Hrvatsko asfaltersko društvo

Croatian asphalt association

Otpornost asfaltnih mješavina na zamor
Resistance to Fatigue of Asphalt Mixes

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Međunarodni seminar ASFALTNI KOLNICI 2017
International seminar ASPHALT PAVEMENTS 2017
Opatija, 05.–06. 04. 2017.

Fatigue

Fatigue

(from Wikipedia, the free encyclopedia)

Fatigue may refer to:

Fatigue (medical), a state of physical and/or mental weakness

Fatigue (material), structural damage from repeated loading

Fatigue

Standard EN 12697-24:2012 Bituminous mixtures - Test methods for hot mix asphalt - Resistance to fatigue

3.1 General

3.1.1

fatigue

reduction of strength of a material under repeated loading when compared to the strength under a single load

3.1.2

conventional criteria of failure

number of load applications, Nf/50, when the complex stiffness modulus Smix,0 has decreased to half its initial value

3.1.3

initial complex stiffness modulus

complex stiffness modulus, Smix,0, after 100 load applications

3.1.4

fatigue life of a specimen

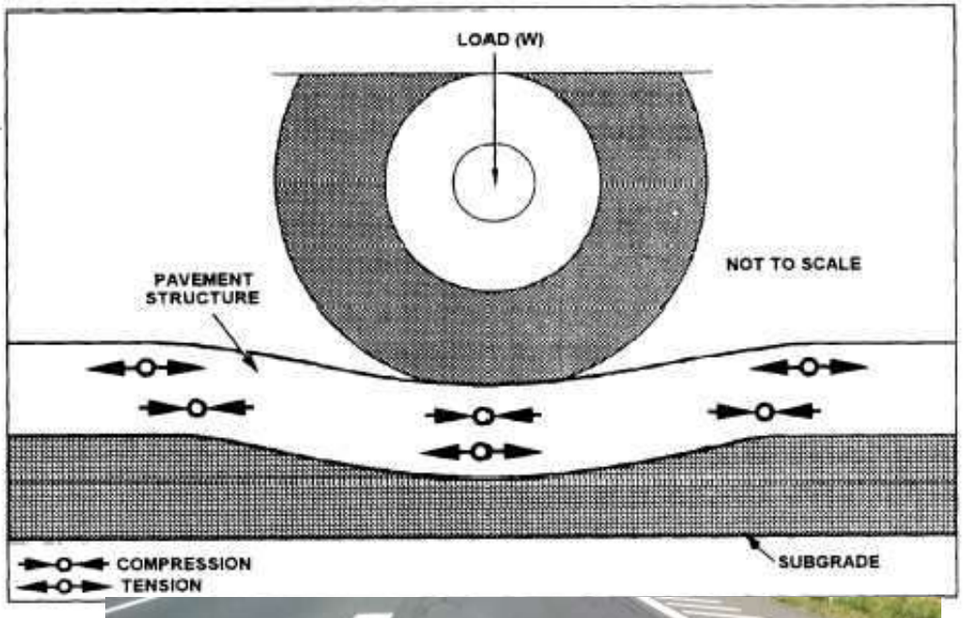
number of cycles Ni,j,k corresponding to the conventional failure criterion at the set of test conditions k (temperature, frequency and loading mode)

Note 1 to entry: A loading mode could be constant deflection level, or constant force level, and or any other constant loading condition.

Fatigue

On the road it represents:

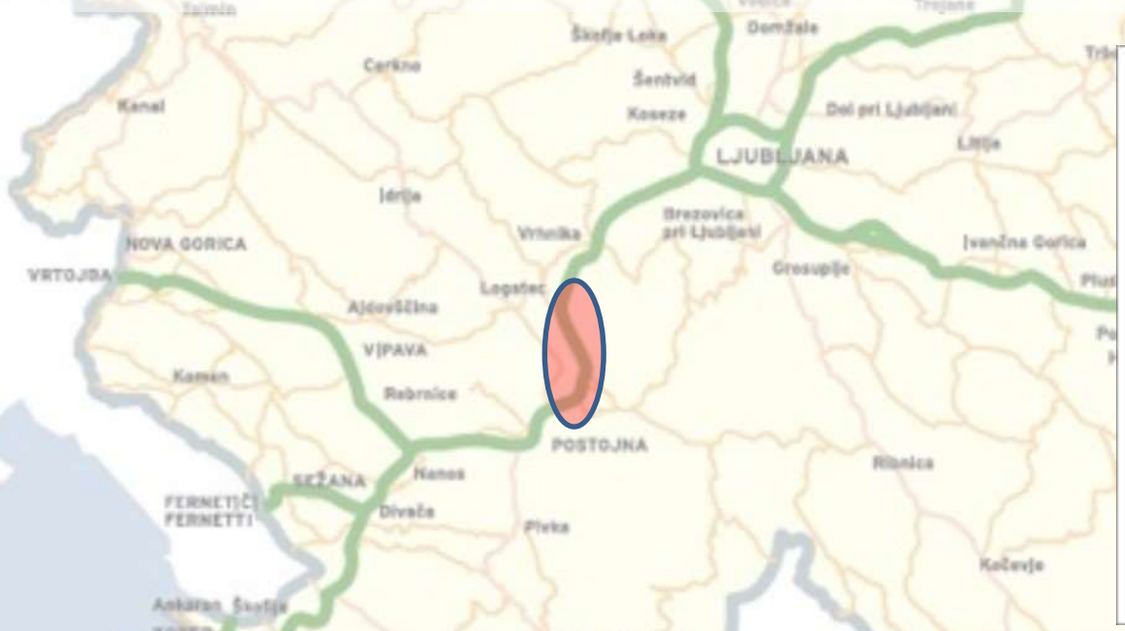
- statically uncritical load, that can lead to functional defects (fatigue cracking) or even failure of a pavement part, if sufficiently frequently applied
- it affects all asphalt pavement layers
- the most affected is the lowest asphalt (base) layer

