Aalto University
School of Engineering

REMIX - Jatkuu

Michalina Makowska, M.Sc.
Kalle Aaroma, M.Sc.
Prof. Terhi Pellinen, PhD

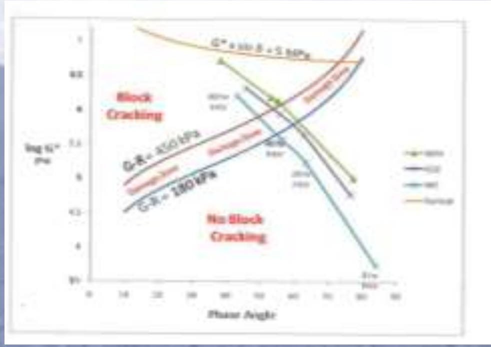
24.11.2016

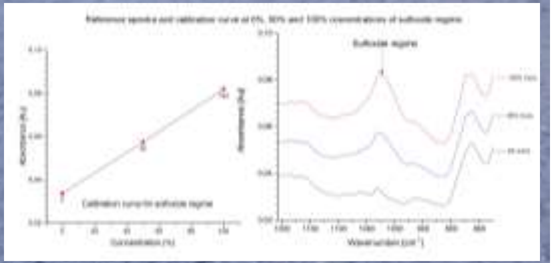
Outline

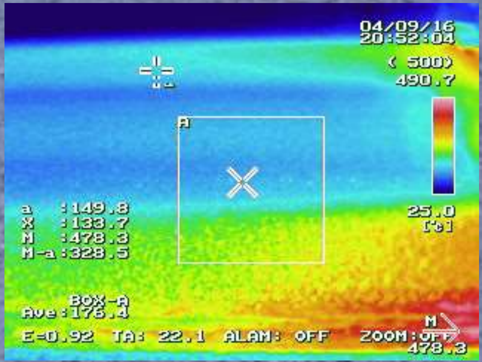
1. The parameter of a good performance
2. How to achieve that parameter – rules of rejuvenation
3. Risks associated with REMIX process and rejuvenation
4. The most common problems observed on the Test sites

5. Fawad – presents how the rejuvenation depends from bitumen, rejuvenator, temperature and time

6. → The studies on thermal conductivity



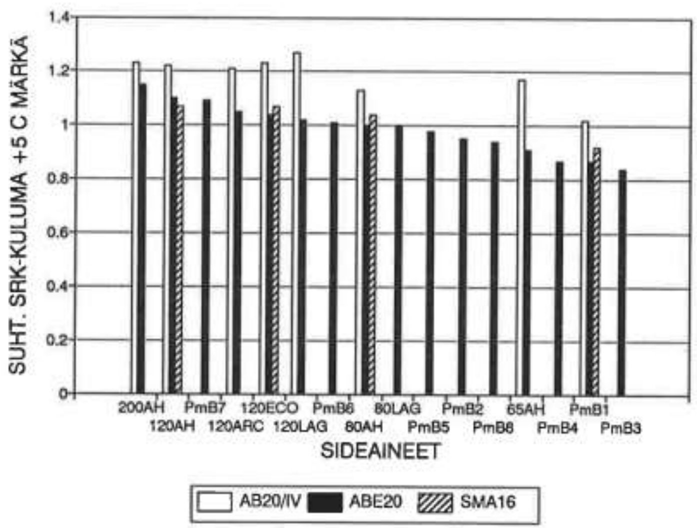




Aalto University
School of Engineering

Glover-Rowe parameter as a performance criteria

ASTO: The type of gradation is crucial, but bitumen rheology is important too

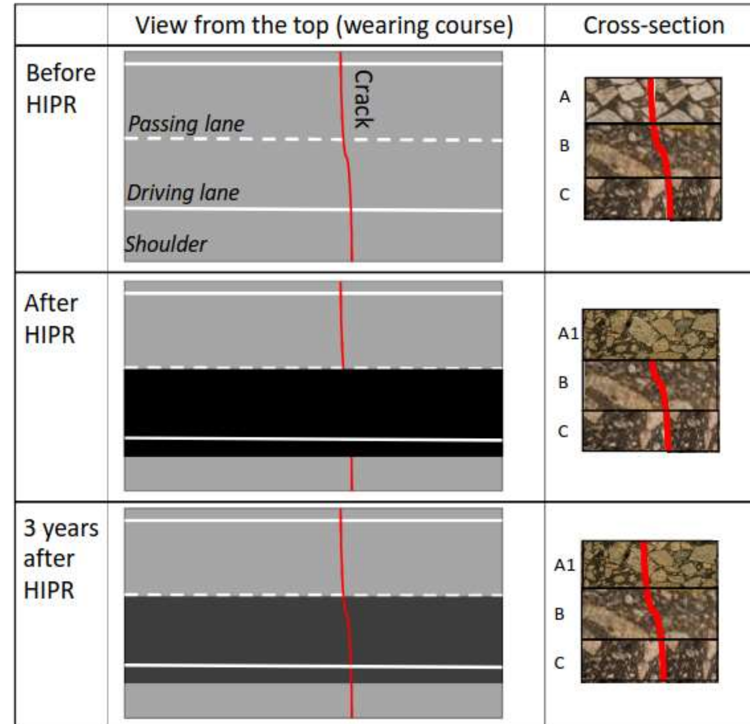


Kuva 16/3.4. Sideaineiden merkitys asfaltin suhteellisessa kulumisessa +5 °C märkä, (SRK).

*Taulukko 25/3.3. Pyöräurituslaitteessa tutkitut erikoispäällystekoetien massat. Kiviaines on Koskenkylä, paitsi referenssissä Teisko *.*

Koeosuus	Massatyyppi	Sideaine	Deformaatio (mm)
1 *	AB 20/IV	B-120 AH	12.2
2	AB 20/IV	B-120 LAG	12.8
3	AB 20/IV	PmB 1	5.1
4	ABE 20	B-80 LAG	8.6
5	ABE 20	PmB 1	4.1
6	SMA 16 saksal. käyrä	PmB 1	3.0
7	SMA 16	PmB 1	3.9
8	SMA 16	B-80 + gilsoniitti	2.1

The performance criteria development for bitumen based on resistance to reflective cracking and ravelling



