Asphalt mixture performance and testing

Development of High-Performance Asphalt Mixes

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Abstract

The purpose of our research is to develop a high-performance, long-life asphalt mix by adding hydrated lime. Nowadays the average lifetime of asphalt surfaces varies between 10 to 15 years, which can be extended if the asphalt contains hydrated lime. During our research process we designed 10 different asphalt mixes, each with different hydrated lime doses (0-10-15-20-25-30% hydrated lime/limestone filler) and tested the following properties: • Water sensitivity according to EN 12697-12 • Wheel tracking resistance according to EN 12697-22 with small wheel equipment in air • Fatigue resistance according to EN 12697-24, two-point bending test with trapezoidal specimens • Stiffness modulus according to EN 12697-26, IT-CY test • Low temperature cracking properties according to EN12697-46, TSRST test After evaluating the laboratory tests, we selected the best properties and the respective hydrated lime dosage ratio for the each mix type. With ALIZE software we modelled different pavement solutions focusing on mechanical parameters and could detect the beneficial effect of hydrated lime on the mixtures compared to reference (without hydrated lime). Finally, we chose an SMA 11 mF 25-55 / 65 and an AC 22 binding mNM 10-40 / 65 mix to construct a trial section on an internal roadway of an asphalt-mixing plant, so that we could monitor the exact traffic load on the pavement structure. The trial section is divided into two parts: one built with a hydrated lime mix and one without. Dynamic sensors (stain gages) are inserted into and between the asphalt layers and linked by data logger units to test the pavement structure’s longitudinal behaviour. Our research, started in 2017, finishes with building the trial section in 2018. Our presentation shows the related laboratory test results, the layout of the pavement structure, the construction of the trial section and the first results of its behaviour.

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1. INTRODUCTION

Road transportation has been increasing in the past decade. More and more vehicles use the road network and hence the proper road pavement structure has an essential role. The vast part of Hungarian road network was built with asphalt pavement and its service lifetime is an economical and engineering issue as well. Therefore, the objective of this study is to develop long-life asphalt mixtures by adding hydrated lime filler. Though its usage is well known in the road construction industry, there has not been a significant improvement concerning the usage of hydrated lime in Hungary. In the frame of this study 10 various asphalt mixtures with different hydrated lime dosage were designed and tested under laboratory conditions. The optimal lime content was determined based on the asphalt mechanical properties (e.g. fatigue behaviour, stiffness, rutting resistance). After choosing the most appropriate job mix formula, two asphalt mixtures containing hydrated lime were selected to build a test section in order to examine their on-site performance. These asphalt mixtures were produced in asphalt mixing plant. The laboratory and on-site tests were performed by Central Laboratory of Colas Hungary.

2. RESEARCH BACKGROUND

The effects of using hydrated lime in asphalt mixtures have often been studied over the last decade. In most cases, the focus was on the improving pavement performance due to better fatigue behaviour [1]. A significant proportion of research projects found a better fatigue resistance using hydrated lime in different asphalt mixture types [2, 3, 4]. In addition, the highest improvement rates have been verified in the moisture resistance and the lower scale of ageing [5, 6, 7, 8, 9]. A conclusion of a research project showed that the stiffness of bitumen mortar was improved in contrast with an other research project [6], where the stiffness modulus of asphalt mixtures showed no significant increase by adding hydrated lime [10]. In that study, a stronger effect of hydrated lime was found on the paving grade bitumen compared to the polymer modified bitumen (PmB).

The field experience showed that using hydrated lime in asphalt mixture had no negative effect on the compactibility [8]. The in situ measurements of compaction using γ-nuclear gauge confirmed a good compaction degree of SMA surface layer. The variability of compaction within the test sections with hydrated lime were lower than within the reference section.

3. MATERIALS AND TEST METHODS

As first step, ten existent job mix formula were selected, which are commonly used in Hungary. They were mixed in laboratory with six different hydrated lime dosage between 0% - 10% - 15% - 20% - 25% - 30% of the asphalt filler. The asphalt mixtures were the following types:

- SMA 11 surface (mF) 25/55-65,
- AC 11 surface (F) 50/70,
- AC 11 surface (mF) 25/55-65,
- AC 22 binder (mF) 25/55-65,
- AC 22 binder (F) 50/70,
- AC 16 surface (F) 50/70,
- AC 16 binder (mNM) 10/40-65,
- AC 16 surface (mF) 25/55-65,
- AC 16 binder (mNM) 25/55-65.

The three binder types were tested neat, as mortar with filler and with various hydrated lime dosages. Raw material tests were performed on the selected aggregates. Asphalt tests were performed on each mixtures, which are listed in Table 1. and Table 2. with the adherent European Standards.

