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The changes as a result of REMIX part of the project

REMIX- päällysteiden kehittäminen - tuloksia suunnittelun ja toteutuksen avuksi

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Selection of targets

The goal is to unify the properties of the pavements in Finland

1. The low volume vs. the high volume mix (AC vs. SMA)
2. The low volume vs. the high volume road aggregate (class IV vs. I)
3. <u>The low volume vs. the high volume road bitumen (160/220 vs. 70/100)</u>

Introduction of minimum Pen/maximum viscosity at 25 ° C on the new pavement in line with the similar overlay pavements

RHEOLOGICAL TARGETS!!!!

Why? Resistance to cold temperature and brittleness is a function of the rheological properties of the binder

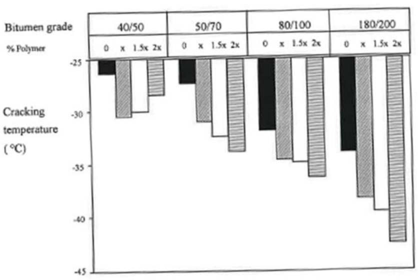
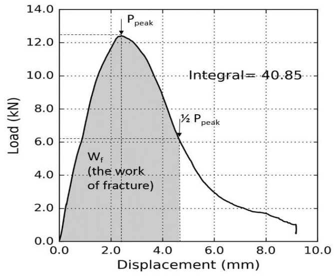
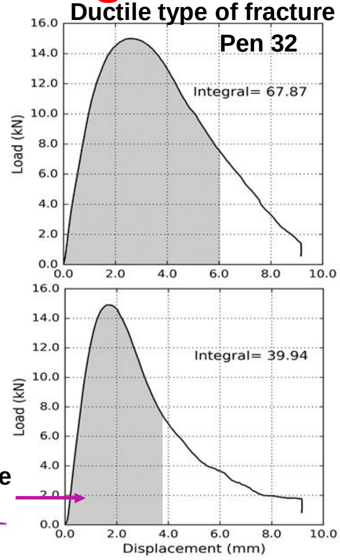


Figure 3.5 Theoretical cracking temperature for 4 grades of bitumen and 3 polymer levels [30].

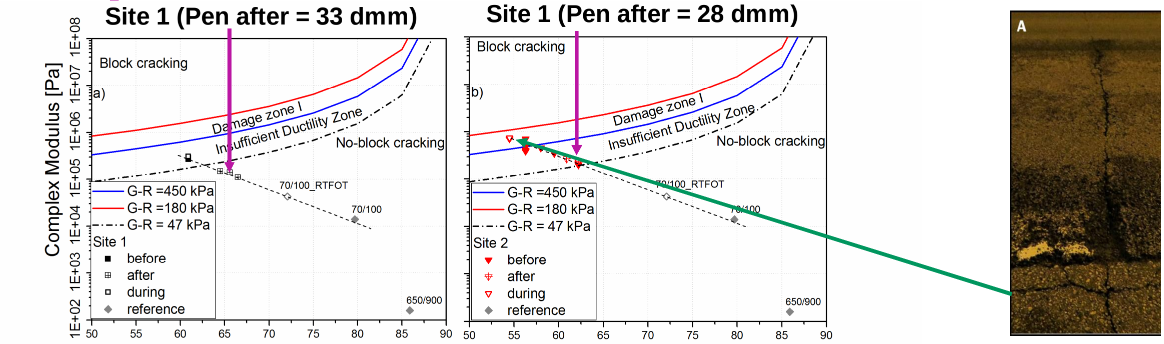
Huayang Zheng
"On the low temeprature cracking of asphalt pavements", Doctoral Dissertation, Stockholm 1995



Brittle type of fracture
Pen 28



Recycling of pavements – linked performance to rheology of binder after the process



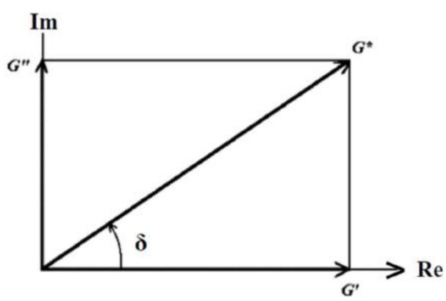
Frequency of <u>0,01 Hz</u> and T=15 ° C – NO TRAFFIC, Temperature induced damage

Makowska M., Aromaa K., Pellinen T., "The rheological transformation of bitumen during the recycling of repetitively aged asphalt pavement", EATA2017, Zurich, Switzerland, 12-14 June 2017, Road Materials and Pavement Design, Volume 18, 2017, Issue sup2: EATA 2017, pp. 50-65. DOI: 10.1080/14680629.2017.130426

Why Phase angle?