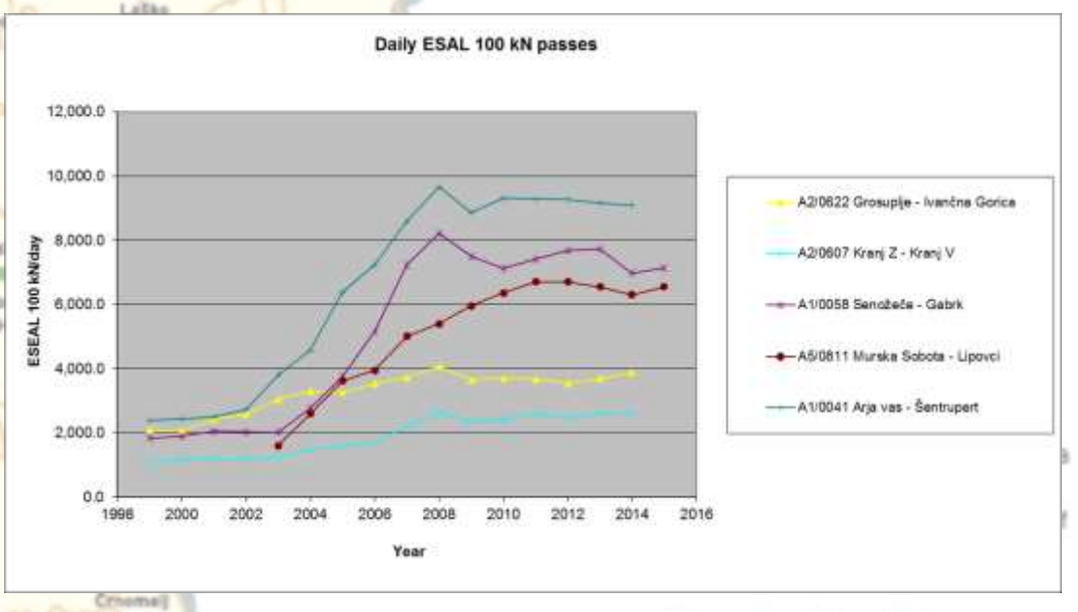


Fatigue loading

For example on A1 Highway section **Unec–Postojna** AADT in 2014 was **42.413** vehicles per day (1,6 % more than in 2013 - 41.754), **6.474** heavy truck vehicles per day (0,7 % more than in 2013 - 6.432) i.e. **15 %** of AADT and approximately **5.750** daily ESAL 100 kN passes.

In the 20-years pavement design period it means app. **60 million** ESAL 100 kN passes and that causes fatigue of asphalt pavement layers.





Fatigue loading

Traffic loads on European roads are growing:

- Axle loads have almost everywhere risen from 80 kN to 100 kN
- Effect of narrower (Super Single) truck tyres
- Even larger trucks in future (GigaLiner)

Fatigue testing

Standard EN 12697-24:2012 Bituminous mixtures - Test methods for hot mix asphalt - Part 24: Resistance to fatigue

Annex A (normative) Two-point bending test on trapezoidal shaped specimens

Annex B (normative) Two-point bending test on prismatic shaped specimens

Annex C (normative) Three-point bending test on prismatic shaped specimens

Annex D (normative) Four-point bending test on prismatic shaped specimens

Annex E (normative) Indirect tensile test on cylindrical shaped specimens

The procedure is used:

a) to rank bituminous mixtures on the basis of resistance to fatigue;
b) as a guide to relative performance in the pavement;
c) to obtain data for estimating the structural behavior of the road; and
d) to judge test data according to specifications for bituminous mixtures.

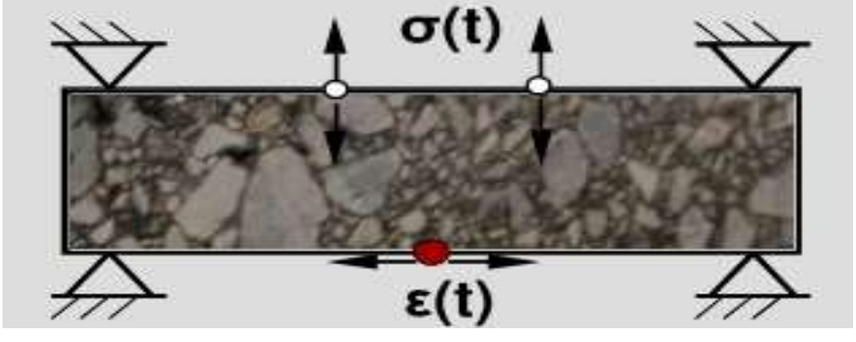
Results obtained from different test methods or using different failure criteria are not assured to be comparable.

Fatigue testing

Standard EN 12697-24:2012 Bituminous mixtures - Test methods for hot mix asphalt - Part 24: Resistance to fatigue

Annex D (normative) Four-point bending test on prismatic shaped specimens

The inner and outer clamps are symmetrically placed and slender rectangular shaped specimens (prismatic beams) are used. The specimens are subjected to four-point periodic bending with free rotation and translation at all load and reaction points by loading the two inner load points in the vertical direction, perpendicular to the longitudinal axis of the beam. The vertical position of the outer clamps shall be fixed. The applied load is sinusoidal and during the test, the load needed for the bending of the specimen, the deflection and the phase lag between these two signals are measured as a function of time. The fatigue characteristics of the material tested are determined from these measurements.



Fatigue testing

Standard EN 12697-24:2012 Resistance to fatigue

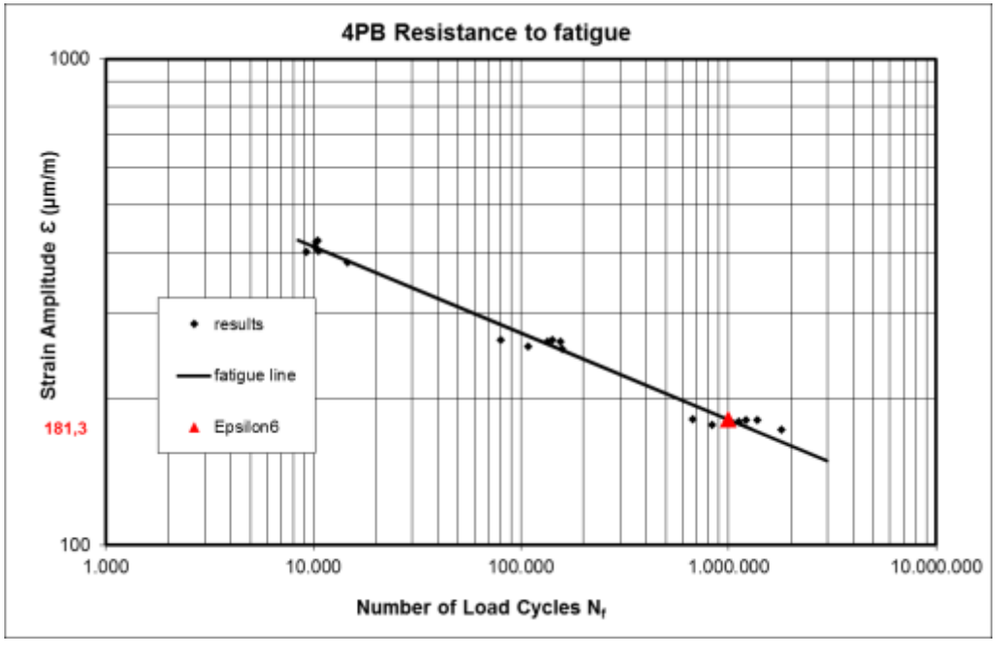
Annex D (normative) Four-point bending test on prismatic shaped specimens

