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Stockerau, mb/sesa

Client: European Lime Association
26, rue des Deux Englises
B-1000 Brussels - Belgium

Date of order: 06.10.2011

PROJECT REPORT

on comparative assessment of asphalt in accordance with ÖNORM EN 13108-1 and ÖNORM B 35080-1

Asphalt mixture AC 16 deck 70/100, A5, G7 modified by hydrated lime and without modification

Scope:

207	total pages, thereof
31	pages report
5	annexes
10	figures
-	graphics
13	tables

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V.2012

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Annexes

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1. GENERAL

Nievelt Ingenieur GmbH was assigned by the European Lime Association, represented by Mr. Bert d'Hooghe and Mr. Dipl.-Eng. Christof Kunesch, to assess comparatively an asphalt layer, manufactured by addition of hydrated lime and the same one without modification.

It was agreed during preliminary discussions on the mentioned assignment that the selected asphalt mixture AC 16 deck 70/00, A5, G7, will be manufactured in an asphalt mixing plant once with addition of hydrated lime and once without addition of hydrated lime and then will be comparatively analysed within the asphalt mixture and binder tests (empiric and performance tests).

The priority was given to the production of asphalt mixtures in an asphalt mixing plant and not in the laboratory, because the experience shows that strong shear force at mixing procedure is required for the purpose of homogeneous distribution of hydrated lime, having product-specific large surface area, in the asphalt mixture.

The selected asphalt mixture is a very used for a combined asphalt base and wearing course according to ÖNORM EN 13108-1 [1], ÖNORM B 3580-1 [2] and RVS 08.97.05 [3]. As rule, this asphalt mixture will be used for secondary roads and mostly placed as 4,0 – 8,0 cm thick single layer, but also for rural roads of the lowest load category defined in Austria. In this case the thickness of the placed layer is 4,0 – 9,0 cm.

The aims of comparative materials tests are the following:

- Comparative assessment of high and low temperature behaviour of the mentioned asphalt mixture modified by hydrated lime and without modification
- Comparative assessment of fatigue behaviour and stiffness of the asphalt mixture modified by hydrated lime and without modification
- Comparative assessment of characteristics of bitumen, recovered from the asphalt mixture modified by hydrated lime and without modification

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- Basing on results of carried out tests a statement is to be made about the changes in performance as well as the service life time of the asphalt layers containing hydrated lime and without it.

2. CONCEPT

Before both asphalt mixtures (with and without hydrated lime) have been produced in an asphalt mixing plant, comparative materials tests were carrying out in the testing laboratory for the purpose of the determination of binder content for both mixtures in such a way so as these mixtures show comparable volumetric values.

The paving grade bitumen 70/100 according to ÖNORM EN 12591 [4] and to ÖNORM B 3610 [5] as well as aggregates 0/2, 2/4, 4/8, 8/11 and 11/16 according to ÖNORM EN 13043 [6] and ÖNORM B 3130 [7] were used as basic materials for both asphalt mixtures.

As agreed, the aggregates of dolomitic nature – it means rock material with good adhesion to bitumen – was used.

2.1 Requirements concerning asphalt mixtures

The requirements of the Austrian regulation RVS 08.97.05 concerning these asphalt mixtures result from ÖNORM EN 13108-1 and the national implementation document ÖNORM B 3580-1.

Essential requirements are demonstrated in Table 1.

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Table 1

Parameter	Unit	Requirements according to RVS 08.97.05	Maximum range within type testing
Maximum grain size D	*mm*	16	-
Binder content	*% by mass*	$B_{min3,0}$	0,6
Void content	*% by vol.*	$V_{min0,5}$ / V_{max4}	2,0
Passing sieve d:22 mm	*% by mass*	100	12
Passing sieve d:16 mm	*% by mass*	90 - 100	12
Passing sieve d:11 mm	*% by mass*	70 - 88	12
Passing sieve d:2 mm	*% by mass*	25 - 45	12
Passing sieve d:0,5 mm	*% by mass*	12 - 27	12
Passing sieve d:0,063 mm	*% by mass*	4,0 - 10,0	4,0

Annex 1 contents an extract from the regulation RVS 08.97.05 and ONR 23580 [8], which describes in detail the requirements concerning asphalt mixtures.

2.2 Designed asphalt mixtures

Table 2 describes the composition of the asphalt mixtures, which are to be compared.

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Table 2

Parameter: Dosage	Parameter: Basic materials	Unit	Mixture without modification	Mixture modified by hydrated lime
Predosing	Dolomite 0/2	*% by mass*	37	37
	Dolomite 2/4	*% by mass*	12	12
	Dolomite 4/8	*% by mass*	17	17
	Dolomite 8/11	*% by mass*	14	14
	Dolomite 11/16	*% by mass*	20	20
Dosing in hot condition	Aggregates	*% by mass*	89,0	88,9
	Filler, size < 0,063 mm	*% by mass*	6,0	4,0
	Hydrated lime	*% by mass*	0,0	2,0
	Bitumen 70/100	*% by mass*	5,0	5,1

The intended filler content for both mixtures was specified as 7,5 % by mass. The category Ka_{25} in accordance with ÖNORM EN 13043 can be met by adding hydrated lime of 2,0 % by mass.

3. TESTS CARRIED OUT

According to the assignment general, prescriptive properties, performance related properties and performance based properties of both asphalt mixtures, which are to be compared, are to be evaluated. The prescriptive and performance based asphalt mixture properties have been evaluated by Nievelt Labor GmbH.

The performance based properties (asphalt and binder performance tests) occurred by order at the testing laboratory of the Technical University Vienna, Research Center of Road Engineering, Faculty of Civil Engineering, Institute of Transportation.

The overview of the test program carried out is described in Tables 3 and 4.

