**
- **Binder/mastic adhesion to aggregate -- ?**
- **Aggregate quality and hardness tests – always needed**
- **Use of modified binders with hot-in-place rehabilitation??**