- Test is carried out at temperature of +20 °C and with frequency 30 Hz, at 3 different strain levels with 6 repetitions per level = at least 18 samples
- The fatigue test shall be continued until the calculated modulus Smix has dropped to half its initial value or until the specimen breaks.
- On the basis of the results the fatigue line shall be drawn by making a linear regression between the natural logarithms of Ni,j,k and the natural logarithms of the initial strain amplitude (strain amplitude at the 100th cycle). The shape of the fatigue line is expressed in the following formula:

$$\ln (N_{i,j,k}) = A_0 + A_1 \times \ln (\varepsilon_1)$$

where i is the specimen number; j represents the chosen failure criteria; k represents the set of test conditions; εi is the initial strain amplitude measured at the 100th load cycle

- Initial strain corresponding with a fatigue life of 10^6 cycles or ε_6 as resistance to fatigue in standards EN 13108-1,-5



Fatigue test results

Fatigue line $\ln(N) = A_0 + A_1 * \ln(\varepsilon)$		Fatigue line $N = k_1 \cdot \varepsilon^{k2}$		Characteristics	
$q = A_0$:	**43,066**	$\log_{10} k_1$:	**18,703**	Number of specimen:	18
$p = A_1$:	**-5,625**	k_2:	**-5,625**	Cycles for strain-charact.:	1000000
R^2:	0,986			Mean value of E_{ini} [MPa]:	4263
$s_{x/y}$:	0,242			strain-characteristics [µm/m]:	**181,3**

Code	Temp [°C]	Strain [µm/m]	E_{ini} [MPa]	E_{fat} [MPa]	N_{fat} [-]
Hi4E	20	381,9	3249	1625	14561
Hi8A	20	420,5	2732	1366	10331
Hi8E	20	423,8	4250	2125	10494
Hi9B	20	409,6	3943	1972	10191
Hi9D	20	403,2	3706	1853	10550
Hi7E	20	401,3	2499	1250	9257
Mi4A	20	256,4	4644	2322	108100
Mi5B	20	253,5	3931	1965	157440
Mi5D	20	262,4	2875	1438	154860
Mi6D	20	264,3	4479	2240	142350
Mi9A	20	262,3	4615	2308	134160
Mi6B	20	264,4	5419	2710	80250
Lo5C	20	180,6	3295	1648	1220513
Lo7D	20,0	181,2	5121,2	2561	670300
Lo7C	20,0	179,3	6069,5	3035	1121250
Lo6C	20,0	176,8	5873,2	2937	831220
Lo8C	20,0	172,6	4087,5	2044	1801720
Lo7A	20,0	181,0	5943,2	2972	1381690

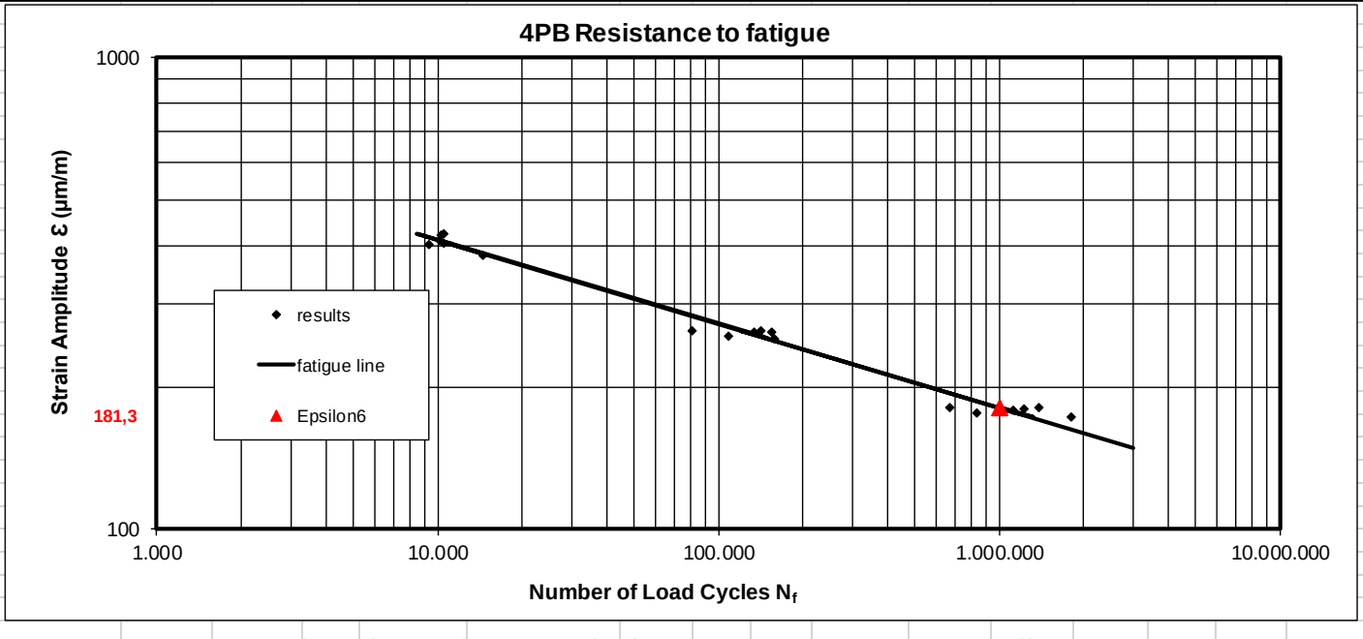
Recollect results

Code	Auxiliary information			
	ln(strain)	$\ln(N_{fat})$	strain	$N_{fat, calc}$
----	5,00	14,91	149,1	3000000
----	6,02	9,21	411,1	10000
Hi4E	5,95	9,59	381,9	15140
Hi8A	6,04	9,24	420,5	8810
Hi8E	6,05	9,26	423,8	8431
Hi9B	6,02	9,23	409,6	10216
Hi9D	6,00	9,26	403,2	11157
Hi7E	5,99	9,13	401,3	11462
Mi4A	5,55	11,59	256,4	142469
Mi5B	5,54	11,97	253,5	151732
Mi5D	5,57	11,95	262,4	125137
Mi6D	5,58	11,87	264,3	119986
Mi9A	5,57	11,81	262,3	125227
Mi6B	5,58	11,29	264,4	119806
Lo5C	5,20	14,01	180,6	1021790
Lo7D	5,20	13,42	181,2	1005014
Lo7C	5,19	13,93	179,3	1065126
Lo6C	5,17	13,63	176,8	1153297
Lo8C	5,15	14,40	172,6	1320395
Lo7A	5,20	14,14	181,0	1010929