Different origin influences the path (G*) and blending also alters the path

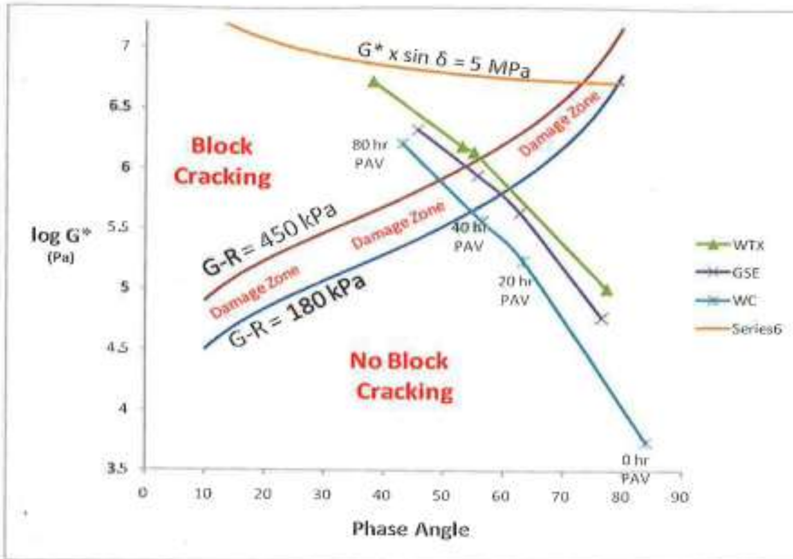
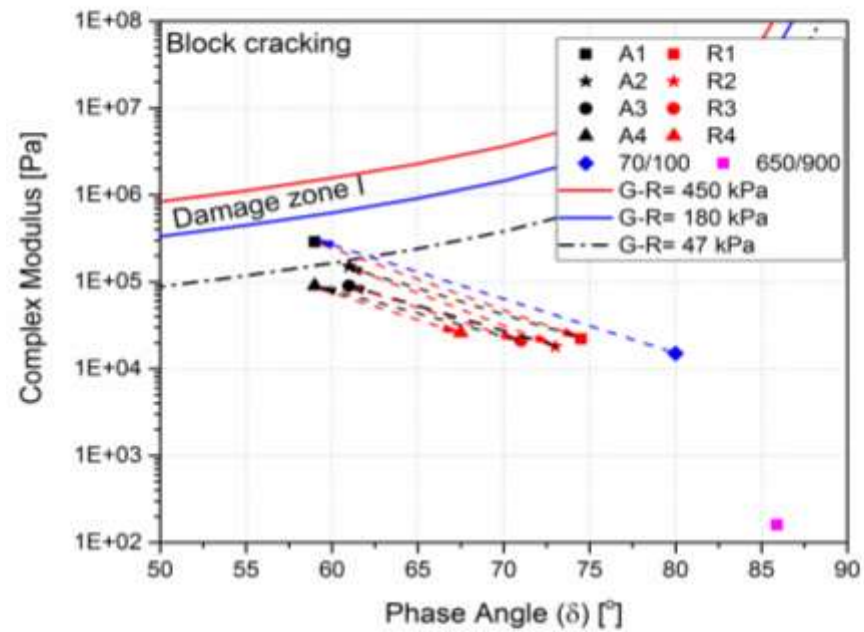


Fig. 2. PAV-aged Binders Passing through the Glover-Rowe Damage Zone



G*→ Pen correlation may not hold exactly for different origin binder and multiply recycled material

King, G., Anderson, M., Hanson, D., & Blankenship, P. (2012). Using Black Space Diagrams to Predict Age-Induced Cracking. In A. Scarpas, N. Kringos, I. Al-Qadi, & A. Loizos (Ed.), *7th RILEM International Conference on Cracking in Pavements* (pp. 453-463). Delft: RILEM Bookseries, Springer.

Makowska et al. , paper submitted for EATA 2017

The areas for which G-R parameter after construction was inside Insufficient Ductility Zone region had transverse cracking and ravelling <u>within a year</u>

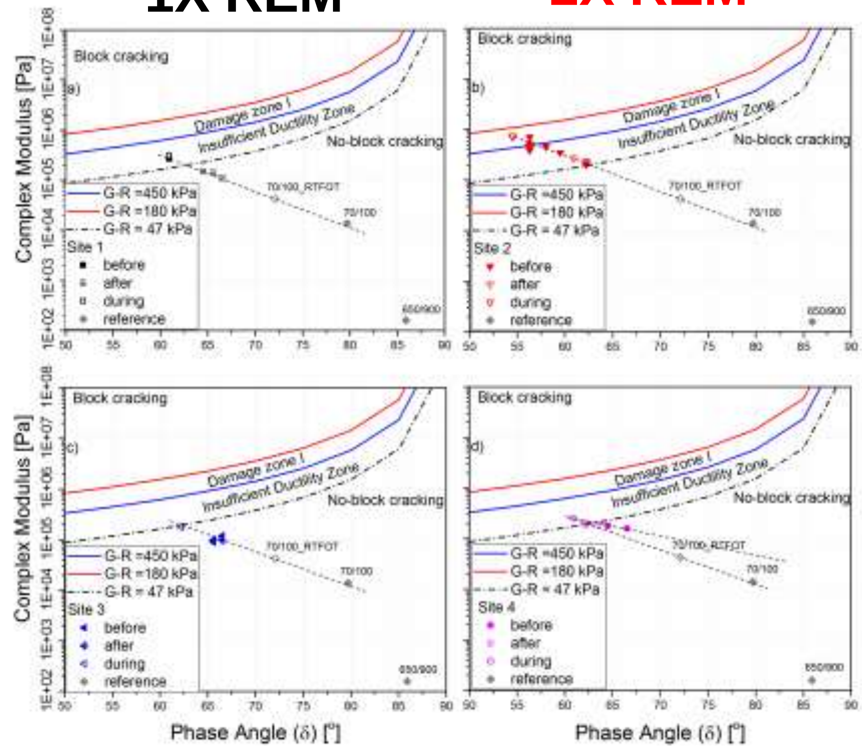
G-R parameter:

$$G'/(\frac{\eta'}{G'}) = G\ x\ ((\cos\delta)^2/\sin\delta)\ x\ \omega$$

G* and δ at T = 15 °C and ω = 0,005 rad/s

1X REM

2X REM



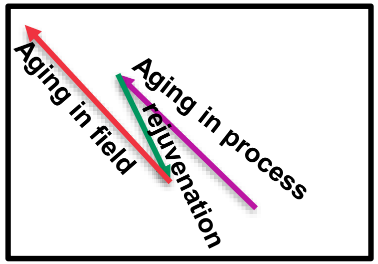
3X REM

1X REM

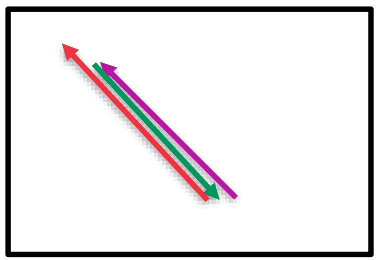
Paper submitted and accepted for EATA 2017

How can we use the damage zone and Insufficient Ductility Zone in the future?