Cross-over point 45 °

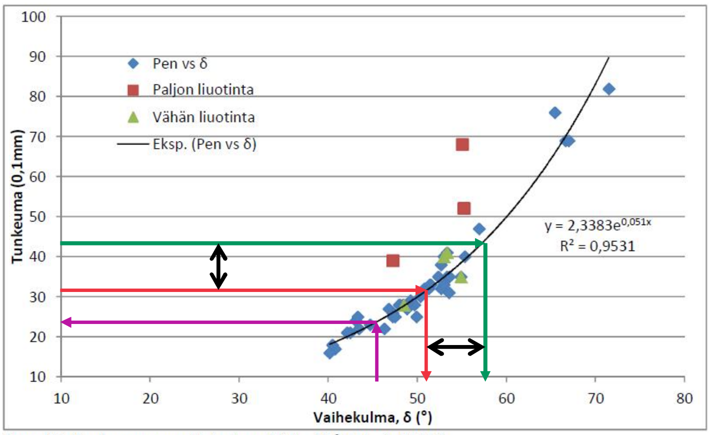
Viscous behavior
Phase angle = 90 °
Material changes shape and relaxes under stress



Elastic behavior
Phase angle = 0 °
Material elongates and breaks

Kuva 7. Kompleksimoduulin vektoriesitys kompleksitasossa: varastomoduuli (G') eli reaalinen osa x-akselilla, häviömoduuli (G'') eli imaginäärinen osa y-akselilla sekä vaihekulma δ.

The material needs to have viscous response in order to heal the cracks



Kuva 56. Tunkeuma vs. vaihekulma, δ (T = 25 °C, f = 1,78 Hz).

Dominant elastic behavior at 25 ° C and above 90 km/h

Suggested minimum viscous behavior for 3-4 years at high traffic volume (Pen 32 dmm, G-R> 47 kPa)

Typical fresh overlay properties 5-6 years viscous behavior

↔ OK performance

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Aromaa, Kalle, diplomityö (2016)
Bitumin vanhenemisen ja elvyttämisen vaikutukset sen reologisiin ominaisuuksiin

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Select targets for bitumen rheology

If an **alternative is an overlay** (LTA) **with 70/100** à choose "Jännostunkeuma" region as the lowest target, and "Tunkeuma" as the highest target.

	Unit	50/70	70/100	100/150	160/220
Penetration (**Tunkeuma**)	0,1 mm	50-70	70-100	100-150	160-220
Residual Penetration after RTFOT (**Jännostunkeuma**)	%	>50	>46	>43	>37
(**Jännostunkeuma**)	0,1 mm	25-35	**32**-46	43-64	59-81
Jännostunkeuma above middle of range	0,1 mm	**31**	**40**	**54**	**71**

Considers aging during pavement reheating

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These values are calculated using percent of residual penetration (jäännöstunkeuma) given in Table 52 in Asfalttinormit 2017.

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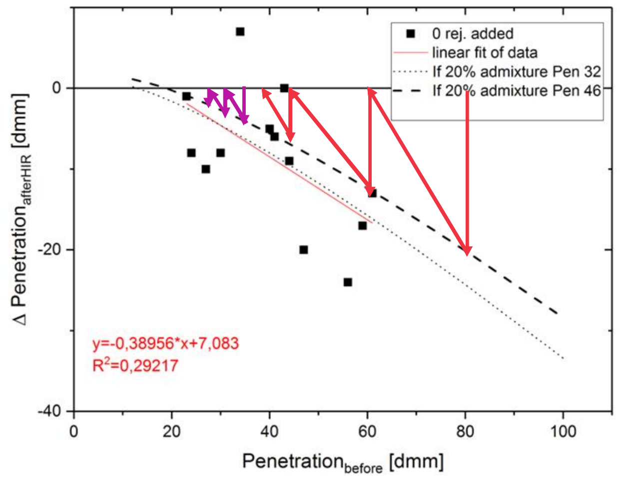
The drop in Penetration due to the HIR process