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Table 3

Asphalt tests	Standard	Mixture without modification 1)	Mixture modified by hydrated lime 2)	Tests carried out by
Prescriptive properties	RVS 08.97.05	X	X	Nievelt
Scheibler-Lime content 3)	ÖNORM L 1084	X	X	
Hydrated lime content 3)	TP Gestein-StB Part 3.9 [22]	X	X	
Performance related test of deformation ability, Wheel tracking test	ÖNORM EN 12697-22	X	X	
Performance based test of low temperature behaviour, Low temperature cracking and properties by uniaxial tension test (TSRST)	prEN 12697-46	X	X	TU Vienna
Performance based test of high temperature behaviour, Cyclic compression test	ÖNORM EN 12697-25	X	X	
Performance based test of stiffness behaviour, 4-points-bending-beam (4-PBB)	ÖNORM EN 12697-26	X	X	
Performance tests of resistance to fatigue, 4-points-bending-beam (4-PBB)	ÖNORM EN 12697-24	X	X	

1) AC 16 deck 70/100, A5,G7
2) AC 16 deck 70/100, A5,G7, Ka25
3) Evaluated on recovered granular material of < 0,063 mm

Table 4

Tests of bitumen	Standard	Mixture without modification 1)	Mixture modified by hydrated lime 2)	Tests carried out by
Bitumen recovery 3)	ÖNORM EN 12697-3	X	X	Nievelt
Penetration at 25 °C	ÖNORM EN 1426 [15]	X	X	
Softening point ring-and-ball	ÖNORM EN 1427 [16]	X	X	
Fraass breaking point	ÖNORM EN 12593 [17]	X	X	
Performance based test of high temperature behaviour, Complex shear modulus and phase angle (DSR)	ÖNORM EN 14770 [18]	X	X	TU Vienna
Performance based test of low temperature behaviour, Flexural creep stiffness (BBR)	ÖNORM EN 14771 [19]	X	X	

1) AC 16 deck 70/100, A5,G7
2) AC 16 deck 70/100, A5,G7, Ka25
3) from the mixture of binder and solvent (toluene)

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4. TEST METHODS AND CONDITIONS

4.1 Descriptive and performance related properties

Descriptive and performance related tests of asphalt mixtures properties occurred according to the requirements of ÖNORM EN 13108-1, ÖNORM EN 13108-20 [9], ÖNORM B 3580-1 and RVS 08.07.05.

Selected test methods and conditions meet the requirements of European test methods of EN 12697 [10], different parts. The deformation ability was determined within the wheel tracking test for 10.000 load cycles at the test temperature of 60 °C.

In order to recover binder the solvent toluene was used. During the tests of recovered bitumen all test conditions of the relevant European standards have been satisfied.

Lime and hydrated lime (calcium hydroxide) content were determined on granular material of < 0,063 mm, recovered from the asphalt mixtures.

4.2 Performance based properties

Performance based properties (asphalt and binder performance tests) were evaluated by the testing laboratory of the Technical University Vienna, Research Center of Road Engineering, Faculty of Civil Engineering, Institute of Transportation.

The final report of TU Vienna, project no. 11432, dated April 2012 [11], is attached as Annex 5 to the current project report. Test methods and conditions are also described in this annex.

Item 2 of the above mentioned report contains information about the preparation of specimen.

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5. TEST RESULTS

5.1 Asphalt mixtures properties

5.1.1 Descriptive properties

Both asphalt mixtures were manufactured in a big asphalt mixing plant in the South of Vienna on October 6, 2011. Approx. 400 kg of each asphalt mixture have been taken for future tests. Before the detailed materials tests, being basic for comparative assessment, have been started, the determination of characteristic mixture properties occurred for the purpose of the verification of selected mixture approach.

Table 5 below contains the comparison of evaluated asphalt mixture properties and their conformity with the requirements of RVS 08.97.05.

Table 5

Parameter	Standard	Unit	Mixture without modification	Mixture modified by hydrated lime	Requirement
Soluble binder content	ÖNORM EN 12697-1	*% by mass*	4,8	4,9	≥ 3,0
Max. specific density	ÖNORM EN 12697-5	*Mg/m³*	2,590	2,583	-
Bulk density	ÖNORM EN 12697-6	*Mg/m³*	2,512	2,498	-
Void content	ÖNORM EN 12697-8	*% by vol.*	3,0	3,3	2,0 - 4,0
Void content in aggregates		*% by vol.*	15	15	-
Voids filled with bitumen		*%*	79	80	-
Marshall stability	ÖNORM EN 12697-34	*kN*	10,3	9,6	-
Marshall flow		*mm*	4,1	4,1	-
Passing sieve 22 mm	ÖNORM EN 12697-2	*% by mass*	100	100	100
Passing sieve 16 mm			99	98	90 - 100
Passing sieve 11 mm			81	82	74 - 86
Passing sieve 2 mm			36	37	30 - 42
Passing sieve 0,5 mm			16	16	13 - 25
Passing sieve 0,063 mm			7,3	7,4	5,5 - 9,5

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The detailed evaluation of asphalt mixtures with and without hydrated lime is described in Annex 2 to this report.

5.1.2 Lime and hydrated lime content

Table 6 contains results of carried out tests.

Table 6

Filler tests	Unit	Mixture without modification	Mixture modified by hydrated lime
Scheibler-Lime content 1)	% by mass	100	84
Hydrated lime content 1)	% by mass	-	19,2 2)

1) Evaluated on recovered granular material of < 0,063 mm, the portion of hydrated lime is added to the lime content.
2) The recovery rate is approx. 70 % and is in terms of used aggregates unexpected low.

5.1.3 Wheel tracking test

From asphalt mixture samples test plates were prepared through the compaction of mixtures by rolling compaction segment according to the ÖNORM EN 12697-33. These plates have been installed into the wheel tracking test device and were tested in accordance with the requirements of ÖNORM EN 12697-22. Table 7 contains the summary of results, and Annex 3 – detailed test reports of Nievelt Labor GmbH.