Table 1. List of performed bitumen tests and the adherent European Standards

Determination of the softening point. Ring and Ball method	EN 1426:2016
Determination of needle penetration	EN 1427:2016
Determination of the Fraass break point	EN 12593:2007

Table 2. List of performed asphalt tests and the adherent European Standards

Determination of stiffness modulus (IT-CY test and 2PB)	EN 12697-26:2012 Appendix "C"
Fatigue test (2PB)	EN 12697-24:2013 Appendix "A"
Determination of the water sensitivity	EN 12697-12:2009 method "A"
Low temperature cracking and properties by uniaxial tension tests TSRST	EN 12697-46:2012
Wheel tracking test (small wheel)	EN 12697-22:2003+A1:2008

4. LABORATORY TEST RESULTS

As the aggregate tests were only performed to verify their conformity to the European and Hungarian Standards, they are not imparted in this study.

During the laboratory phase of this study approximately 54 bitumen tests and 300 asphalt mixture tests were performed.

The three different bitumen were tested with and without filler part. The compound of the mortar was 62,5 v% of bitumen and 37,5 v% of filler. The filler had different hydrated lime content with 10 m%, 15m %, 20 m%, 25 m% and 30 m% and also without hydrated lime. Figures 1-2-3. present the percentage change of basic parameters comparing to neat bitumen as a result of filler and the different hydrated lime dosage. LF is marked, where limestone filler was mixed into asphalt mixtures. If hydrated lime (HL) was mixed, the marking also contains the added amount of hydrated lime as a given part of filler.

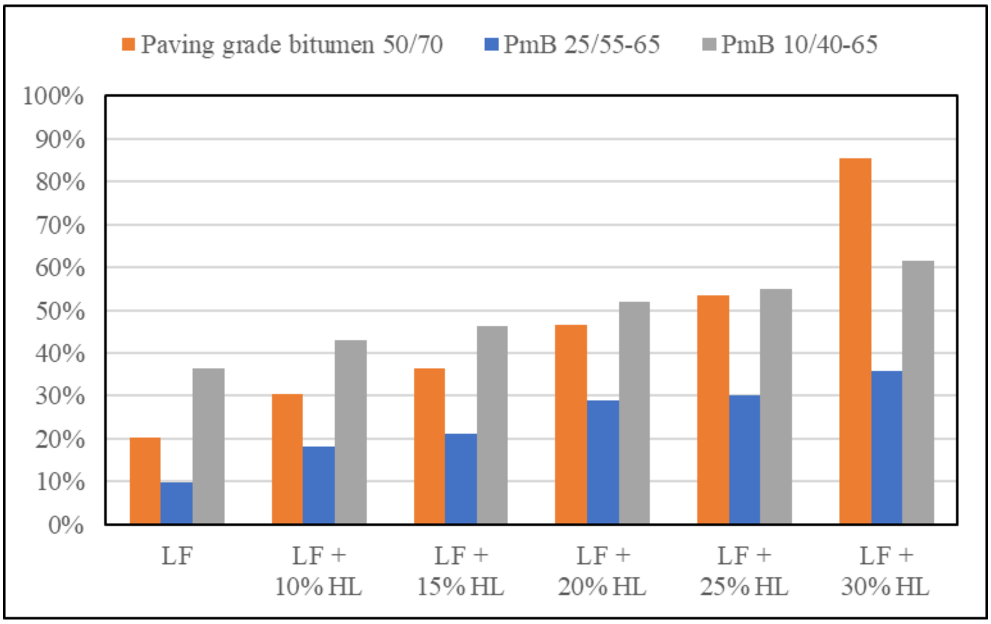

Figure 1. Increase of softening point R&B of mortars comparing to neat bitumen parameter