Fatigue test results

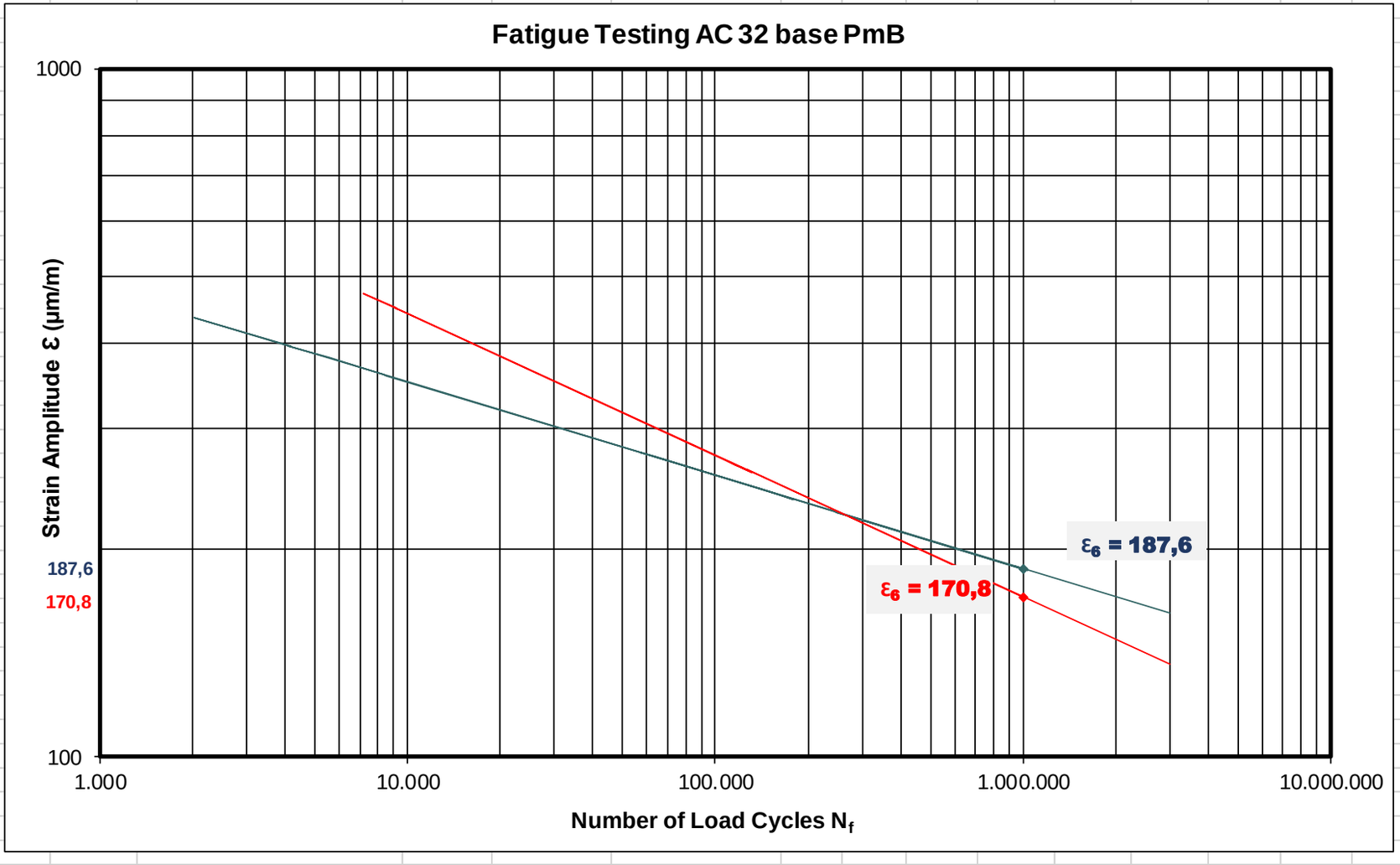
Asphalt mix dynamic testing - resistance to fatigue

lab.	asphalt mix	producer	materials			test type		testing conditions			samples		ε_{10}^{6}	density	E_{ini}	no. reps	road section
no.			aggregate	filler	bitumen	standard	type	temp	freq.	strain	date	no.					
								[°C]	[Hz]	[μm/m]			[μm/m]	[Mg/m^3]	[MPa]	[N_{fat}]	
1	**AC 22 bin PmB 45/80-65 A1, A2**				PmB 45/80-65			°C	Hz	[μm/m]							**H3/0089 Dunajska-Celovška**
																	29.07.2016
							4 PB										DN: 574-A-16 mix
						EN 12697-24 Ann. D	Fatigue	20	30	181	29.09.16	Lo5C	2,403	3295	1648	1220513	
										181		Lo7D	2,428	5121	2561	670300	
										179		Lo7C	2,424	6069	3035	1121250	
										177		Lo6C	2,412	5873	2937	831220	
										173		Lo8C	2,411	4088	2044	1801720	
										181		Lo7A	2,424	5943	2972	1381690	
									mean Lo	**179**			**2,417**	**5065**	**2532**	**1171115**	
										256		Mi4A	2,405	4644	2322	108100	
										254		Mi5B	2,400	3931	1965	157440	
										262		Mi5D	2,397	2875	1438	154860	
										264		Mi6D	2,406	4479	2240	142350	
										262		Mi9A	2,389	4615	2308	134160	
										264		Mi6B	2,391	5419	2710	80250	
									mean Mi	**261**			**2,398**	**4327**	**2164**	**129527**	
										382		Hi4E	2,404	3249	1625	14561	
										421		Hi8A	2,403	2732	1366	10331	
										424		Hi8E	2,400	4250	2125	10494	
										410		Hi9B	2,408	3943	1972	10191	
										403		Hi9D	2,405	3706	1853	10550	
										401		Hi7E	2,425	2499	1250	9257	
									mean Hi	**408**			**2,408**	**3576**	**1788**	**11225**	
									mean	275			2,406	4367	2183	462352	DN:587-A-16