Table 7

Asphalt tests	Unit	Mixture without modification	Mixture modified by hydrated lime
Average void content in the test plates	% by vol.	3,9	3,7
Average wheel tracking slope WTS_{air}	mm	0,22	0,17
Average rut depth RD_{air}	mm	11,8	9,0
Proportional rut depth PRD_{air} 1)	%	19	15

1) Thickness of test plates: 60 mm

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5.1.4 Performance based test of low temperature behaviour

The low temperature behaviour was evaluated by the laboratory of the Technical University Vienna, Research Center of Road Engineering, by means of cooling down (TSRST) in accordance with prEN 12697-46 [12]. Table 8 below and Figure 1 demonstrate the summary of results. The detailed results are in Annex 5 to the current report.

Table 8

Parameter	Unit	Mixture without modification			Mixture modified by hydrated lime		
Specimen no.	-	K311B	K311D	K311F	K312A	K312B	K312G
Void content	% by vol.	3,6	3,8	3,3	4,0	3,3	3,5
Void content 1)	% by vol.	3,6			3,6		
Failure stress 1)	N/mm²	4,03			4,66		
Failure temperature 1)	°C	-28,8			-27,1		

1) Average of three single values

Figure 1

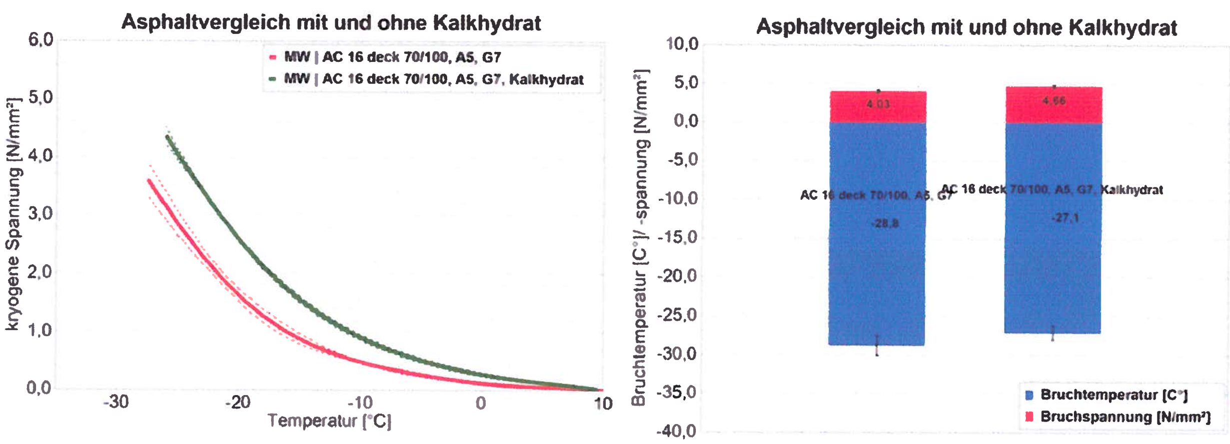

Figure 1: Summary of average values of both asphalt mixtures, copy from [11]

5.1.5 Performance based test of high temperature behaviour

The performance based test of high temperature behaviour was carrying out by the laboratory of the Technical University Vienna, Research Center of Road Engineering within a cyclic compression test according to the requirements of ÖNORM EN 12697-25. Table 9 and Figure 2 are dedicated to the summary of test results, which are in detail demonstrated in Annex 5.

Table 9

Parameter	Unit	Mixture without modification			Mixture modified by hydrated lime		
Specimen no.	-	T456A	T456B	T456C	T458B	T458C	T456D
Void content	*% by vol.*	3,6	2,6	2,5	3,0	3,0	4,6
Void content [1)]	*% by vol.*	2,9			3,4		
Creep [1)]	*°C*	-0,316			-0,310		

1) Average of three single values

Figure 2

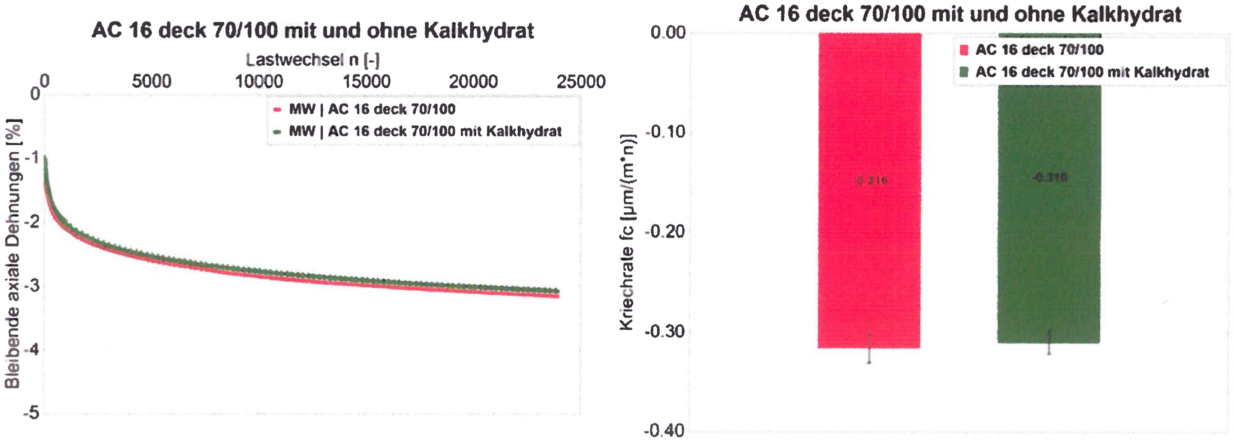

Figure 2: Summary of average values of both asphalt mixtures, copy from [11]

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5.1.6 Performance based stiffness and fatigue behaviour

Stiffness and fatigue behaviour has been evaluated by 4-points-bending beam (4-PBB) according to the requirements of ÖNORM EN 12697-26 [13] and ÖNORM EN 12697-24 [14] at the laboratory of the Technical University Vienna, Research Center of Road Engineering.

