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FunDBitS
Functional Durability-related Bitumen Specification

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Permanent Deformation (rutting):
Correlations and recommendations for further bitumen testing

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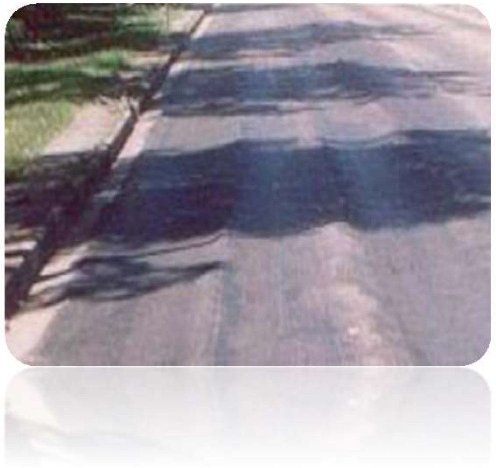
Introduction

- **Permanent deformation** *or* **rutting**
  Visco-plastic deformations in the asphalt layer caused by the repeated passage of heavy vehicles, particularly under low speed traffic and high temperature conditions



The higher the temperature → The greater the tendency to **rutting**

Test methods to assess both bitumen properties and asphalt behaviour to **permanent deformation** are typically conducted at elevated temperatures

Test methods to address bitumen properties and asphalt behaviour

- “Data form”

Binder properties

Elevated service temperature properties

Complex modulus	DSR	
	other	
Dynamic viscosity	Cone&Plate	
	Coaxial cylinders	
	Capillary viscosimeter	
	other	
Zero Shear Viscosity	Oscillation method	
	Creep method	
	other	
Softening point	R&B	x
Creep stiffness	Repeated Creep Test	
Compliance and recovery	MSCR test	
	Elastic recovery	x

Intermediate and/or low service temperature properties

Complex modulus	DSR	
	other	
Penetration	Penetration	x

Ageing/Wheathering

short term ageing	RTFOT	
	TFOT	
	RFT	
	other	
long term ageing	PAV	
	RCAT	
	Modified German RFT	
	Modified RTFOT	

State binder

Pure	
Modified	x
Unaged	x
Short term aged	
Long term aged	
Recovered	

Mixture properties

Elevated service temperature properties

Stiffness	Stiffness test	
Permanent deformation	Wheel tracking test	x
	Cyclic compression test	
	other	

Intermediate and/or low service temperature properties

Stiffness	Stiffness test	
Strength	Indirect tensile test	x
	Direct tensile test	
	other	
Low temperature cracking	Thermal stress restrained specimen test	
	Crack propagation test	
	other	
Fatigue cracking	Fatigue test	x
Adhesion	Aggregate/Binder affinity	
	Particle loss of Porous Asphalt	
	other	

Test methods to address bitumen properties

> Viscosity

- Capillary Viscometer Test
- Coaxial Cylinder Viscosity (CCV) Test
- Cone and Plate Viscosity Test
- Creep Zero/Low Shear Viscosity (ZSV/LSV) Test
- Oscillation Zero/Low Shear Viscosity (ZSV/LSV) Test

> Softening point

- Ring and Ball (R&B) Test method

> Elastic and recovery properties

- Multiple Stress Creep and Recovery (MSCR) Test
- Elastic Recovery Test

> Complex modulus and phase angle

- Dynamic Shear Rheometer (DSR) Test

> Performance Grading

- Performance Grade (PG) classification (Superpave high temperature parameter)

Test methods to address asphalt behaviour

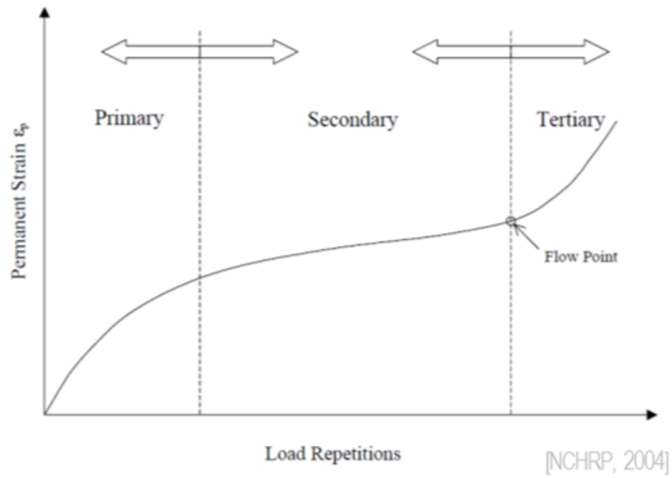
> in Europe

- Wheel Tracking test, WTT (EN 12697-22)
- Cyclic compression test, CCT (EN 12697-25)