Fatigue AC 32 base PmB

lab.no.	mix .no.	asphalt mix	materials		test type	testing conditions			$\ln(N)=A_0-A_1*\ln(\varepsilon)$		ε_{10}^6	density	E_{ini}	no. reps
			agreggate	bitumen	standard	temp	freq.	load	A_0	A_1				
						[°C]	[Hz]	[µm/m]			[µm/m]	[Mg/m^3]	[MPa]	[N_{fat}]
603-A-14	498-A-14	AC 32 base PmB 45/80-50 A1,A2	limestone	PmB 45/80-50	EN 12697-24 Ann. D	20	30	274	52,330	-7,358	187,6	2,480	3909	401436
879-A-14	616-A-14	AC 32 base PmB 45/80-65 A1,A2	limestone	PmB 45/80-65	EN 12697-24 Ann. D	20	30	292	38,774	-4,855	170,8	2,423	4759	369864
Povprečna vrednost - x						20	30	283	45,552	-6,107	179,2	2,452	4334	385650

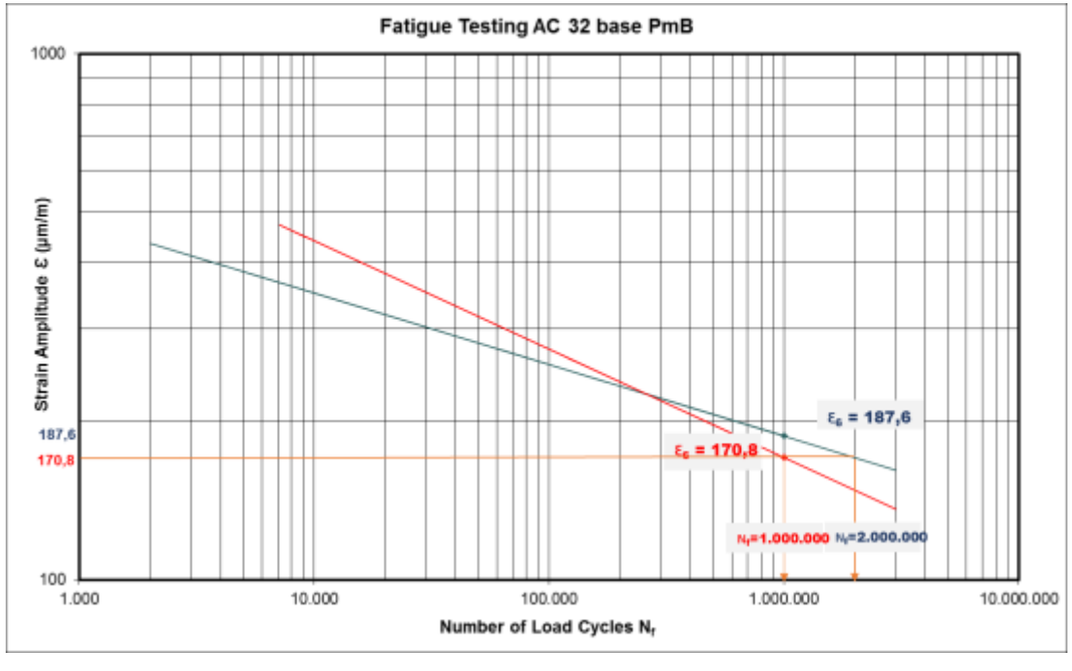


Fatigue AC 32 base PmB

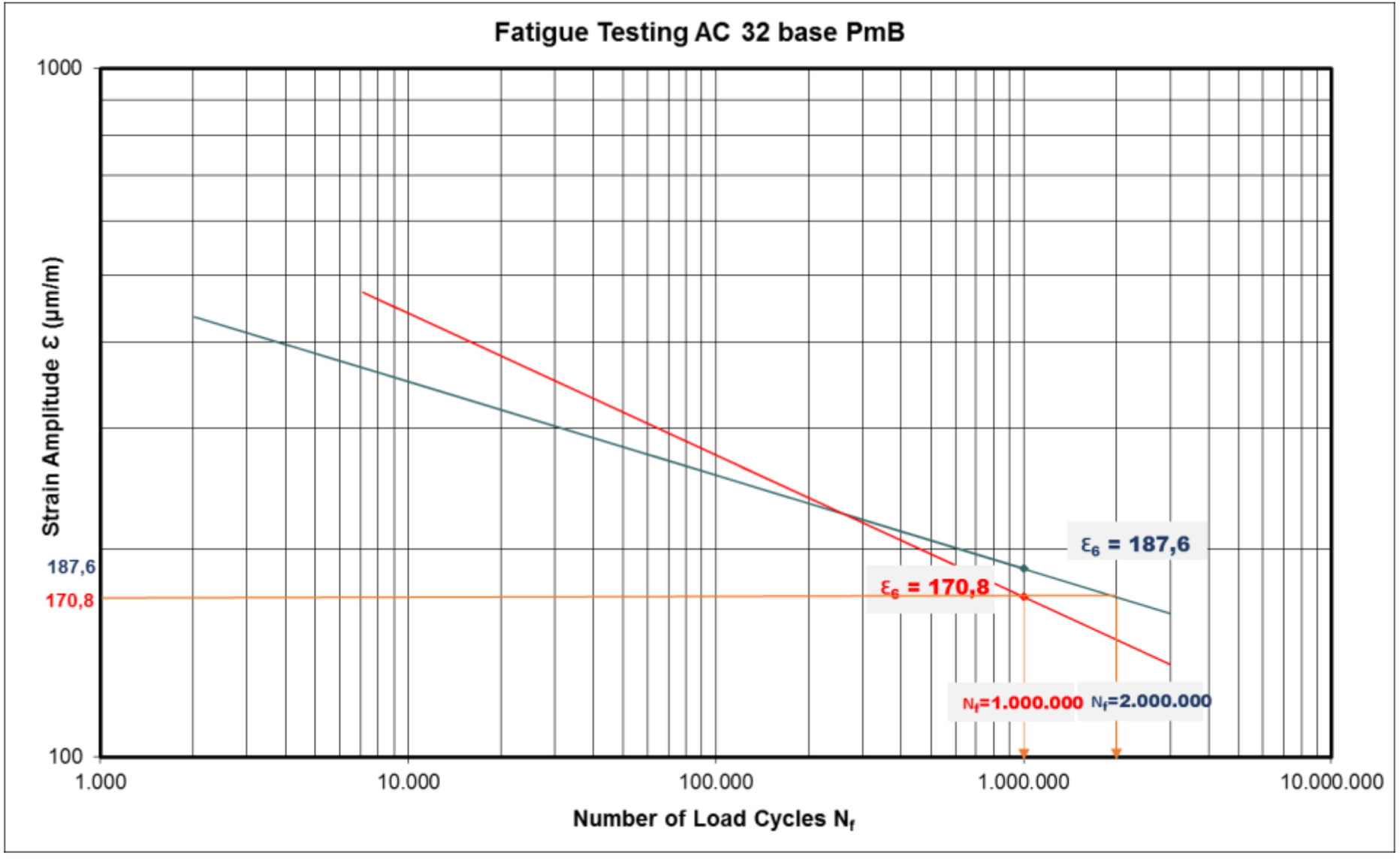
ASPHALT MIX ANALYSIS RESULTS: AC 32 base PmB 45/80-50(65)