(1)
Due to the circumstance that the void content in the asphalt specimens influences on the stiffness test results, the laboratory of the Technical University Vienna, Research Center of Road Engineering did not consider the results, achieved on the test plate E428. This plate was manufactured from the asphalt mixture without hydrated lime (Scenario 1, see also the following issue (2)).

Extract from the report [11]: *"It is to be noted that the results of testing specimens of the plate E428 were not used because of the considerably lower void content. Also for this reason the void content in the mentioned specimens is not considered in the diagram [Note: stiffness, see Figures 3 and 4]".*

For a statement about the stiffness of both asphalt mixtures this description is sufficiently because the asphalt mixtures with hydrated lime and without addition of this component show significant differences. The following Figures 3 and 4 demonstrate the summary of results. The detailed results are attached to this report as Annex 5.

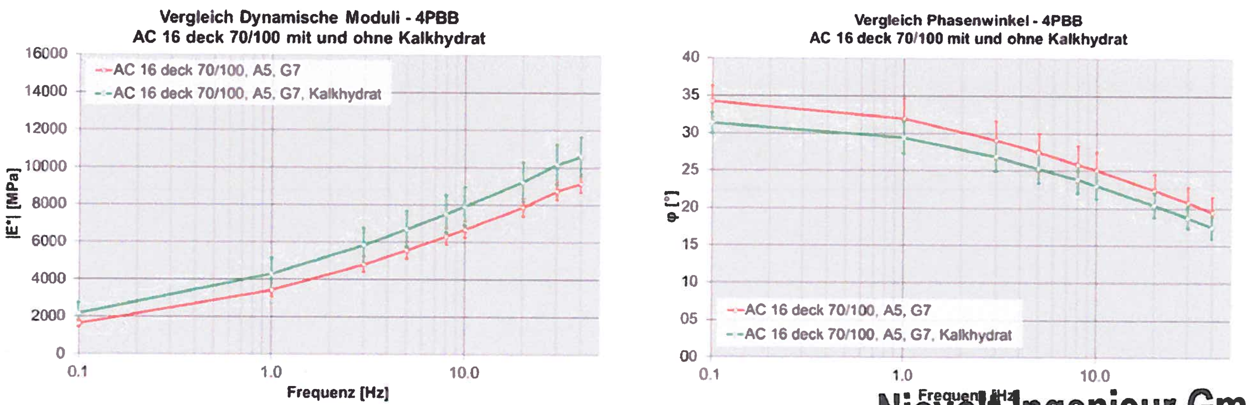

Figure 3: Summary of average values of both asphalt mixtures; copy from [11]

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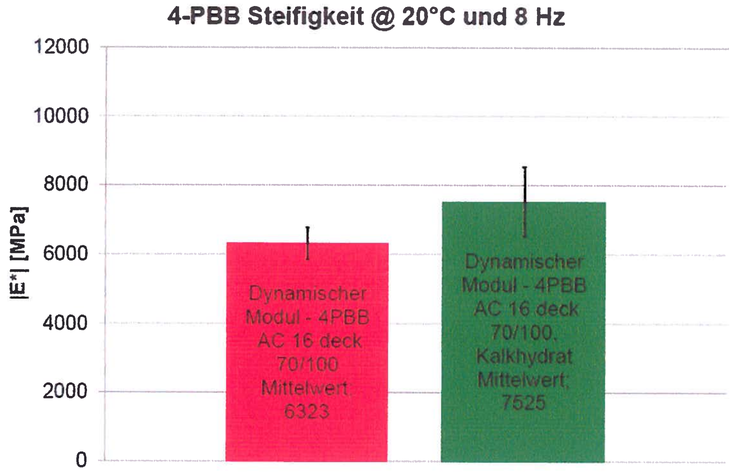

Figure 4: Summary of average values of both asphalt mixtures; copy from [11]

(2)

According to the literature about fatigue no any big differences between asphalt mixtures containing hydrated lime and without hydrated lime can be expected by comparison to the normal dispersion of fatigue tests. The dispersion of fatigue characteristics within all worldwide usual test methods is very high, and so the interpretation of test results is difficult. By reason of a small number of specimens specified in the relevant standard regulations, the application of the statistical method for identification of outliers is not possible and does not provide any usable results.

According to the applied standard regulations for 4-points-bending beam 6 specimens for each kind of asphalt and test frequency have been prepared. The dispersion of test values (the number of load repetitions until fatigue) is up to 600 % (!) and is very strong in comparison to possible influence of the modification of asphalt mixtures by hydrated lime. The dispersion of individual values at the evaluation of stiffness is significantly smaller.

So in order to evaluate the results of fatigue resistance tests different scenarios have been contemplated taking in account different test values.

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<u>Scenario 0:</u>

All individual results were contemplated without consideration of void content in specimens. The detailed analysis of void contents given in Tables 10 and 11, make obvious that the specimens of Plate E428 are denser than these ones of the other plates. But the difference against the other plates (specimens) is not even 1 % by volume and is thus in the range of the dispersion, which is usual for the determination of bulk and specific densities. It should be stressed that as rule the asphalt mixtures taken for tests will be placing in one layer of larger thickness. At good compaction on site it is possible to reach void content in this layer comparable with these one of the test plate E428.

<u>Scenario 1:</u>

All individual results except of the specimens prepared from Plate E428, were analysed (the void content in these specimens is E428A = 1,4 % by vol., E428B = 1,6 % by vol., E428C = 1,7 % by vol.). The evaluation of the Woehler curves occurred without taking into account of these three specimens.

<u>Scenario 2:</u>

At this scenario all prepared specimens have been evaluated except of these ones from Plate E428B (testing at another strain amplitude). For each strain amplitude (three different strain amplitudes for the asphalt mixture without hydrated lime and the same number of amplitudes for the asphalt mixture modified by hydrated lime) average values and standard deviations of <u>load repetitions until fatigue</u> have been calculated.

This was followed by the evaluation of 85 % - confidence interval (range: between the average value reduced about the standard deviation, and the average value increased about the standard deviation). All specimens having a smaller or higher number of load repetitions than the range were not taken into account at the evaluation of the Woehler curves.