> other used tests

- SUPERPAVE shear tester, SST
- Simple Performance Tests, SPT
  (e.g. Dynamic modulus test; Flow Number; Flow Time)

Rutting process in asphalt mixes under repeated loads



Densification

Shear deformation (constant volume)

[M.L.Antunes, 2005]

Possible correlations derived from literature review

Bitumen viscosity

Number of found relevant studies

- Capillary Viscometer Test: (1)
- Coaxial Cylinder Viscosity Test: 0
- Cone and Plate Viscosity Test: 0
- Creep Zero/Low Shear Viscosity: 3 (4)
- Oscillation Zero/Low Shear Viscosity: 2

Note: EVT – Equiviscous temperature

Paper	Correlated data	Type of correlation	Data sets	R^2	Comment
Paper 042 (Robertus et al., 2012)	WT Rut Rate [mm/s) vs. ZSV (kPa*s)	Power (y= a.x^b)	14	0.93	U / UA
			30	0.49	U & PMB
Paper 043 (Morea, 2012)	WT rut rate (µm/min) vs. LSV (Pa*s)	y=a+b/x	29	0,87	U & PMB / UA & A
				0,86	
Paper 047 (Gungor & Sağlik, 2012)	Axial deformation [mm] from TCCT vs. ZSV [Pa*s]	Power (y= a.x^b)	12	0.92	U & PMB / A (TCCT@40ºC)
			12	0.84	U & PMB / A (TCCT@50ºC)
Paper 067 (Guericke & Schlame, 2008)	HWT Rut Depth (mm) vs. ZSV [Pa*s]	Power (y= a.x^b)	25	0.81	U & PMB / A (WTT at +40° C)
			6	0.91	U & PMB / A (WTT at +50° C)
			11	0.91	U & PMB / A (WTT at +60° C)
Paper 499 (De Visscher & Vanelstraete, 2009)	PRD [%] vs. EVT1 [° C]	Linear (y= a + bx)	6	0.86	U
			11	0.83	U & PMB
	PRD [%] vs. EVT2 [° C]	Linear (y= a + bx)	6	0.85	U
			11	0.49	U & PMB
	Creep rate [µm/m/n] vs. EVT1	Linear (y= a + bx)	6	0.83	U
			11	0.77	U & PMB
	Creep rate [µm/m/n] vs. EVT2	Linear (y= a + bx)	6	0.83	U
			11	0.76	U & PMB

Bitumen viscosity

- Studies on **creep Zero/Low Shear Viscosity** show that correlation between binder viscosity (ZSF/LSV) and **wheel tracking** parameter is good only when **non modified binders** are used. However, when the axial strain from **Triaxial Cyclic Compression Tests** (TCCT) is linked to ZSF/LSV, a good correlation can be achieved even when **modified binders** are taken into consideration
- Studies on **oscillation Low Shear Viscosity** reveal that good correlations could be achieved when:
  - the binder viscosity (ZSF/LSV) is linked with the rut depth (WT) and
  - the equiviscous temperature 1 (EVT1, temperature at which the viscosity measured at very low shear rate is 2000 Pa.s) is linked to the proportional rut depth (WT) and the creep rate (**TCCT**)