NO.	LAB. NO.	DATE	BIT. TYPE	BIT. CONT.	AGGREGATE MIX CHARACTERISTICS: Passing through sieve (mm) 0,063	0,09	0,25	0,71	2.0	4.0	8.0	11.2	16	22,4	31,5	>31,5	ASPHALT MIX CHARACTERISTICS: Bulk density	Max. density	Air voids content	Voids filled w. bit.	Voids in min. aggreg.	Max density min.agr.
				% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	Mg/m^3	Mg/m^3	% (V/V)	%	% (V/V)	kg/m^3
SIST EN				12697-1 /12	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-6 /12 1)	12697-5 /10 2)	12697-8 /04	12697-8 /04 3)		
1	498-A-14	06.06.14	PmB 45/80-50	4,0	5,1	5,7	9,5	14,0	23,6	32,8	47,5	56,2	70,3	85,1	100,0		2,498	2,585	**3,3**	**74,8**	13,3	2764
2	616-A-14	04.07.14	PmB 45/80-65	4,1	4,2	4,9	10,0	15,8	26,8	38,0	53,0	63,0	72,7	87,9	100,0		2,390	2,534	5,7	63,2	15,4	2709

No	DN IGM	DN ASF	DATE	ASPHALT MIX	BIT	Mix Temp.	BIT after extraction	RB °C SIST EN 1427 2007	PEN mm/10 SIST EN 1426 2007	Duct cm DIN 52 013 2007	Fraass °C SIST EN 12593 2007	IP SIST EN 12591 tč.A 2009	el.rec. % SIST EN 13398 2010	Force ductility 10 °C: cm dukt	J/cm2 E0,2	J/cm2 E0,4	J/cm2 Ecelotna	J/cm2 E's	N sila	Force ductility 25 °C: cm dukt	J/cm2 E0,2	J/cm2 E0,4	J/cm2 Ecelotna	J/cm2 E's	N sila
1	321	498	06.06.14	AC 32 base PmB 45/80-50 A1,A2	Starfalt 45/80-65	165	PmB 25/55-65	73,4	34,0	**50,4**	**-14,5**	2,4	76,5	**44**	4,7	10,0	**11,1**	5,3	35,0	**94**	0,5	1,2	**2,9**	0,7	4,0
2	372	616	04.07.14	AC 32 base PmB 45/80-65 A1,A2	Starfalt 45/80-65	170	PmB 25/55-65	74,0	35,7	27,1	-13,8	2,6	80,5	37	6,0	11,1	10,5	5,1	45,3	79	0,9	1,9	2,7	0,9	5,5