So for the evaluation of the Wohler curves only those specimens were considered whose load repetition until fatigue meets the range of confidence interval of 85%.

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(3)

Tables 10 and 11 contain the complete results evaluated by the Technical University of Vienna (Scenario 0), as well as three additional columns regarding various scenarios of consideration of individual values.

Table 10

Specimen no. -	Void content % by vol.	Strain amplitude µm/m	Load repetitions until fatigue -	Stiffness at 100th load repetition MPa	S0 1)	S1 2)	S2 3)
E429B	3,2	260-216	108.882	6.591	-	-	X
E430C	2,6		76.750	7.513	-	-	-
E431A	2,3		58.846	8.372	-	-	-
E432B	2,9		34.768	7.564	-	-	-
E428C	1,7		38.373	8.856	-	X	-
E429C	3,4	200-201	284.603	7.017	-	-	-
E432C	3,2		171.121	7.431	-	-	X
E430A	2,3		329.570	7.723	-	-	-
E431B	2,4		328.004	8.514	-	-	-
E428A	1,4	160	710.189	9.554	-	X	-
E430B	2,3	140-141	2.848.891	7.937	-	-	-
E431C	2,5		805.849	8.539	-	-	-
E429A	2,8		810.331	7.697	-	-	-
E432A	2,8		3.617.219	7.782	-	-	X
E433B	2,4		2.778.225	8.139	-	-	-
E428B	1,6	100	9.809.640	9.541	-	X	X

1) Scenario 0 (all individual results)
2) Scenario 1 (without results evaluated on the test plate E428)
3) Scenario 2 (individual results within the range of load repetitions until fatigue)

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Table 11

Specimen no. -	Void content Vol.-%	Strain amplitude µm/m	Load repetitions until fatigue -	Stiffness at 100th load repetition MPa	S0 1)	S1 2)	S2 3)
E434C	2,7	257-261	61.038	7.931	-	-	-
E435B	2,4		47.325	7.620	-	-	-
E436C	2,9		57.206	7.987	-	-	-
E437A	3,2		61.655	8.407	-	-	-
E439C	2,9		20.040	9.778	-	-	X
E438B	2,9		87.006	8.578	-	-	X
E436A	2,6	198-200	433.011	8.165	-	-	-
E438C	3,1		168.312	9.365	-	-	X
E439A	2,9		188.232	9.853	-	-	-
E434A	2,6		501.010	8.554	-	-	-
E437B	3,1		300.007	8.988	-	-	-
E434B	2,5	140	1.080.031	8.992	-	-	X
E435A	2,5		3.244.138	8.510	-	-	-
E436B	2,2		1.729.010	9.014	-	-	-
E437C	3,6		4.275.976	9.369	-	-	-
E438A	2,8		4.548.035	9.777	-	-	-
E439B	3,1		6.529.602	9.916	-	-	X

1) Scenario 0 (all individual results)
2) Scenario 1 (without results evaluated on the test plate E428); it concern only one plate without hydrated lime (Scenario 0 is equal to Scenario 1)
3) Scenario 2 (individual results within the range of load repetitions until fatigue)

(4)

Figure 5 below demonstrates the Woehler curves for Scenario 2 (individual results within the range for the parameter "Load repetition until fatigue") worked out by Nievelt Ingenieur GmbH and resulting from the values evaluated by the Technical University Vienna, Research Center of Road Engineering.

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This figure describes the correlation between the strain amplitude ε and the number of load repetitions until fatigue $N_{f/50}$.

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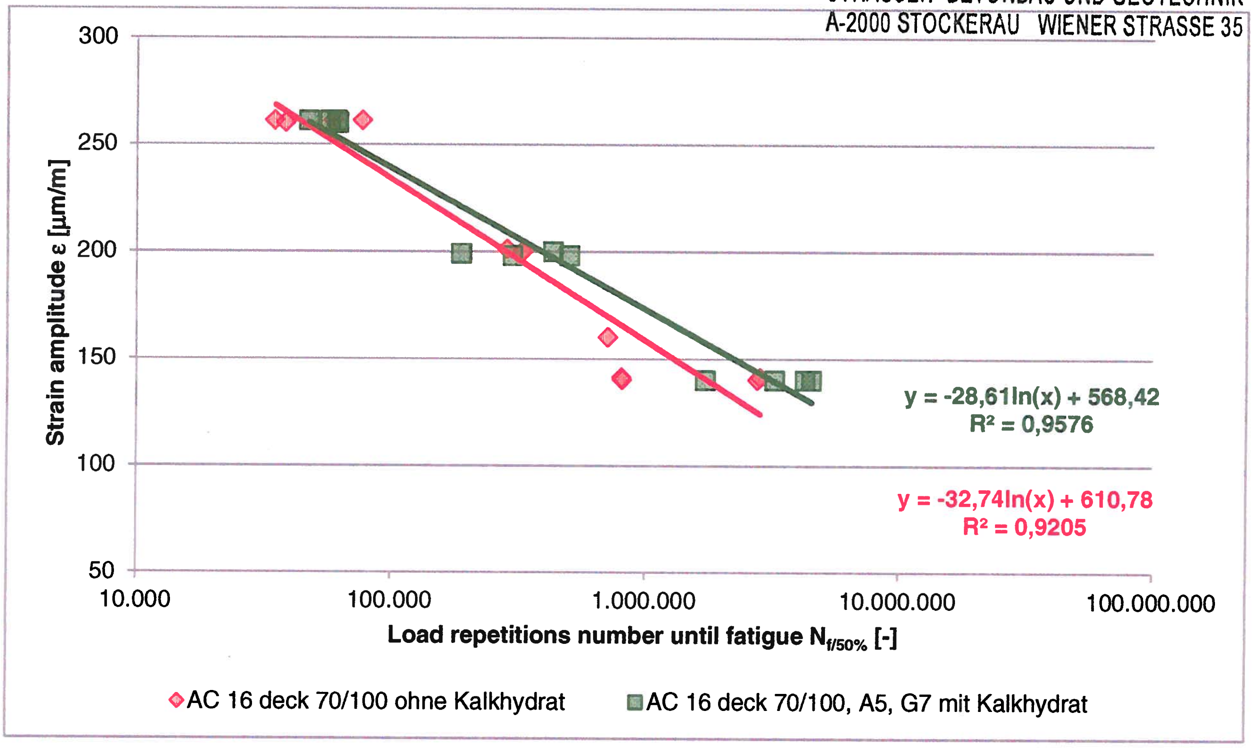