When we add admixture of Pen 32 to pavement of Pen 80 we ”AGE” the pavement

We know that low traffic pavement are more affected by REMIX than high traffic
- Highest alteration to bitumen properties

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About the Apparent Newtonian Viscosity (ANV) used in a very old equation

$$loglog(visc_{target}) = a * loglog(visc_{aged}) + b * loglog(visc_{admix}) + c * loglog(visc_{rej})$$

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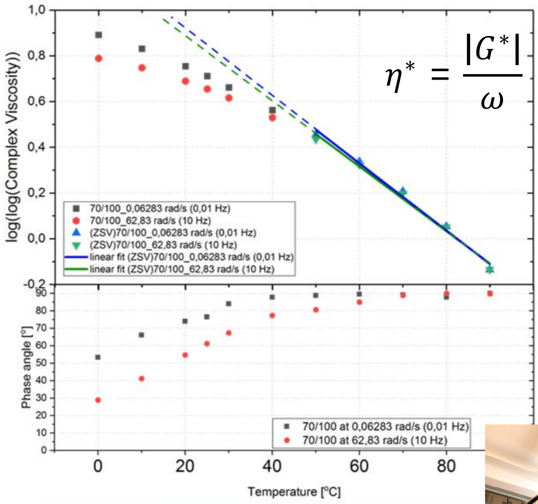
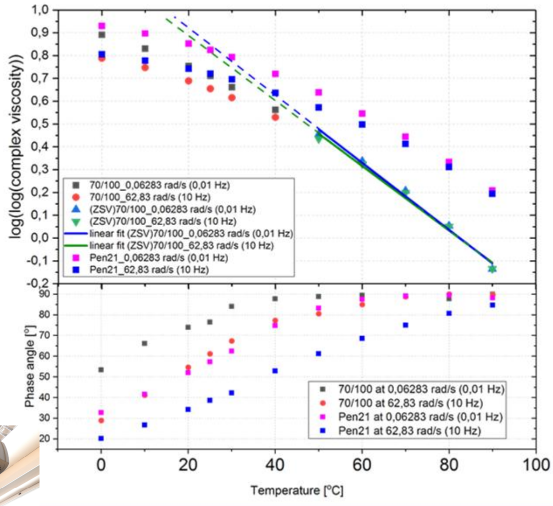
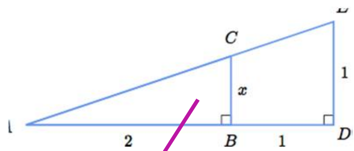
Complex Viscosity is Zero Shear Viscosity in viscous state (phase angle = 90 °)

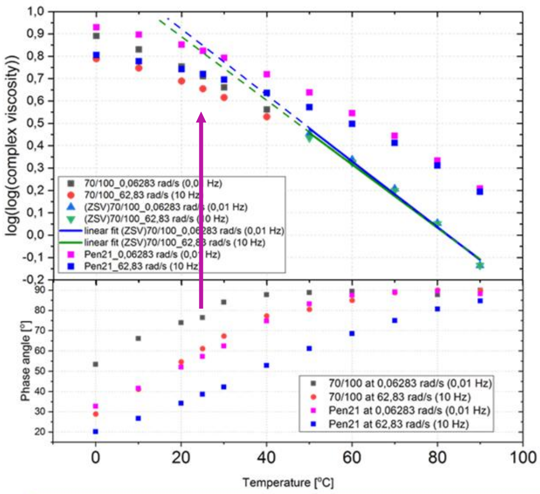


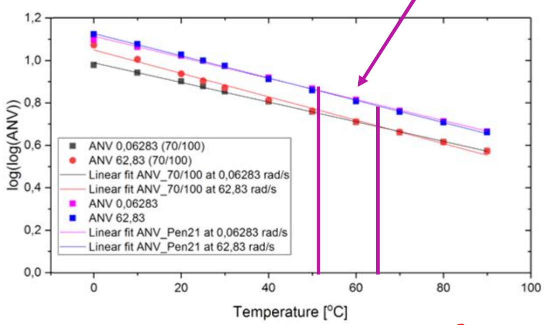
$$\eta^* = \frac{|G^*|}{\omega}$$



Correcting the Complex Viscosity by phase angle







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

Result of blending ratio should be the same at every temperature due to the proportion

Bonaquist, Pellinen, Witczak,
Development of Relationship between Binder Viscosity and Stiffness,
Dep, of Civil Eng. University of Maryland, 1998.