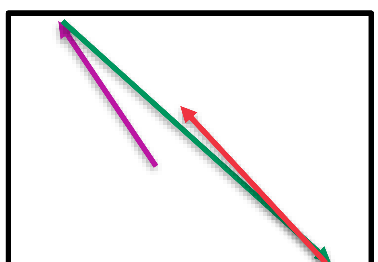
Damage in maintenance

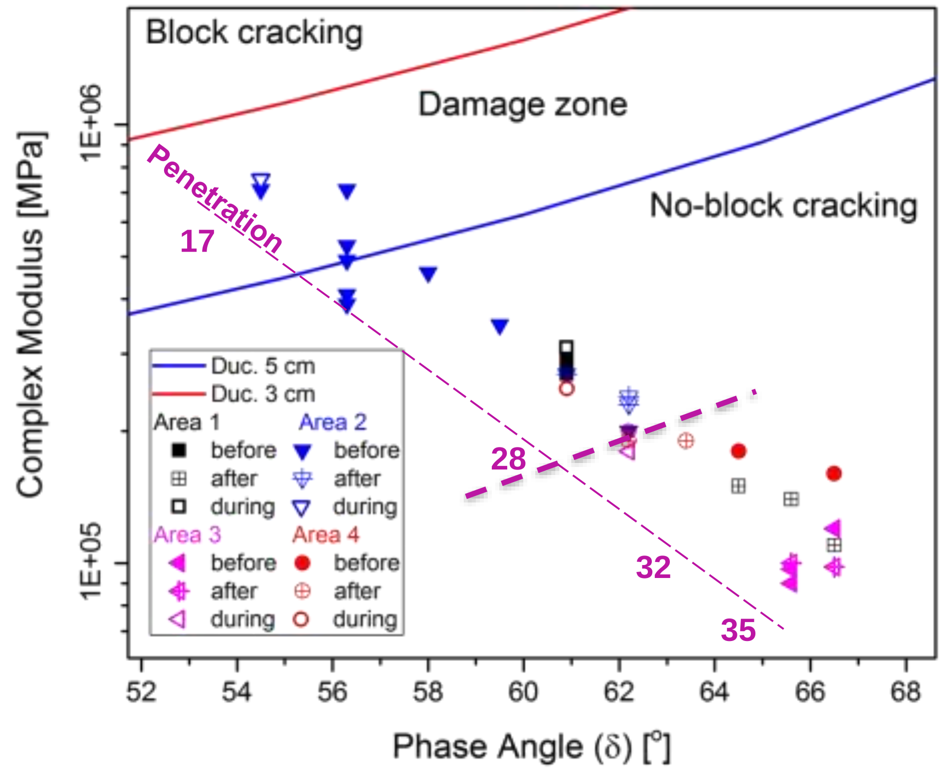


Maintenance



Rehabilitation





Corresponds rather well with Penetration
Damage Zone – Pen 22
Insufficient Ductility Zone – Pen 28

G-R parameter corresponds well with Penetration (<u>at the moment</u>)

Damage Zone – Pen 22

- Below this value: ravelling, cracking, pot holes are observed

Insufficient Ductility Zone – Pen 28

- Below this value: ravelling, cracking, pot holes - developing <u>within a year!</u>

Good performance – Pen 32

<u>Potential to use it as a varranty requirement.</u>

<u>Suggested evaluation with existing data about failed construction sites for comparison</u>

Before more data is gathered suggestion is to follow the normal bitumen QC

Retained Penetration requirement – <u>the suggested minimum</u>

Penetration of 70 dmm after RTFOT 46% → Pen 32 dmm

Penetration of bitumen 50/70 – 50% → Pen 25 dmm ??

Penetration of bitumen 160/200 – 39% → Pen 59 dmm

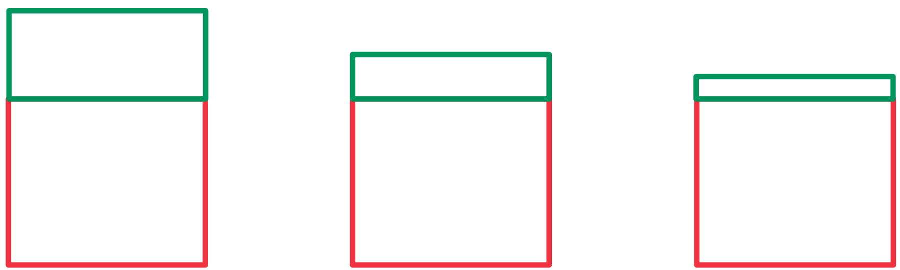
→ Requires a knowledge of the grade of the original bitumen

Aalto University
School of Engineering

Rules of rejuvenation

The use of the soft rejuvenators is limited due to previous research

- In the past the researchers used a known concentration per weight of bitumen, e.g 5% rejuvenator or fixed amount of rejuvenator per m2 or 100 kg, e.g. 200 g/m2



- We postulate that the aim should be to compare mechanical response at the equiviscous state of bitumen

But soft bitumens are hard to measure Penetration and oil rejuvenators do not have G* or Pen

The Penetration based equation would limit the rejuvenators to only bitumen based materials

The viscosity based blending equation was used to determine the ratios of bitumen and rejuvenator to obtain equiviscous mixture

$$(a+b)*lg(lg(visc_{mix})) = a*lg(lg(visc_1)) + b*lg\,(lg(visc_2))$$

How to measure the viscosity at 25°C for aged bitumen?

Bitumens →DSR→ G*→
Rejuvenators→DSR→ viscosity

Because the phase angle for tested materials was different than 90°, meaning partially elastic, we used a conversion equation from Pellinen et al. (2007)

$$\eta = \frac{|G^*|}{\omega}\left(\frac{1}{\sin\delta}\right)^{a_0+a_1\omega+a_2\omega^2}$$

where:

η = apparent Newtonian viscosity, in Pas;
G^* = binder complex shear modulus, in Pa;
ω = angular frequency, in radians/sec;

δ = phase angle in radians;
a_0, a_1, a_2 = fitting parameters
(for combined dataset of unmodified and modified binders a_0 = 3.639216, a_1 = 0.131373, a_2 = -0.000901).