Figure 5: Woehler curve for Scenario 2

(5)

Figure 5 contains also linear regression equation in a double logarithmic function for Scenario 2. Taking into account of this equation a so called durability ε_6 for both asphalt mixtures within the assumed different scenarios can be calculated basing on the number of load repetitions (1.000.000) required by the relevant standard. Table 12 illustrates the results of these calculations also in regard to Scenarios 0 and 1.

For being in the position to evaluate the fatigue effect of different asphalt mixtures at different strain amplitudes (150, 200 und 250 µm/m) load repetitions until fatigue for single scenarios were calculated involving the linear regression equation and also comparatively described.

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Detailed results for Scenarios 0, 1 and 2 are in Annex 4 and the comparative description is in Table 12.

Table 12

Parameter	Unit	Scenario S0 1)		Scenario S1 2)		Scenario S2 3)	
Asphalt mixture AC 16 deck 70/100	-	without Ka	with Ka	without Ka	with Ka	without Ka	with Ka
Strain amplitude ε_6 Durability $N_{I/50} = 10^6$ LW	µm/m	164	172	163	172	158	173
Alteration of durability	%	-	**+5**	-	**+5**	-	**+9**
Alteration of stability at strain amplitude of **250** µm/m	%	-	-10	-	-17	-	**+12**
Alteration of stability at strain amplitude of **200** µm/m	%	-	+15	-	+12	-	**+39**
Alteration of stability at strain amplitude of **150** µm/m	%	-	+48	-	+50	-	**+74**

1) Scenario 0 (all individual results)
2) Scenario 1 (without results evaluated on the test plate E428)
3) Scenario 2 (individual results within the range of load repetitions until fatigue)

(6)
Due to the strong dispersion of individual results it is difficult to access the significance of the test results. If you consider each confidence interval in regard to the Woehler curves of the asphalt mixtures modified by hydrated lime as well as without modification, they overlap. As described, the reason is that there is a very strong dispersion within the test of fatigue in comparison with the influence of the modification by hydrated lime.

5.2 Characteristics of recovered bitumen

5.2.1 General characteristics

Binder has been recovered from both asphalt mixtures. The test results are shown in the table 13.

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Table 13

Bitumen tests	Standard	Mixture without modification [1)]	Mixture modified by hydrated lime [2)]
Penetration at 25 °C	ÖNORM EN 1426	59	57
Softening point - Ring and Ball	ÖNORM EN 1427	51,1	52,9
Fraass breaking point	ÖNORM EN 12593	-12	-11

1) AC 16 deck 70/100, A5, G7
2) AC 16 deck 70/100, A5, G7, Ka25
3) Recovered from the binder-solvent mixture (solvent toluene)

5.2.2 Performance based dynamic shear modulus and phase angle

The binder for the determination of performance based characteristics of bitumen has been recovered by Nievelt Labor GmbH and delivered to the laboratory of the Technical University Vienna, Research Center of Road Engineering.

The diagrams in Figure 6 show the results of the determination of complex shear modulus and phase angle of both binder systems. The evaluated values (DSR) characterize the binders at high temperatures.

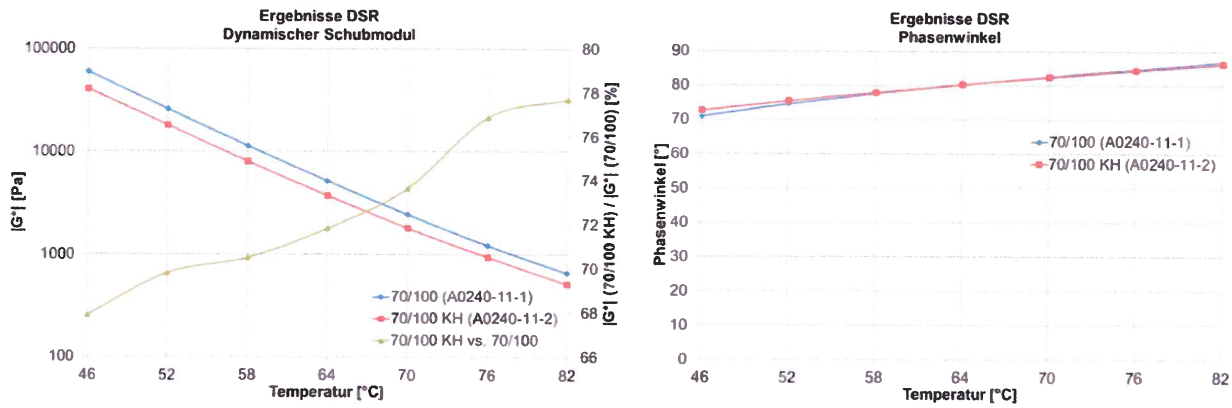

Figure 6: Summary of average values of both asphalt mixtures, copy from [11]

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5.2.3 Performance based flexural creep stiffness of bitumen

The binder for the determination of performance based characteristics of bitumen has been recovered by Nievelt Labor GmbH and delivered to the laboratory of the Technical University Vienna, Research Center of Road Engineering.

The diagrams in Figure 7 show the results of the determination of flexural creep stiffness and relaxation behaviour of both binder systems. The evaluated values (DSR) characterize the binders at low temperatures.