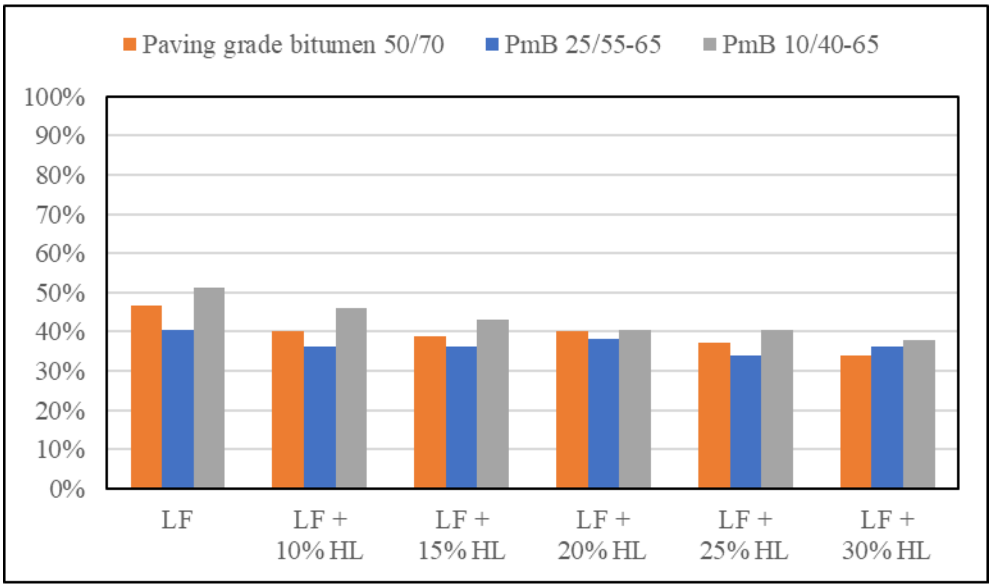

Figure 2. Decrease of needle penetration of mortars in percent of neat bitumen penetration (100%)

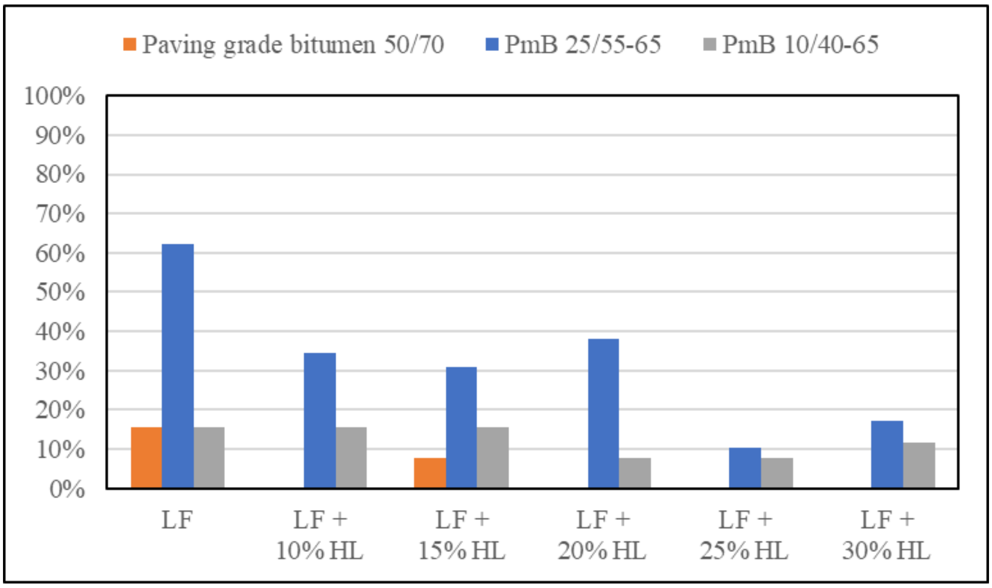

Figure 3. Percentage decrease of Fraass breaking point comparing to neat bitumen parameter

From the bitumen test results the followings can be concluded:

- Softening point increases as the HL content increases. Based on the difference of the maximum and minimum value the paving grade bitumen 50/70 is the most sensitive to the changing of HL content.
- Needle penetration decreases up to 35-50% as filler and hydrated lime are added to the bitumen. The PmB 25/55-65 is the least sensitive to the changing of HL content.
- There is little or no decrease in Fraass breaking point at paving grade bitumen 50/70 and just a little changing at PmB 10/40-65. However, the Fraass breaking point shows a significant increase at PmB 25/55-65 as filler is added, this effect is less prevailing with increasing of HL dosage.

All laboratory tests in Table 2. were performed on 10 types of asphalt mixtures. Figure 5. and 6. show the results of two, in Hungary frequently used asphalt mixture types, which were selected to present the development of parameters. At the other 8 asphalt mixtures the similar trends can be observed at various HL contents.