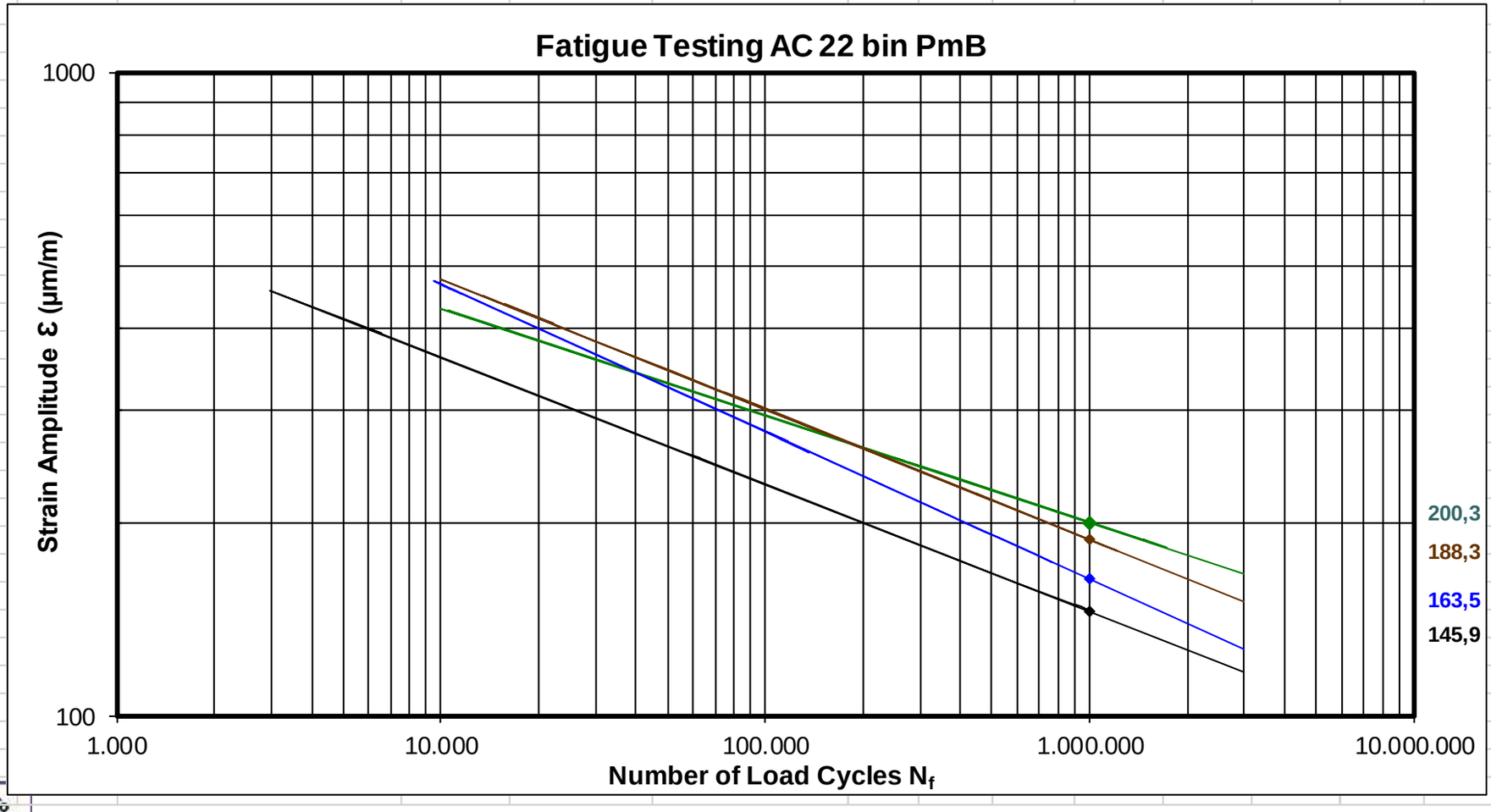


Fatigue AC 32 base PmB



Fatigue AC 22 bin PmB

lab.no.	mix .no.	asphalt mix	materials		test type	testing conditions			ln(N)=A_0-A_1*ln(ε)		ε_{10}^6	density	E_{ini}	no. reps
			agreggate	bitumen	standard	temp	freq.	load	A_0	A_1				
						[°C]	[Hz]	[µm/m]			[µm/m]	[Mg/m^3]	[MPa]	[N_{fat}]
457-A-12	290-A-12	AC 22 bin PmB 45/80-50 A2	limestone	PmB 45/80-50	EN 12697-24 Ann. D	20	30	264	45,673	-6,011	200,3	2,428	5738	928810
928-A-13	837-A-13	AC 22 bin PmB 45/80-65 A1A2	limestone	PmB 45/80-65	EN 12697-24 Ann. D	20	30	300	39,635	-4,929	188,3	2,398	4302	312898
268-A-14	226-A-14	AC 22 bin PmB 45/80-65 A2	limestone	PmB 45/80-65	EN 12697-24 Ann. D	20	30	308	36,091	-4,371	163,5	2,389	5293	237108
1054-A-14	944-A-14	AC 22 bin PmB 45/80-65 A1A2	limestone	PmB 45/80-65	EN 12697-24 Ann. D	20	30	271	39,091	-5,072	145,9	2,412	7189	433574
Mean value - x						20	30	286	40,123	-5,096	174,5	2,407	5631	478097

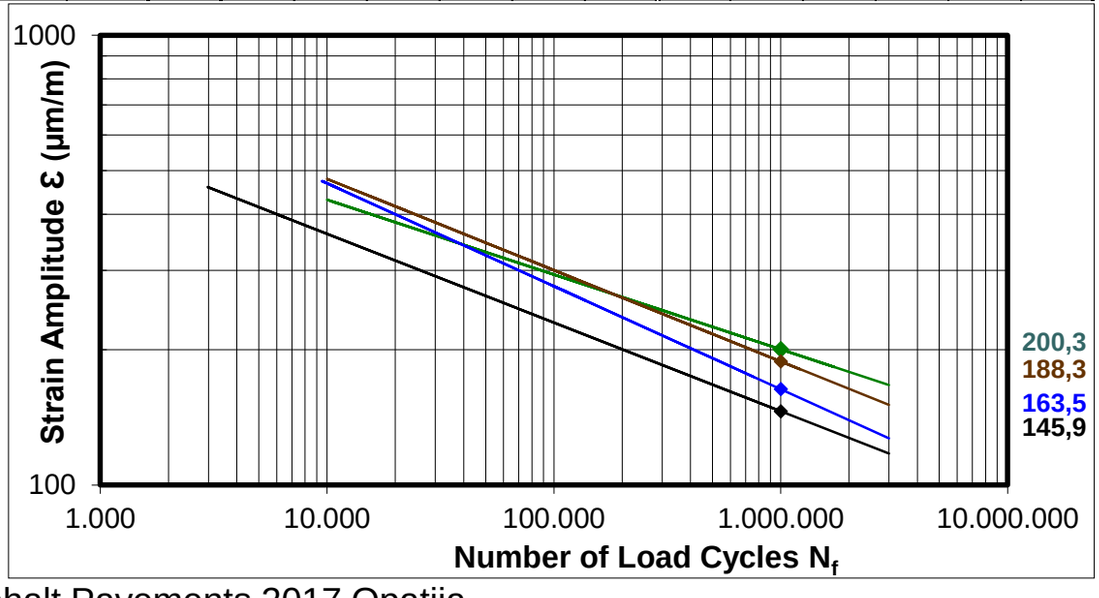


Fatigue AC 22 bin PmB

ASPHALT MIX ANALYSIS RESULTS: AC 22 bin PmB 45/80-65

NO.	LAB. NO.	DATE	BIT. TYPE	BIT. CONT.	AGGREGATE MIX CHARACTERISTICS: Passing through sieve (mm) 0,063	0,09	0,25	0,71	2.0	4.0	8.0	11.2	16	22,4	31,5	>31,5	ASPHALT MIX CHARACTERISTICS: Bulk density	Max. density	Air voids content	Voids filled w. bit.	Voids in min. aggreg.	Max density min.agr.
				% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	% (m/m)	Mg/m^3	Mg/m^3	% (V/V)	%	% (V/V)	kg/m^3
SIST EN				12697-1 /12	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-2 /07	12697-6 /12 1)	12697-5 /10 2)	12697-8 /04	12697-8 /04 3)		
1	290-A-12	25.05.12	PmB 45/80-50	**4,0**	7,0	7,7	11,1	17,0	31,5	45,0	61,2	70,1	82,3	98,2	100,0		2,424	2,536	**4,4**	**68,2**	13,9	2703
2	837-A-13	12.10.13	PmB 45/80-65	4,0	4,9	5,6	11,1	16,7	25,5	33,6	50,2	62,0	77,5	100,0	100,0		2,400	2,531	5,2	64,4	14,6	2698
3	226-A-14	09.04.14	PmB 45/80-65	3,8	7,3	7,8	11,0	17,4	34,7	46,2	66,7	80,0	89,7	99,4	100,0		2,405	2,574	6,6	57,9	15,6	2741
4	944-A-14	31.10.14	PmB 45/80-65	**3,6**	6,7	7,2	10,4	16,3	29,1	39,4	53,6	63,2	79,4	99,1	100,0		2,401	2,538	5,4	61,2	13,9	2688