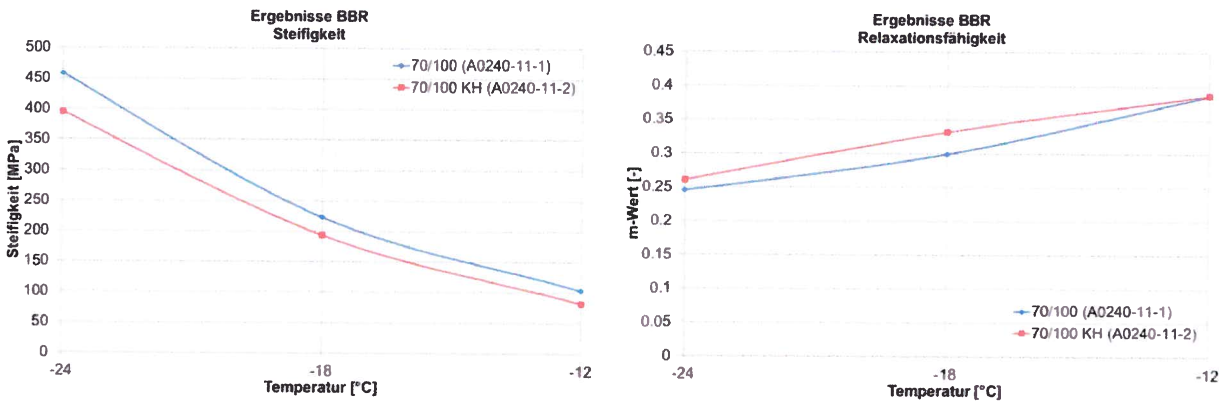

Figure 7: Summary of average values of both asphalt mixtures, copy from [11]

6. INTERPRETATION OF RESULTS

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6.1 General

The comparative assessment of asphalt mixture containing hydrated lime and without modification occurred in regard of asphalt mixture AC 16 deck 70/100, A5, G7. This asphalt mixture was manufactured in an asphalt mixing plant using identical mix design. The only difference between both mix designs is that the pure calcium hydroxide of 2,0 % by mass in accordance with ÖNORM EN 459-1 has been added into the asphalt mixer directly.

The carried out tests of asphalt mixture show for both asphalt mixtures comparable volumetric characteristics (void content, void content in mineral material, voids filled with binder) as well as comparable particle size distributions. Considering the usual recovery rate the addition of hydrated lime could be confirmed within the test of the filler recovered from one of both asphalt mixtures. The recovery rate of 70% is very low, what could be caused by not homogeneous distribution of hydrated lime in the asphalt mixture.

In order to achieve the same void content in the asphalt mixture the binder content at the mix design for the asphalt mixture with hydrated lime was increased about 0,1% by mass.

For the production of both asphalt mixtures a non-adhesive critical rock material (aggregates of dolomitic nature) was chosen. This choice was agreed with the Client with the objective not to superimpose the positive influence of the added hydrated lime on the adhesion between the binder and aggregates with the performance based characteristics, which are to be evaluated.

6.2 Characteristics of recovered bitumen

General as well as performance based characteristics of recovered bitumen have been evaluated (see Table 13 and Figures 6 and 7 for results).

From the evaluated general characteristics, such as penetration at 25 °C, softening point ring-and-ball and Fraass breaking point, can be derived that bitumen used for the production of the asphalt mixtures in the asphalt mixing plant, is soft bitumen 70/100. This circumstance influenced also on the results of triaxial test at the temperature of 50 °C (see the definition of the problem in Item 6.4).

The comparison of the determined complex shear modulus and phase angle of both recovered binders show that the stiffness of bitumen from the asphalt mixture containing hydrated lime at high temperatures (DSR) is lower that of this one from the asphalt mixture without hydrated lime. The phase angle at high temperatures is comparable. There is no difference in regard to the viscosity of both binders.

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The results of the determination of the flexural creep stiffness and of the relaxation behaviour of bitumen samples by means of BBR paint different pictures than those of the asphalt mixtures evaluation. As illustrated in Figure 7, the binder from the asphalt mixture containing hydrated lime shows lower stiffness and better relaxation behaviour at low temperatures.

The results of recovered bitumen tests appear only partly plausible. So the question is whether the changes in behaviour of recovered bitumen can generally be detected. Having big surface, hydrated lime affects first of all the mastics of the asphalt mixture, and not any big changes in bitumen characteristics are visible.

Obviously, the application of soft bitumen 70/100 had an adverse effect on the evaluation of the deformation behaviour at high temperatures. Because of the test temperature at the wheel tracking test as well as at the cyclic compression test is above the softening point of the mentioned bitumen, larger deformations than expected resulted at wheel tracking test, but at the cyclic compression test not any significant difference was observed.

6.3 Low temperature behaviour

For the comparative assessment of the low temperature behaviour results of cool down tests were used.

The comparison of the test results for both asphalt mixtures show (see Figure 1 and Table 8) that at cooling down the asphalt mixture containing hydrated lime receives more serious cryogenic stress.

The failure temperature of both asphalt mixtures (as key parameter of failure due to the overrun of the tensile strength) is almost the same (-28,8 and -27,1 °C), because the asphalt mixture containing hydrated lime can obviously absorb much stronger cohesive strength. Regarding the parameter of crack formation at cold weather both asphalt mixtures are according to the highest class known in Austria.

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In summary, it can therefore be said that through small differences in failure temperature no significant degradation of low temperature characteristics of this asphalt mixture sort can be expected. As a further test a comparative test of "tensile strength reserve" would be recommended. This reserve can be determined by means of superposing of results of uniaxial tension test at low temperature by results of common uniaxial tension test.

6.4 High temperature behaviour

The high temperature behaviour of both asphalt mixtures can be evaluated basing on results of wheel tracking tests (see Table 7) as well as of cyclic compression test (see Table 9 and Figure 2).

The wheel tracking tests show that the rut depth in case of the asphalt mixture containing hydrated lime is smaller. This circumstance confirms the improvement of the high temperature behaviour by adding hydrated lime to the asphalt mixture.