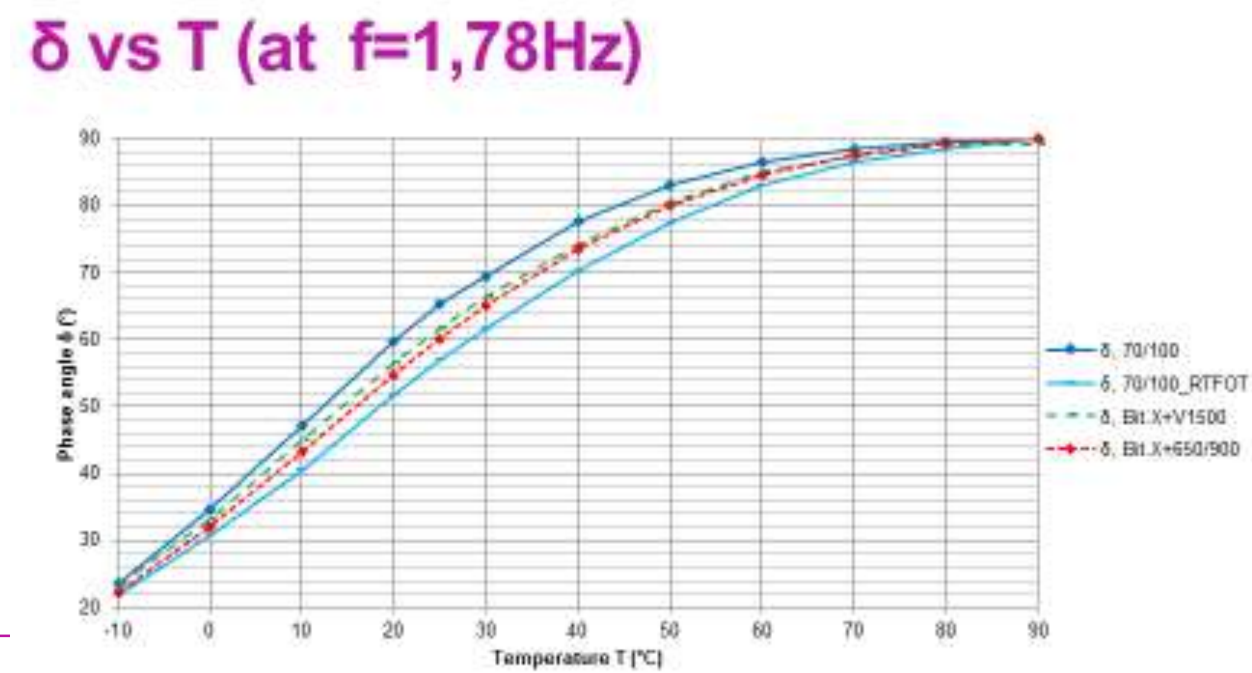
Test drive in the laboratory

Bitumen	Rejuvenator amount [%]	Penetration measured [dmm]	Penetration predicted from G*	G* at 1,78 Hz and 25°C [Pa]	Phase angle [°]	G*/sind=1 kPa
B50	-	53		n/a	n/a	
B50+B800	7,12	61	56	$9{,}73 \cdot 10^{-5}$	60,19	69
B50+V1500	4,68	61	64	$8{,}09 \cdot 10^{-5}$	61,69	67
B50+R1	2,11	*72*				
B50+R2	2,44	65				

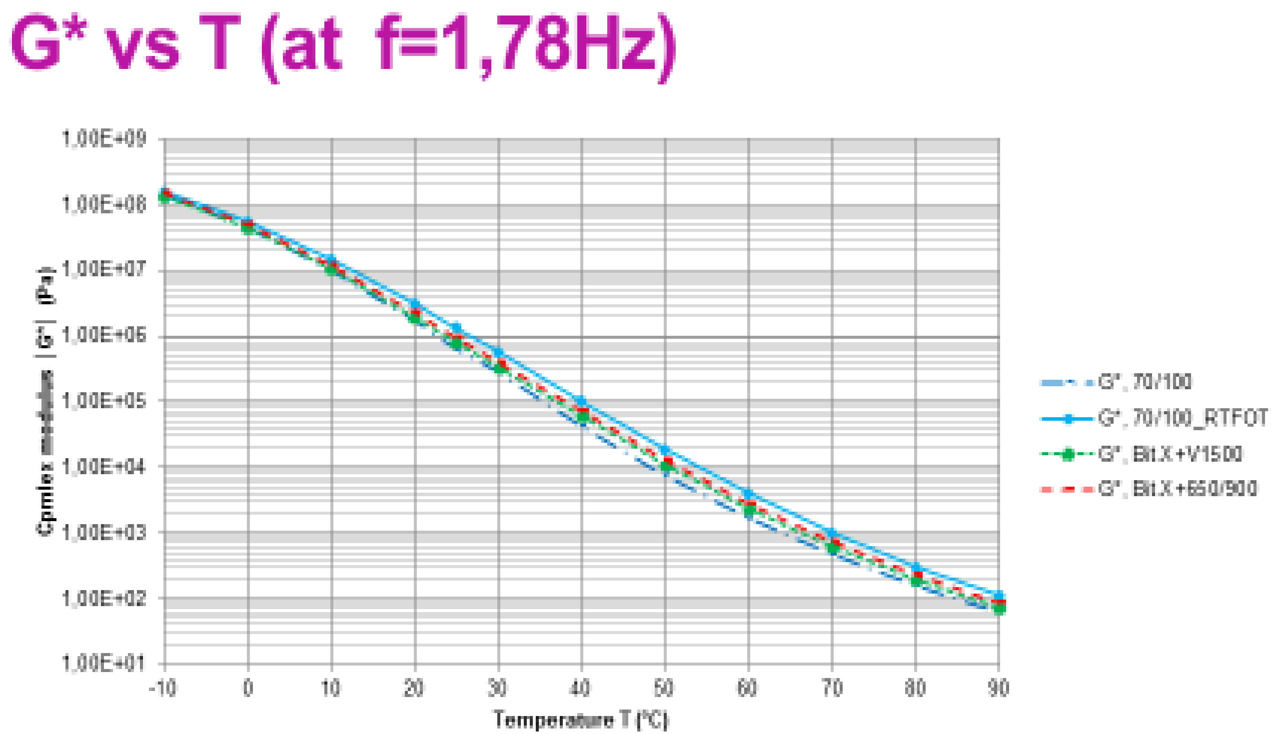
Equiviscous at 25 deg C

Small overflow of rejuvenator = big impact

Phase angle at temperatures is very close for both blends, with being closer to the original by using V1500



Again by using the V1500 it seems that the curve is beneath the curve of blend with 650/900