Possible correlations derived from literature review

Bitumen softening point

Number of found relevant studies

- Ring and Ball (R&B) test method: 7

Paper	Correlated data	Type of correlation	Data sets	R^2	Comment
Paper 026 (Eckmann et al., 2012)	Rut depth [mm] vs. softening point [° C]	Linear (y= a + bx)	4	0.82	U (20/30 pen grade) + PMB
			4	0.99	U (35/50 pen grade) + PMB
Paper 042 (Robertus et al., 2012)	Rut rate [mm/s] vs. softening point [° C]	Linear (y= a + bx)	19	0.68	U + PMB
			7	0.95	U
Paper 067 (Guericke & Schlampe, 2008)	Rut depth [mm] vs. softening point [° C]	Linear (y= a + bx)	11	0.84	U + PMB
Paper 425 (Dreessen & Pascal, 2009)	Softening point [° C] vs. rut depth [mm]	Logarithmic (y= a lnx + b)	13	0.60	U + PMB
Paper 504 (Tusar et al., 2009)	Rut depth [mm] vs. softening point [° C]	Logarithmic (y= a lnx + b)	7	0.91	U + PMB
Paper 532 (Renken, 2012)	Rut depth [mm] vs. softening point [° C]	Non correlation found	N/A	N/A	N/A
Paper 558 (Reyes-Lizcano et al., 2009)	Accumulated axial strain [%] vs. softening point [° C]	Linear (y= a + bx)	9	0.54	PMB

Bitumen softening point by R&B test method

- Some studies find a reasonable correlation between **R&B** and **wheel tracking** results, even when polymer-modified binders are used for testing. But these studies are generally limited to samples from the same binder source, i.e. one unmodified bitumen-base was used to produce the polymer-modified samples. When a **mix of unmodified and modified binders** is used that are not from the same base bitumen, poor correlations were found.
- **R&B** is considered as a traditional test method with a large background in data. However, it is of general understanding that this test is not suitable **for modified bituminous binder**

Possible correlations derived from literature review

Bitumen elastic and recovery properties

Number of found relevant studies

- Elastic Recovery Test: 0
- Multiple Stress Creep and Recovery Test: 8

Paper	Correlated data	Type of correlation	Data sets	R^2	Comment
Paper 042 (Robertus et al., 2012)	WTT small size, rut rate vs. J_{nr} (T=45 and 60 ºC; t=1 kPa)	logy=a*log x	20	0,79 UA 0,90 RTFOT	5U, 11 PmB,2 wax modified, 2 special
Paper 185 (D'Angelo et al., 2007)	ALF of FHWA vs. J_{nr} (T=64 ° C; t=25,6 kPa)	Linear (y= a + bx)	6	0,81	U and PmB
Paper 185 (D'Angelo et al., 2007)	Field rutting (after 6 yrs) vs. J_{nr} (T=64 ° C; t=0,8 kPa)	Linear (y= a + bx)	7	0,77	U and PmB
Paper 516 (Laukkanen et al., 2014)	WTT large size device vs. J_{nr} (t= 3200 Pa)	Linear (ax+b) rut rate	9	0,98	U&PMB/UA
Paper 562 (Tabatabaee& Tabatabaee, 2010)	unconf. cyclic creep test vs. J_{nr} (t= 3200 Pa)	not clear ? Linear ?	6	0,83	U&CMB / A U.D.C. at 40° C

Paper	Correlated data	Type of correlation	Data sets	R^2	Comment
Paper 023 (Dueñas et al.,2012)	WTT, rut depth vs. J_{nr} (T=60 ºC; t=3,2 kPa)	Linear (y= a + bx)	4	0,87	U, PmB and Crumb Rubber Modified
Paper 023 (Dueñas et al.,2012)	Compliance in CCT vs. J_{nr} (T=60 ºC; t=3,2 kPa)	Linear (y= a + bx)	4	0,69	U, PmB and Crumb Rubber Modified
Paper 023 (Dueñas et al.,2012)	% recovery in CCT vs. %Recovery MSCR (T=60 ºC; t=3,2 kPa)	Linear (y= a + bx)	4	0,96	U, PmB and Crumb Rubber Modified
Paper 035 (Dreessen & Gallet, 2012), paper 425 (Dreessen& Pascal, 2009) paper 501 (Dreessen et al., 2009)	WTT large size device, rut depth vs. J_{nr} (T=60 ºC; t=3,2 kPa)	Linear (y= a + bx)	15	0,44	7U, 6 PmB and 2 special All RTFOT
Paper 035 (Dreessen & Gallet, 2012), paper 425 (Dreessen& Pascal, 2009) paper 501 (Dreessen et al., 2009)	WTT large size device, rut depth vs. J_{nr} (T=60 ºC; t=25,6 kPa)	Linear (y= a + bx)	15	0,77	7U, 6 PmB and 2 special All RTFOT

MSCR parameters: %R - Percent recovery &
J_{nr} - non-recoverable creep compliance