Apparent Newtonian viscosity corrected with frequency and phase angle

DSR allows us to measure complex viscosity (Cox-Merz rule)

$$\eta^* = \frac{|G^*|}{\omega}$$

The correction:

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

where

η_{VTS} - viscosity from ASTM viscosity-temperature equation or apparent Newtonian viscosity

| G*| - measured shear modulus

δ – measured phase angle

ω – angular frequency used to measure G* and δ

a_0, a_1, a_2 – fitting parameters

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Bonaquist, Pellinen, Witczak,
Development of Relationship between Binder Viscosity and Stiffness,
Dep, of Civil Eng. University of Maryland, 1998.

Fitting parameters

Subset	Number of measurements	a_0	a_1	a_2	Coefficient of determination (R^2)
Non-modified tank	321	3.254765	0.109889	-0,000696	0.964
Modified tank	108	7.312996	0.062311	-0.000468	0.93
All	676	3.639216	0.131373	-0.000901	0.858

HUOM! THE MODIFIED BITUMEN IS NOT THE SUBJECT OF FOLLOWING STUDIES. THE RULES OF REJUVENATION WERE ESTABLISHED FOR NON-MODIFIED BITUMEN AT THE MOMENT.

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Bonaquist, Pellinen, Witczak,
Development of Relationship between Binder Viscosity and Stiffness,
Dep, of Civil Eng. University of Maryland, 1998.

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How to calculate?

Example

75 kg/m^2 aged pavement at Pb=5,8%
25 kg/m^2 admixture at Pb=5,8%

Rejuvenators considered in calculations:

650/900 (use of apparent Newtonian viscosity - using correction factors)
V1500 (measured rotational viscosity at 25 ° C)
Rej2 (measured rotational viscosity at 25 ° C)

Solution (for the used example)

$$loglog(visc_{target}) = a * loglog(visc_{aged}) + b * loglog(visc_{admix}) + c * loglog(visc_{rej})$$

$$\frac{b}{a} = \frac{m_{admix} * P_{b\_admix}}{m_{aged} * P_{b\_aged}} = \frac{25*5{,}8}{75*5{,}8} = \frac{1}{3}$$

$$b = \frac{m_{admix} * P_{b\_admix}}{m_{aged} * P_{b\_aged}} * \boldsymbol{a} = \frac{1}{3}a$$

$$c = 1 - a - b = 1 - 1\frac{1}{3}a$$

Solution (general)

$$a = \frac{loglog\eta_{target} - loglog\eta_{rejuv}}{loglog\eta_{aged} + \frac{m_{adm} * P_{b\_adm}}{m_{aged} * P_{b\_aged}}\left(loglog\eta_{adm} - loglog\eta_{rejuv}\right) - loglog\eta_{rejuv}}$$

η_{rejuv} - **rotational viscosity or ANV**

$\eta_{adm}, \eta_{aged}, \eta_{target}$- **apparent Newtonian viscosity (preferably 25 °** C; 0,01Hz)

Why this approach?

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Existing equations and problems

1. $Pen25°C_{blend} = 10^{\frac{A*\log(Pen25°C_{fresh})+B*\log(Pen25°C_{aged})+C*\log(Pen25°C_{rejuv})}{100}}$

2. $logG^*_{target} = a * logG^*_{aged} + b * logG^*_{adm} + c * logG^*_{rejuv}$

3. $loglog(visc_{target}) = a * loglog(visc_{aged}) + b * loglog(visc_{admix}) + c * loglog(visc_{rej})$

Example:
Aged bitumen Penetration 22 dmm
Admixture 70/100_RTFOT
Target: 70/100_RTFOT

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Penetration based equation

1. $$Pen25°C_{blend} = 10^{\frac{A*\log(Pen25°C_{fresh})+B*\log(Pen25°C_{aged})+C*\log(Pen25°C_{rejuv})}{100}}$$

V1500 and oil based rejuvenators are not having Penetration. Not applicable.