Aalto University
School of Engineering

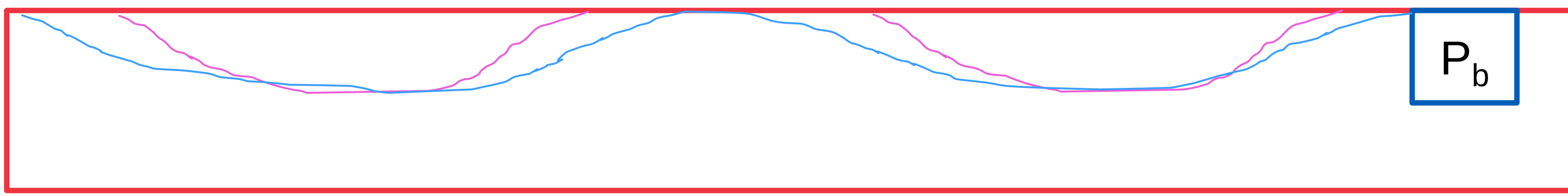
The creep is not an issue when the amount of rejuvenator is controlled

Area 4 +	Max. density	Air voids (SSD) [target 2%]	Creep [%]	
No rejuvenator	2,439	1,7	0,511	
V1500	2,430	1,4	0,440	
R1	2,435	1,3	0,230	
R2	2,434	1,7	0,537	

The complex issue of controlling the viscosity of bitumen during the hot in-place recycling

When RAP + admixture + rejuvenator → in plant → simple

Parameters : bitumen content (RAP and admixture), Penetration of RAP and virgin and rejuvenator



When RAP(surface) + admixture + rejuvenator → in-place → complex

Parameters: bitumen content (RAP and admixture), Penetration of RAP and virgin and rejuvenator**, <u>volume of rut</u>, density of the pavement, density of the admixture**

Calculations for one Penetration of bitumen in aged pavement + 650/900

	Pen of old	volume of layer to be remixed/depth of remix	rut depth	volume of rut	effective mass	Pbold	Density of old pavement [maximum]	bitumen type in admixture	Pb ad	maximum density of admix	Admixture amount	minimum admixture to refil the rut	Type of rejuvenator	Rejuvenator amount [kg/M2]	calc pen	Result B800	Target 70/100 RTFOT (40Pen)	Target name
3	16	0,04	16	0,008	76,8	5,8	2400	70/100	5,4	2400	159,1016	19,2	650/899	0,25	40,46	0,943502	0,942588	70/100 RTFOT
4	16	0,04	16	0,008	76,8	6	2400	70/100	5,4	2400	165,7341	19,2	650/900	0,25	40,45	0,94346	0,942588	70/100 RTFOT
5	16	0,04	16	0,008	76,8	6,2	2400	70/100	5,4	2400	172,3636	19,2	650/900	0,25	40,45	0,943421	0,942588	70/100 RTFOT
6	16	0,04	16	0,008	76,8	6,4	2400	70/100	5,4	2400	178,9842	19,2	650/900	0,25	40,44	0,943386	0,942588	70/100 RTFOT
7	16	0,04	16	0,008	76,8	6,6	2400	70/100	5,4	2400	185,5968	19,2	650/900	0,25	40,44	0,943354	0,942588	70/100 RTFOT
8	16	0,04	16	0,008	76,8	6,8	2400	70/100	5,4	2400	192,2025	19,2	650/900	0,25	40,44	0,943325	0,942588	70/100 RTFOT
9	16	0,04	16	0,008	76,8	7	2400	70/100	5,4	2400	198,8017	19,2	650/900	0,25	40,43	0,943298	0,942588	70/100 RTFOT
10	16	0,04	25	0,0125	66	5,8	2400	70/100	5,4	2400	141,6161	30	650/899	0,25	41,18	0,942395	0,942588	70/100 RTFOT
11	16	0,04	25	0,0125	66	6	2400	70/100	5,4	2400	144,802	30	650/900	0,25	40,98	0,942717	0,942588	70/100 RTFOT
12	16	0,04	25	0,0125	66	6,2	2400	70/100	5,4	2400	145,8932	30	650/900	0,25	40,64	0,943293	0,942588	70/100 RTFOT
13	16	0,04	25	0,0125	66	6,4	2400	70/100	5,4	2400	150,8581	30	650/900	0,25	40,58	0,943354	0,942588	70/100 RTFOT
14	16	0,04	25	0,0125	66	6,6	2400	70/100	5,4	2400	155,7945	30	650/900	0,25	40,52	0,943414	0,942588	70/100 RTFOT
15	16	0,04	25	0,0125	66	6,8	2400	70/100	5,4	2400	160,552	30	650/900	0,25	40,46	0,943492	0,942588	70/100 RTFOT
16	16	0,04	25	0,0125	66	7	2400	70/100	5,4	2400	172,844	30	650/900	0,25	40,85	0,942713	0,942588	70/100 RTFOT
17	16	0,04	16	0,008	76,8	5,8	2400	70/100	5,8	2400	148,1274	19,2	650/899	0,25	40,46	0,943502	0,942588	70/100 RTFOT
18	16	0,04	16	0,008	76,8	6	2400	70/100	5,8	2400	154,3067	19,2	650/900	0,25	40,45	0,943459	0,942588	70/100 RTFOT
19	16	0,04	16	0,008	76,8	6,2	2400	70/100	5,8	2400	160,4769	19,2	650/900	0,25	40,45	0,943421	0,942588	70/100 RTFOT
20	16	0,04	16	0,008	76,8	6,4	2400	70/100	5,8	2400	166,6389	19,2	650/900	0,25	40,44	0,943386	0,942588	70/100 RTFOT
21	16	0,04	16	0,008	76,8	6,6	2400	70/100	5,8	2400	172,7937	19,2	650/900	0,25	40,44	0,943355	0,942588	70/100 RTFOT
22	16	0,04	16	0,008	76,8	6,8	2400	70/100	5,8	2400	178,9419	19,2	650/900	0,25	40,44	0,943326	0,942588	70/100 RTFOT
23	16	0,04	16	0,008	76,8	7	2400	70/100	5,8	2400	185,0843	19,2	650/900	0,25	40,43	0,943299	0,942588	70/100 RTFOT

Less fresh is needed for deeper rut

The density determines ”how much bitumen at 4 cm”, the rut ”how much is not”