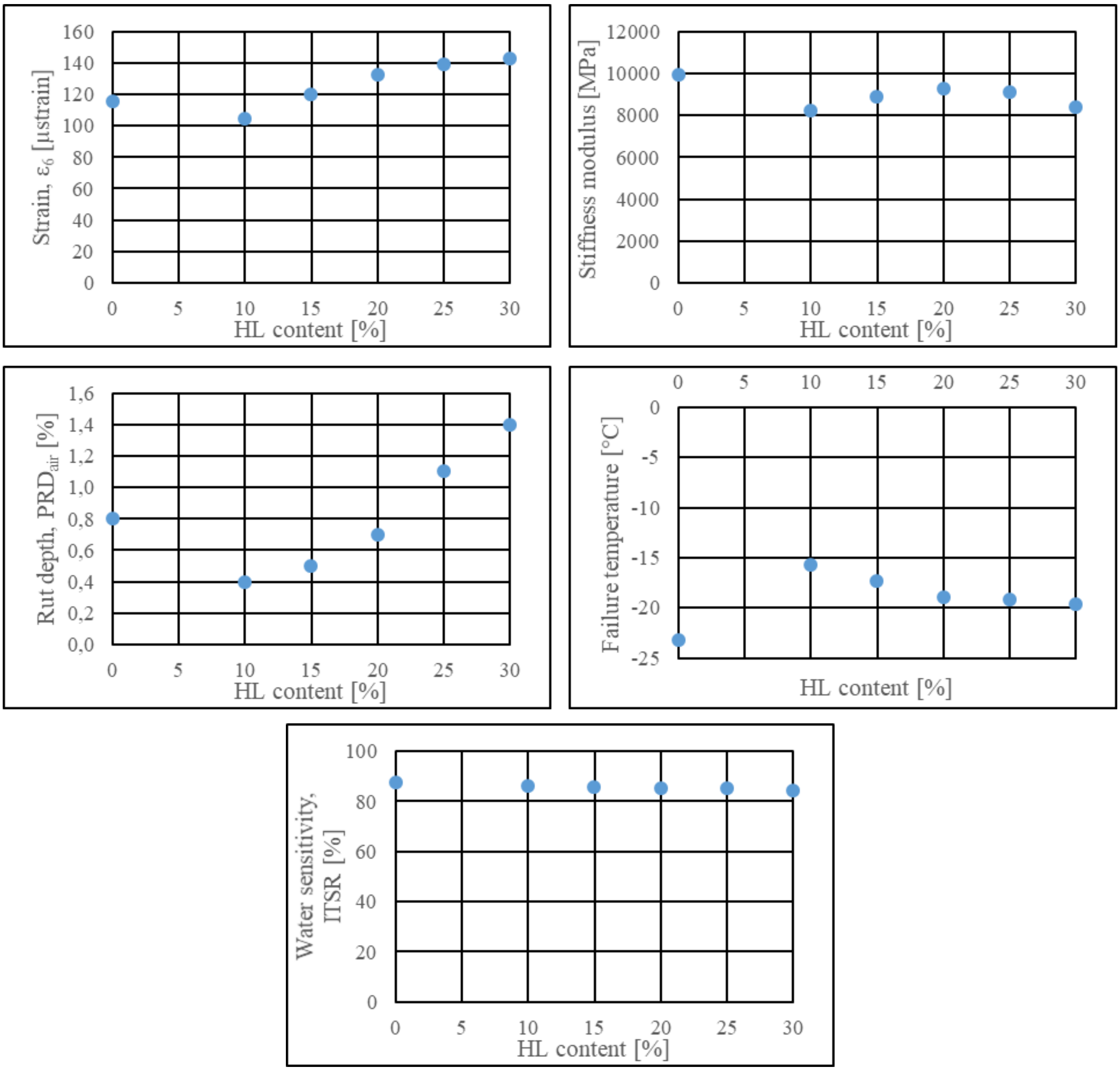

Figure 4. a-e Mechanical properties of AC 22 binder (mNM) 10/40-65 as a function of HL dosage