AND WE ASSUME PEN OF 650/900 !

	A [wt.%]	B[wt.%]	C[wt.%]
S22_800(1)	20,81	62,46	**16,73**
S22_V15(1)	-	-	-
S22_NY(1)	-	-	-

Complex modulus based equation

2. $$logG^*_{target} = a * logG^*_{aged} + b * logG^*_{adm} + c * logG^*_{rejuv}$$

V1500 can have G*, but same geometry in DSR can be used to measure rotational viscosity.

Oil based rejuvenators are not having G* - NOT APPLICABLE

Result depends on **Frequency** and **Temperature**

Use of this equation provides an average of 17,69% ± 2,83%.

	Temp.	Freq.	G^*_{aged}	G^*_{rej}	G^*_{adm}/ G^*_{target}	A	B	C
	°C	Hz	Pa	Pa	Pa	[wt.%]	[wt.%]	[wt.%]
S22_800(4)	10	0,1778	13880000	60330	4761000	63,36	21,12	15,52
	10	1,778	33160000	419800	14740000	64,05	21,35	14,59
	25	0,1778	1216000	1679	281700	61,77	20,59	17,64
	25	**1,778**	**4304000**	**14450**	**1328000**	**62,76**	**20,91**	**16,32**
	30	0,1778	482600	555	109200	61,93	20,64	17,42
	30	1,778	1956000	4992	576000	62,86	20,95	16,19
	60	0,1778	2288	7	446	58,03	19,34	22,63
	60	1,778	17600	66	3993	58,98	19,66	21,35
S22_V15(4)	-	-	-	-	-	-	-	-
S22_NY(4)	-	-	-	-	-	-	-	-

Viscosity based equation (Apparent Newtonian Viscosity + rotational)

3. $loglog(visc_{target}) = a * loglog(visc_{aged}) + b * loglog(visc_{admix}) + c * loglog(visc_{rej})$

Potentially applicable to all considered fluids – bitumen and oil based rejuvenators.

The best frequency-temperature couple 25 ° C- 0,0683 rad/s (0,01Hz), but low STD due to change of the T and f.

Calculated for 650/900

	Four Temperatures Three frequencies	Four Temperatures two frequencies	0,01 Hz, four Temperatures	0,1778 Hz, four temepratures	1,778 Hz, four temperatures
Average [%]	17,79	17,55	18,27	17,56	17,54
Stdev. [%]	0,74	0,72	0,54	0,83	0,66

Calculated for V1500

	Three Temperatures Three frequencies	Three Temperatures two frequencies	0,01 Hz, three Temperatures	0,1778 Hz, three temepratures	1,778 Hz, three temperatures
Average [%]	11,75	11,63	11,98	11,63	11,63
Stdev. [%]	1,14	1,15	1,18	1,33	1,07

Calculated for Rej2

	Three Temperatures Three frequencies	Three Temepratures two frequencies	0,01 Hz, two Temperatures	0,1778 Hz, two temepratures	1,778 Hz, three temperatures
Average [%]	5,23	5,17	5,38	5,16	5,18
Stdev. [%]	0,18	0,10	0,27	0,11	0,10

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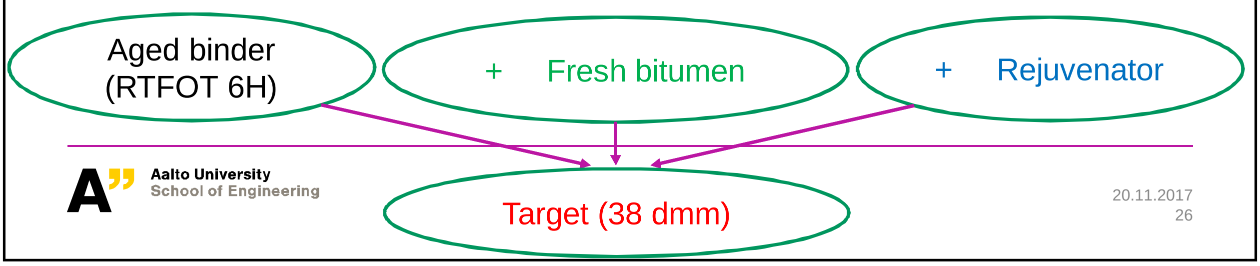
Experiments