No	DN IGM	DN ASF	DATE	ASPHALT MIX	BIT	Mix Temp.	BIT after extraction	RB °C SIST EN 1427 2007	PEN mm/10 SIST EN 1426 2007	Duct cm DIN 52 013 2007	Fraass °C SIST EN 12593 2007	IP SIST EN 12591 tč.A 2009	el.rec. % SIST EN 13398 2010	Force ductility 10 °C: cm dukt	J/cm2 E0,2	J/cm2 E0,4	J/cm2 Ecelotna	J/cm2 E's	N sila	Force ductility 25 °C: cm dukt	J/cm2 E0,2	J/cm2 E0,4	J/cm2 Ecelotna	J/cm2 E's	N sila
1	210	290	25.05.12	AC 22 bin PmB 45/80-50	PmB 45/80-50	165	PmB 10/40-60	**63,3**	31,2	36,5	-16,6	0,6	96,3											0,9	6,4
2	662	837	12.10.13	AC 22 bin PmB 45/80-65	PmB 45/80-65	170	PmB 25/55-65	78,0	**37,7**	22,0	**-19,9**	3,3	78,0								2,2		2,5		18,3
3	198	226	09.04.14	AC 22 bin PmB 45/80-65	PmB 45/80-65	160	PmB 25/55-65	75,0	32,5	**43,6**	-15,1	2,5	71,6	**35**	5,9		**9,8**		43,5	**75**	0,9	1,8	**2,5**	0,9	4,9
4	678	944	31.10.14	AC 22 bin PmB 45/80-65	PmB 45/80-65	165	PmB 25/55-65	72,8	32,6	17,8	-17,6	2,2	78,1*	29	6,1		8,3		44,2	50	1,1	1,9	2,0	0,8	6,3



What influences fatigue characteristics

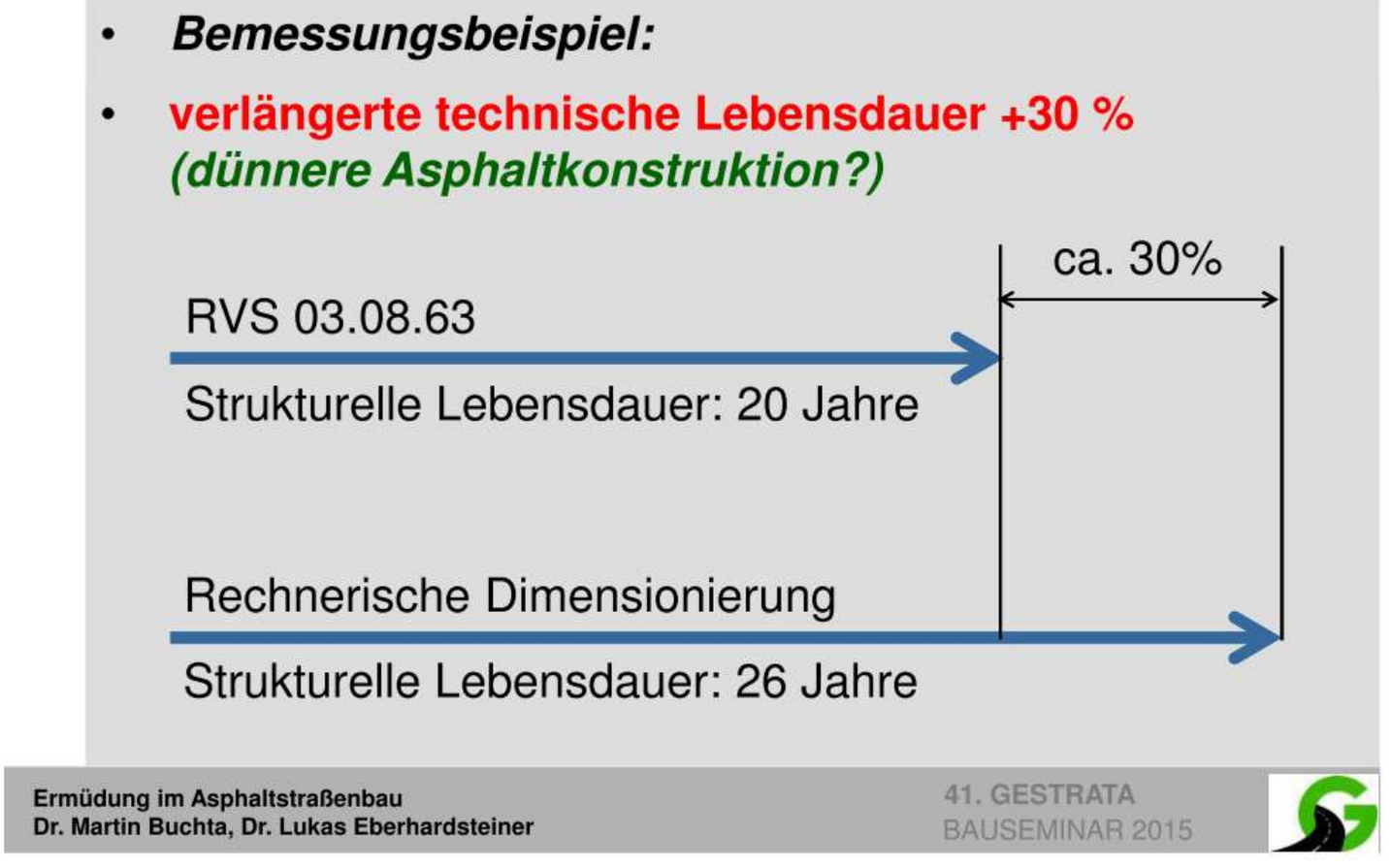
- Type of bitumen
- Bitumen content
- Composition (grading, void content, …)
- Aggregate characteristics
- Filler characteristics
- …

What do fatigue characteristics influence

- Pavement life expectancy
- Strains in upper layers
- Pavement design
- …

Analytical pavement design benefit

Calculated example from Austria for approximately 30 % longer theoretical pavement life with better fatigue characteristics of asphalt binder layer AC 22 bin PmB with ε_6=253 µm/m



Scope of fatigue testing

The fatigue testing results can be used:

- to rank bituminous mixtures on the basis of resistance to fatigue;
- as a guide to relative performance in the pavement;
- to obtain data for estimating the structural behavior of the road;
- to judge test data according to specifications for bituminous mixtures.

Conclusions

Understanding the fatigue of asphalt mixes and various factors that affect the fatigue behaviour can help us improve the design of asphalt mixes itself, and also to increase the pavement life and to improve the pavement design procedures – all the goals, that we as engineers have to reach, to meet the expectations of final road users .

Photo: Rimac Automobili