The effect of Penetration, rejuvenator, admixture – when same final target

2		Pen of old	volume of layer to be remixed/depth of remix	rut depth	volume of rut*	effective mass of pavement/m2	P_{bold}	Density of old pavement[maximum]	bitumen type in admixture	max density of admixture	Pb ad	Admixture amount to reach target [kg]	minimum amount of admixture to refil the rut	Type of rejuvenator	Rejuvenator amount [kg/M2]	Result V1500	Target 70/100 RTFOT	Target
3	70/100	16	0,04	16	0,008	76,8	5,8	2400	70/100	2400	5,4	140,8	19,2	v1500	0,25	0,94357	0,94259	70/100 RTFOT
4	admixture	16	0,04	16	0,008	76,8	6	2400	70/100	2400	5,4	148,4	19,2	v1500	0,25	0,9434	0,94259	70/100 RTFOT
5		16	0,04	16	0,008	76,8	6,2	2400	70/100	2400	5,4	155,7	19,2	v1500	0,25	0,94328	0,94259	70/100 RTFOT
6		16	0,04	16	0,008	76,8	6,4	2400	70/100	2400	5,4	163,0	19,2	v1500	0,25	0,94317	0,94259	70/100 RTFOT
7		16	0,04	16	0,008	76,8	6,6	2400	70/100	2400	5,4	170,2	19,2	v1500	0,25	0,94308	0,94259	70/100 RTFOT
8		16	0,04	16	0,008	76,8	6,8	2400	70/100	2400	5,4	177,4	19,2	v1500	0,25	0,943	0,94259	70/100 RTFOT
9		16	0,04	16	0,008	76,8	7	2400	70/100	2400	5,4	184,4	19,2	v1500	0,25	0,94294	0,94259	70/100 RTFOT
17	70/100	25	0,04	16	0,008	76,8	5,8	2400	70/100	2400	5,4	82,3	19,2	v1500	0,25	0,94287	0,94259	70/100 RTFOT
18	admixture	25	0,04	16	0,008	76,8	6	2400	70/100	2400	5,4	85,6	19,2	v1500	0,25	0,94303	0,94259	70/100 RTFOT
19		25	0,04	16	0,008	76,8	6,2	2400	70/100	2400	5,4	88,8	19,2	v1500	0,25	0,9432	0,94259	70/100 RTFOT
20		25	0,04	16	0,008	76,8	6,4	2400	70/100	2400	5,4	91,8	19,2	v1500	0,25	0,94338	0,94259	70/100 RTFOT
21		25	0,04	16	0,008	76,8	6,6	2400	70/100	2400	5,4	94,8	19,2	v1500	0,25	0,94356	0,94259	70/100 RTFOT
22		25	0,04	16	0,008	76,8	6,8	2400	70/100	2400	5,4	104,4	19,2	v1500	0,25	0,94275	0,94259	70/100 RTFOT
23		25	0,04	16	0,008	76,8	7	2400	70/100	2400	5,4	108,4	19,2	v1500	0,25	0,9428	0,94259	70/100 RTFOT
24	100/150	25	0,04	16	0,008	76,8	5,8	2400	70/100	2400	5,4	54,1	19,2	v1500	0,25	0,94269	0,94259	70/100 RTFOT
25	admixture	25	0,04	16	0,008	76,8	6	2400	70/100	2400	5,4	56,5	19,2	v1500	0,25	0,94281	0,94259	70/100 RTFOT
26		25	0,04	16	0,008	76,8	6,2	2400	70/100	2400	5,4	58,9	19,2	v1500	0,25	0,94294	0,94259	70/100 RTFOT
27		25	0,04	16	0,008	76,8	6,4	2400	70/100	2400	5,4	61,2	19,2	v1500	0,25	0,94308	0,94259	70/100 RTFOT
28		25	0,04	16	0,008	76,8	6,6	2400	70/100	2400	5,4	63,4	19,2	v1500	0,25	0,94322	0,94259	70/100 RTFOT
29		25	0,04	16	0,008	76,8	6,8	2400	70/100	2400	5,4	65,6	19,2	v1500	0,25	0,94338	0,94259	70/100 RTFOT
30		25	0,04	16	0,008	76,8	7	2400	70/100	2400	5,4	67,7	19,2	v1500	0,25	0,94353	0,94259	70/100 RTFOT
31	**50/70**	37	0,04	16	0,008	76,8	5,8	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91709	0,94259	70/100 RTFOT
32	admixture	37	0,04	16	0,008	76,8	6	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,917	0,94259	70/100 RTFOT
33		37	0,04	16	0,008	76,8	6,2	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91693	0,94259	70/100 RTFOT
34		37	0,04	16	0,008	76,8	6,4	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91686	0,94259	70/100 RTFOT
35		37	0,04	16	0,008	76,8	6,6	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91679	0,94259	70/100 RTFOT
36		37	0,04	16	0,008	76,8	6,8	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91672	0,94259	70/100 RTFOT
37		37	0,04	16	0,008	76,8	7	2400	70/100	2400	5,4	19,2	19,2	v1500	0	0,91666	0,94259	70/100 RTFOT

Rut refill is enough to reach target for pavements close to target

Calculations for one Penetration of bitumen in aged pavement + V1500 (density change)