Bitumen recovery properties by the MSCR test

- In general, studies report quite good correlations – often at higher stress levels – for both **paving grade binders** & **polymer modified binders**
- The MSCR test result which is directly related to permanent deformation is **Jnr**. **%R** is correlated in only one study (cyclic creep test on asphalt). This correlation was also fairly good, although the number of binders considered was small (only 4).
- In most studies the MSCR test is compared to wheel tracking tests: either the French WT (large size device) or the Hamburg WT (small size device).
- From some of the papers reviewed, *it seems* that for good correlations with the permanent deformation tests on the asphalt mix, it is better:
  - to test the binders after short-term ageing (e.g. after RTFOT)
  - higher stress levels are used (≥ 3,2 MPa) in the MSCR tests
  - ▸ **Further investigation is needed**

Possible correlations derived from literature review

Bitumen complex modulus (G*) and phase angle (sin δ)

Number of found relevant studies

- Dynamic Shear Rheometer (DSR) Test: **6**

DSR test parameters:

G* - Complex shear modulus

G*/sin δ @ 10 rad/s

R_J - unified evaluation index

Paper	Correlated data	Type of correlation	Data sets	R^2	Comment
Paper 042 (Robertus et al., 2012)	WT Rut Rate vs. G* (kPa)	Power ($y= a.x^b$)	14	0,94	U / UA
			30	<0,70	U & PMB / UA
Paper 047 (Gungor & Sağlik, 2012)	TCCT Deformation (mm) vs. G*/sinδ (kPa)	Power ($y= a.x^b$)	12	0,37	U & PMB / A (TCCT@40ºC)
			12	0,40	U & PMB / A (TCCT@50ºC)
Paper 061. (Beckedahl et al., 2008)	WT Rut Depth (mm) vs. G*/sinδ (kPa)	Power ($y=a.x^b$)	3	0,93	U & PMB / UA
			3	0,95	U & PMB / UA
Paper 067 (Guericke & Schlame, 2008)	HWT Rut Depth (mm) vs. $T_{(G^*/\sin\delta=2.2kPa)}$ (ºC)	Linear	11	0,77	U & PMB / A
Paper 308. (Tan *et al.*, 2014)	WT dynamic stability (time/mm) vs. R_J	Linear ($y= a + bx$)	7	0,99	U & PMB / UA
		Grey relational analysis	2	0,89	U / UA
			5	0,90	PMB / UA
	WT dynamic stability (time/mm) vs. G*/sinδ (KPa)	Linear ($y= a + bx$)	7	0,99	U & PMB / UA
		Grey relational analysis	2	0,89	U / UA
			5	0,59	PMB / UA
Paper 425 (Dreessen & Pascal, 2009)	FWT rutting (%) vs. G*/sinδ (KPa)	Logarithmic ($y= a \ln x+b$)	15	0,27	U & PMB / A

Bitumen complex modulus and phase angle by DSR test

- G* was only considered in one of the studies. In this case, a good correlation was found with the wheel tracking rut rate in the analysis of seven **unmodified bitumen**. Conversely, very weak correlations were detected for most **polymer modified bitumen**. G* generally underestimates the contribution to rutting resistance
- R_J (unified evaluation index) was considered in only one study and a good correlation was found both for **unmodified** and **PMB binders**
- Most of the papers determine G*/sin δ, finding that it is not suitable to evaluate the asphalt resistance to permanent deformation, when analyzing an ensemble of **unmodified** and **polymer modified** bituminous binders. Nevertheless, better correlations are achieved for higher frequencies

Recommendations

- Most promising tests providing better correlations:
  - the **Zero/Low Shear Viscosity (ZSV/LSV) by creep or oscillation** test method [CEN/TS 15325 (ZSV); CEN/TS 15324 (LSV)]
  - the non-recoverable compliance (J_{nr}) from the **Multiple Stress Creep and Recovery (MSCR)** test method [EN 16659]
- Comparing both type of tests (Creep or oscillation Zero/Low Shear Viscosity and MSCR tests), it seems that the <u>MSCR test method is more promising</u> in a near future, given that, at the present, it <u>seems to be an easier test method for the laboratories to implement</u>, there is a <u>European standard</u> specifying the test and it is a method preferred in other countries as well, such as USA.
- **However, further <u>research</u> (namely on the MSCR test stress level) is needed!**

Thanks for your attention!