The new bitumen was aged in laboratory with RTFOT to Target level (2h RTFOT) and Aged level (6h RTFOT)

Name	Temp [°C]	Angular frequency [rad/s]	Complex Modulus, |G*|	Phase Angle, δ	Complex Viscosity, η*	Shear Rate, dγ/dt	Pen [dmm]
650_900_2017_syys	25	0,06283	73	83,1	1159	6,28E-03	n/a
70/100_2017_6h_RTFOT	25	0,06283	255200	55,64	4062000	6,28E-04	22
70/100_2017_2h_RTFOT	25	0,06283	48120	68,35	765900	6,28E-04	38
70/100_2017_fresh	25	0,06283	8690	76,51	138300	6,28E-04	79



The results from the blends

Aged binder (RTFOT 6H) + Fresh bitumen + Rejuvenator

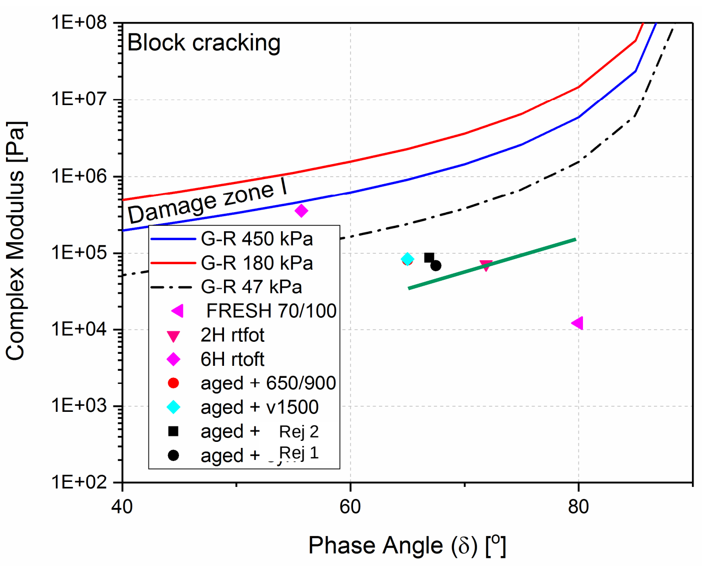
No.	Rejuvenator type	Viscosity type	Viscosity value used [mPa*s]	Rejuvenator [g/m²]	X_{aged}	X_{fresh}	$X_{rejuvenator}$
1	650/900	App. Newt.	1190528	320	0,6673	0,2224	0,1103
2	V1500	Rotational	126000	237	0,6908	0,2303	0,0790
3	Rej1	Rotational	48,2	89	0,7288	0,2429	0,0282
4	Rej2	Rotational	255	112	0,7233	0,2411	0,0356
5	Rej3	Rotational	3020	151	0,7134	0,2378	0,0488

No.	Rejuv. type	M_{aged} [g]	M_{fresh} [g]	M_{rej} [g]	Rejuvenator [g/m²]	X_{aged}	X_{fresh}	X_{rejuv}	Pen [dmm]	SP [°C]
1	650/900	75,1	25,01	12,4185	320	0,6674	0,2223	0,1103	**37**	**57,6**
2	V1500	74,97	24,98	8,6284	237	0,6904	0,2301	0,0795	**36**	**57,6**
3	Rej1	75,08	25,05	3,7175	89	0,7290	0,2426	0,0284	**39**	**56,6**
4	Rej2	74,78	24,88	2,9134	112	0,7230	0,2412	0,0358	**37**	**58,2**
5	Rej3	65,1	21,66	4,468	151	0,7136	0,2374	0,0490	51	53,4
target									**38**	**57,0**

Recovery outside of the damage zone and Insufficient Ductility Zone described by G-R

Next goal:
to target to a certain G-R

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



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