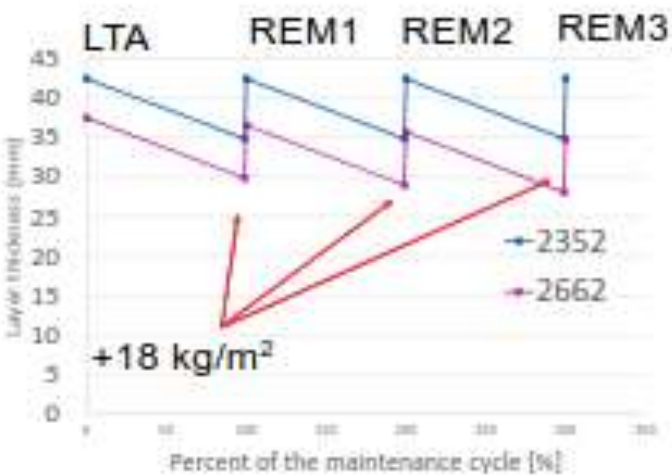
2	Pen of old	volume of layer to be remixed/depth of remix	rut depth	volume of rut	effective mass	Pbold	Density of old pavement [maximum]	bitumen type in admixture	Pb ad	maximum density of admix	Admixture amount	minimum admixture to refil the rut	Type of rejuvenator	Rejuvenator amount [kg/M2]	calc pen	Result B800	Target 70/100 RTFOT (40Pen)	Target name
3	16	0,04	16	0,008	76,8	5,8	2400	70/100	5,4	2400	159,1016	19,2	650/899	0,25	40,46	0,943502	0,942588	70/100 RTFOT
4	16	0,04	16	0,008	76,8	6	2400	70/100	5,4	2400	165,7341	19,2	650/900	0,25	40,45	0,94346	0,942588	70/100 RTFOT
5	16	0,04	16	0,008	76,8	6,2	2400	70/100	5,4	2400	172,3636	19,2	650/900	0,25	40,45	0,943421	0,942588	70/100 RTFOT
6	16	0,04	16	0,008	76,8	6,4	2400	70/100	5,4	2400	178,9842	19,2	650/900	0,25	40,44	0,943386	0,942588	70/100 RTFOT
7	16	0,04	16	0,008	76,8	6,6	2400	70/100	5,4	2400	185,5968	19,2	650/900	0,25	40,44	0,943354	0,942588	70/100 RTFOT
8	16	0,04	16	0,008	76,8	6,8	2400	70/100	5,4	2400	192,2025	19,2	650/900	0,25	40,44	0,943325	0,942588	70/100 RTFOT
9	16	0,04	16	0,008	76,8	7	2400	70/100	5,4	2400	198,8017	19,2	650/900	0,25	40,43	0,943298	0,942588	70/100 RTFOT
31	16	0,04	16	0,008	86,4	5,8	2700	70/100	5,4	2700	183,1234	21,6	650/900	0,25	40,44	0,943365	0,942588	70/100 RTFOT
32	16	0,04	16	0,008	86,4	6	2700	70/100	5,4	2700	190,5593	21,6	650/900	0,25	40,44	0,943331	0,942588	70/100 RTFOT
33	16	0,04	16	0,008	86,4	6,2	2700	70/100	5,4	2700	197,9749	21,6	650/900	0,25	40,43	0,943302	0,942588	70/100 RTFOT
34	16	0,04	16	0,008	86,4	6,4	2700	70/100	5,4	2700	205,3952	21,6	650/900	0,25	40,43	0,943274	0,942588	70/100 RTFOT
35	16	0,04	16	0,008	86,4	6,6	2700	70/100	5,4	2700	212,8087	21,6	650/900	0,25	40,42	0,943248	0,942588	70/100 RTFOT
36	16	0,04	16	0,008	86,4	6,8	2700	70/100	5,4	2700	220,2163	21,6	650/900	0,25	40,42	0,943225	0,942588	70/100 RTFOT
37	16	0,04	16	0,008	86,4	7	2700	70/100	5,4	2700	227,6184	21,6	650/900	0,25	40,41	0,943203	0,942588	70/100 RTFOT

Dense pavements require more admixture – because more old bitumen in same volume of 4 cm layer!

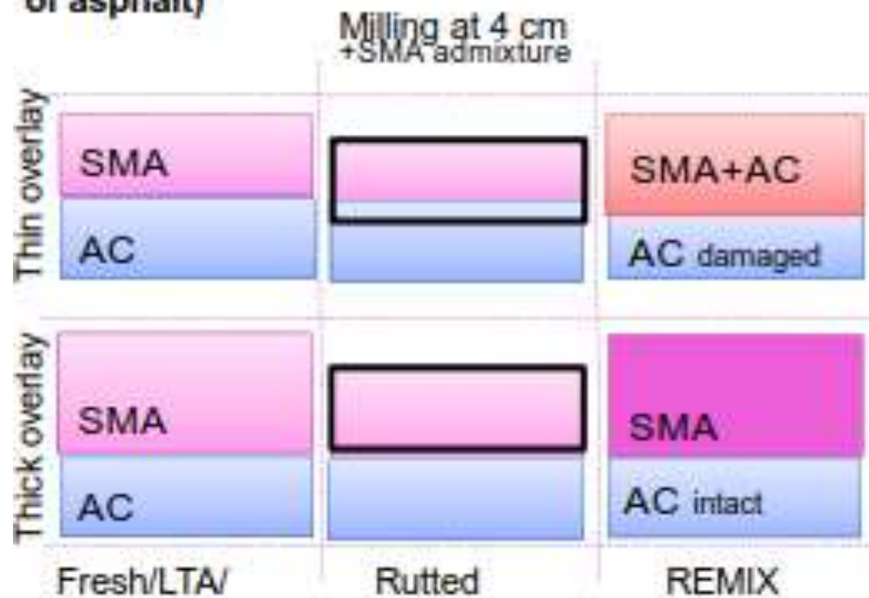
Issues with density

1. **Effective thickness of layer (maximum density of asphalt)**

Current procurement of 100 kg/m² :
At 2400 kg/m³ at 2% air voids (2352 kg/m³)
At 2717 kg/m3 at 2% air voids (2662 kg/m³)



2. **Transfer of base courses into the wearing course due to too thin overlay (maximum density of asphalt)**



Suggestions from steering board

- **Learning how to use such spread sheet on workshops during spring time**

- **Additional information from PTM → volume of rut**
  - At the moment we have depth but not width of it
  - allows to calculate the exact need for admixture
  - Allows to estimate the rejuvenator amount

Aalto University
School of Engineering

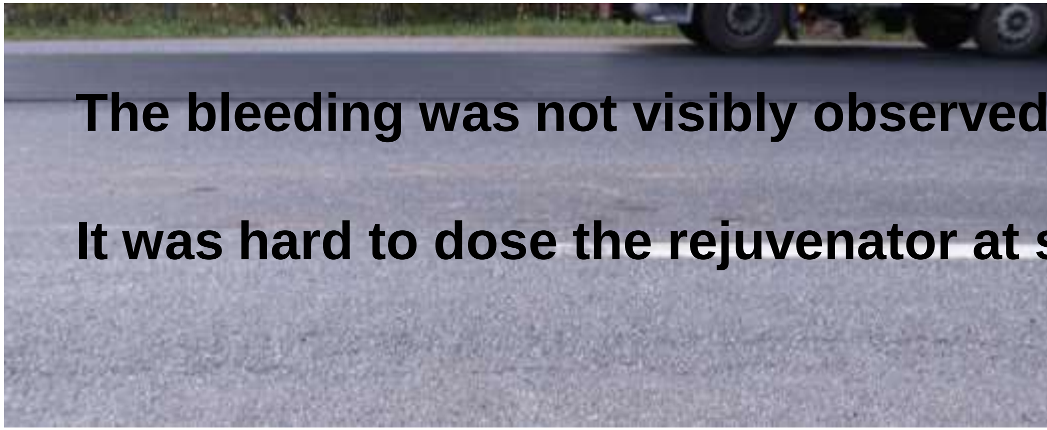
Test sites 2016

Participants

- **5 contractors and 5-6 roads**
- **4 visits to the construction site**
- **4 thermal profile follow-ups**
- **1 test on homogenity due to the speed of REM (4 vs. 8 m/min)**
- **1 test on use of V1500 in place of 650/900**
- **Different heaters (oil and gas)**

- **… sampling and processing afterwards is still ongoing**

No complications were recorded during the construction with rejuvenator v1500




The bleeding was not visibly observed

It was hard to dose the rejuvenator at such small levels (40 is minimum)