But this fact could not be stated during triaxial tests, because both asphalt mixtures show the same creep rate and hence the comparable high temperature behaviour. Although the high temperature behaviour has no significance in case of tested asphalt mixtures due to their application at secondary roads, this result based on results of wheel tracking test and on previous investigations [20] is not plausible.

Possibly it is caused by the test temperature (50 °C) required by the relevant standard. This temperature is already either above or of the softening point of tested bitumen 70/100, and this could affect the triaxial test.

Usually the high temperature behaviour of asphalt mixtures for base and wearing courses will not be tested (requirement of the relevant standard), and asphalt mixtures for binder and base and wearing courses will be tested mainly at the temperature of 40°C.

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6.5 Stiffness

For the evaluation of dynamic stiffness the results of temperature- and frequency-dependant tests with 4-points-bending beam (see Figures 3 and 4) were used.

If the results concerning both asphalt mixtures will be comparing in regard to stiffness and viscosity, than the stiffening of asphalt mixture by addition of hydrated lime can be derived across the whole frequency spectrum.

The phase angles evaluated within dynamic tests, show that across the frequency spectrum the asphalt mixture without hydrated lime is reacting more viscous.

Figure 4 demonstrates comparatively the value of 4-PPB stiffness at 8 Hz and 20°C for the asphalt mixture AC 16 deck 70/100, A5, G7 containing hydrated lime - (7.525 MPa) and (6.323 MPa) without addition of hydrated lime.

So the stiffness of the asphalt mixture containing hydrated lime is approx. above 19 % higher.

6.6 Fatigue behaviour

The evaluation of fatigue behaviour within fatigue testing, comparatively between the asphalt mixtures with and without hydrated lime, is difficult due to the great variability of individual values. This variability is caused not by the tested asphalt mixtures, but by the test method required by the standard regulation.

For this reason different scenarios by using different individual values according to precisely defined criteria, were taken into consideration. These ones are described in details in Item 5.1.6 (2).

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Results (Woehler curve for Scenario 2, Figure 5) and calculations (Table 12 and Annex 4) show that the asphalt mixture containing hydrated lime has an extended durability (between 5 % and 9 %). According to the standard, a strain amplitude ε_6 at 10^6 load repetitions will be calculated for this criterion.

If the durability of the asphalt mixture at strain amplitudes of 150, 200 and 250 µm will be compared, than it will be obvious that at small strain amplitudes the addition of hydrated lime improves the fatigue characteristics increasingly. This circumstance is arising from the stiffening effect of hydrated lime in the asphalt mixture and seems to be logical.

Hence it is derivable that the effect of improvement of the fatigue characteristics at small bending under load is higher (tick asphalt pavements), than at big ones (thin asphalt pavements).

For the calculation of allowed standard load repetitions, and in this way also of the service life of an existing or a new asphalt construction, the stiffness of asphalt layers and the failure criteria (fatigue properties, Woehler curves) are of importance. If the higher stiffness of approx. 19 % resulted from materials testing (Item 6.5), will be inputted in a multi-layer program for calculation of deformation values, so in any case a smaller tensile strain on the bottom edge of the asphalt construction will be achieved depending to the constructive assumptions.

Depending on the failure criterion, the small tensile strain on the bottom edge of the asphalt construction leads inevitably to increasing of allowed standard load repetitions and in this way to a prolongation of the life time.

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7. SUMMARY

Results of comparative tests of asphalt mixtures containing hydrated lime and without modification can be summarized as follows:

General:

- The comparability of general characteristics has been confirmed. Both asphalt mixtures were composed similarly except of the portion of hydrated lime.
- For further bitumen tests in connection with the modification by hydrated lime it doesn't make sense to carry out these ones using recovered bitumen. Hydrated lime affects through its big surface area first of all the mastics of asphalt mixture, and so no significant changes in bitumen parameters are obvious.

Low temperature behaviour:

- Not any significant difference between the asphalt mixtures has been determined. Caused by a big surface area of hydrated lime the breaking temperature of the asphalt mixture containing hydrated lime is lower.
- Both asphalt mixtures are according to the highest class known in Austria in regard to low temperature cracking.

High temperature behaviour:

- From wheel tracking test it was derived that the deformation ability of the asphalt mixture containing hydrated lime is above approx. 20 % higher. At the same service life rut depth in case of the asphalt mixture containing hydrated lime is smaller.
- Possibly through the low viscosity of the used bitumen 70/100 no any improvement of characteristics could be achieved within the cyclic compression test. Both asphalt mixtures show the same creep rate and similar high temperature behaviour.

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Stiffness:

- The stiffness of the asphalt mixture containing hydrated lime is approx. 19 % higher than this one of the same asphalt mixture but modified by hydrated lime.

Fatigue behaviour:

- The addition of hydrated lime positively affects fatigue characteristics of the tested asphalt mixture. Due to the big variability of individual test values during testing by means of test methods in accordance with the European standards, an exact quantification is difficult.
- The durability from +5 % to +9 % at 10^6 load repetitions will be achieved by addition of hydrated lime depending on the observation of single values.
- For the calculation of allowed standard load repetitions the stiffness of asphalt layers is also of importance. Because of the fact that the stiffness of the asphalt mixture containing hydrated lime is approx. 19 % higher, at the same conditions (all asphalt layers are modified by hydrated lime, the same stiffness of unbound courses, the same loading, etc.) the tensile strain at the bottom edge of the asphalt construction is reduced about approx. 10 % (depending on the thickness of the whole asphalt pavement). The reduction of the tensile strain at the bottom edge of the asphalt construction leads in regard to the fatigue to the prolongation of the lifetime.
- If the durability and the stiffening effect of hydrated lime will be superposed for the evaluation of the fatigue behaviour, than the improvement in the range of 10 % - 15 % for usual pavement constructions can be assumed. It is impossible to declare any precise values, because these ones are under influence of additional conditions such as the thickness of the pavement.

Ing. Helmut Nievelt Dr. Martin Buchta

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Expert Head of Engineering Office

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