The contractor calculated that volumetrically above 130 g /m2 of rejuvenator 650/900 bleeding could be a problem

→ 65 g /m2 of V1500 would result in equiviscous bitumen but allow lower voids filled with bitumen

→ So 65 g/m2 was set as the maximum to be used

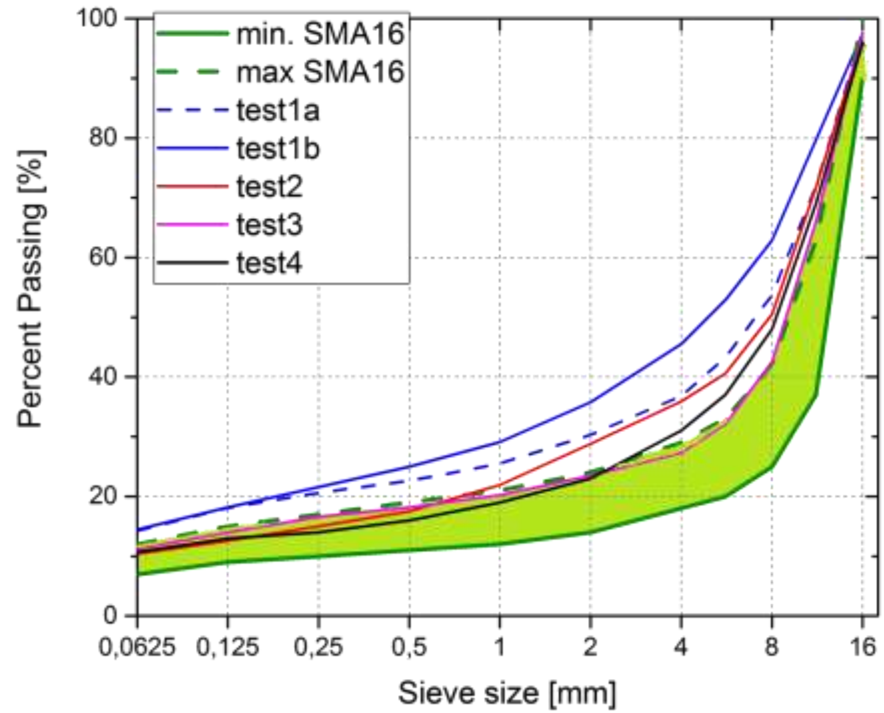
Aggregate gradation and mineralogy

VT1 – the gradation before and after – <u>small difference</u>

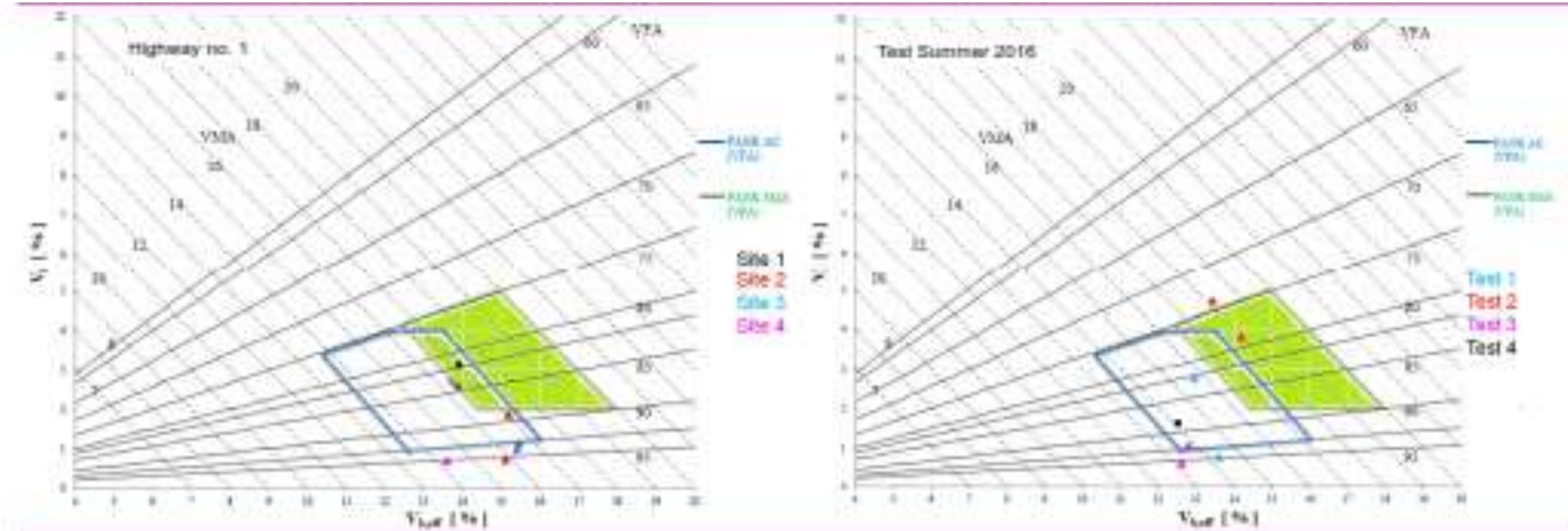
- Hypothesis of REM process crushing the rocks significantly - rejected
- But layer thickness was > 45 mm

Other VTs in 2016 – could not be classified as SMA

- + Layer thickness <40 mm



The volumetric range was more consistant with AC pavements than SMA



The majority of the SMA16 pavements were not in the volumetric range of SMA16.

The density is variable and because of that 100 kg/m^2 is not 4 cm → are we analysing the layer beneath surface?

	Test 1	Test 2	Test 3	Test 4	Test 5
Max. density	2,450	2,717	2,790	2,631	2,421

Aalto University
School of Engineering

Conclusions

Simple suggestions to improve the success rates

1. Too many simplifications in the past
2. A shift from LTA(100 kg) → LTA(4cm) is necessary
3. The minimum bitumen QC requirements are necessary and suggested (use either G-R parameter or Penetration)
4. As the infrastructure ages, the rules of rejuvenation developed for bitumen 100/150 do not apply and rules of rejuvenation and admixture amount choice are proposed
5. Rejuvenation target should be in line with the traffic levels of the road (e.g. low volume road should have a higher end Penetration than Highways)

Simple suggestions to improve the success rates

5. **Use of V graded bitumens is acceptable but needs a design step and care during the construction**
6. **V grade bitumens are suggested for very aged bitumens and mixes prone to bleeding (SMA?)**
7. **Planning and execution of REM works should involve rut depth/volume analysis**
8. **Improved heating control for better rejuvenation**