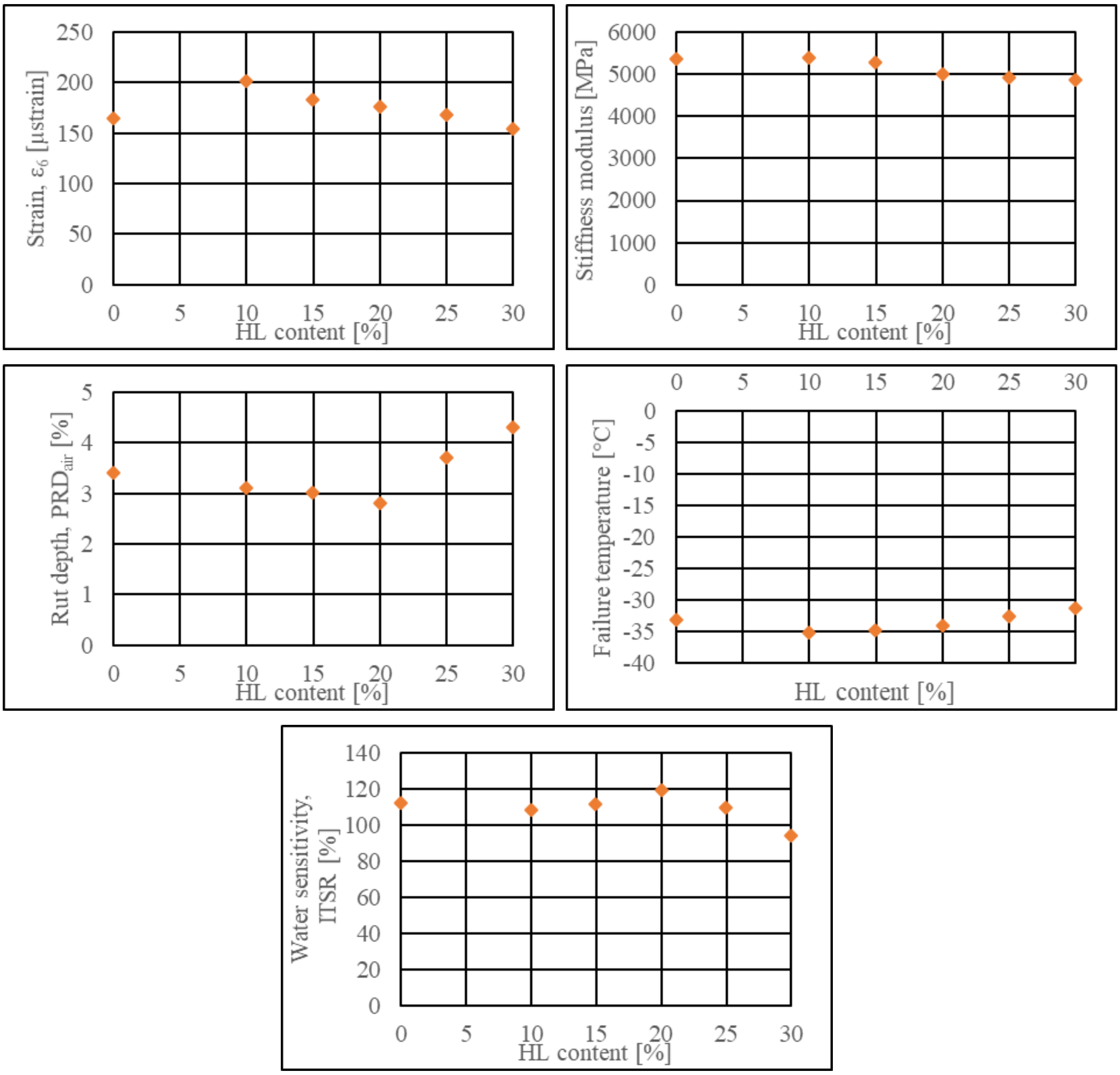

Figure 5. a-e Mechanical properties of SMA 11 surface (mF) 25/55-65 as a function of HL dosage

Based on the asphalt test trends, the following observations can be made generally:

- Fatigue behaviour is improved up to 15-20 m% of HL dosage, then the further adding of HL has less positive effect on this performance parameter.
- Stiffness moduli of asphalt mixtures decrease with increase of HL content.
- Water sensitivity increases as HL is added, but the highest indirect tensile strength ratio (ITSR) value of various asphalt mixtures was measured at different HL content.
- The 10-15 m% HL dosage results the best rutting resistance at various asphalt mixtures.
- At low temperature behaviour no general conclusion can be made. At 5 asphalt mixtures the increase of HL content resulted improvement in this parameter.

5. EVALUATION WITH MULTI CRITERIA DECISION MATRIX

To build a trial section and monitor its performance, two most commonly built asphalt mixture types were selected according to the Hungarian pavement design practice, which are fitted to the circumstances of the planned trial section.

Multi criteria decision matrices (MCDM) were used to determine the preferred dosage of hydrated lime as a part of filler. The weights of matrix were given based on the function and required performance of different asphalt layers. Rankings between basic asphalt mixture and asphalt mixtures with different hydrated lime content were determined based on the laboratory test results by each asphalt mixtures test. Score 1 means the best performance, score 6 means

the lowest one in the ranking. It has to be mentioned here that the rankings do not take into account the measure of difference between the performance results.
Table 3. shows the result of MCDM of AC 22 binder (mNM) 10/40-65 mixtures. The weights were fitted to the expected role of binder course.

Table 3. Multi criteria decision matrix of binder course mixtures examined in laboratory

Criteria	Weighting [%]	Asphalt mixtures					
		Basic	Hydrated lime dosage on filler part [%]				
			10	15	20	25	30
		Score					
Fatigue resistance (ε_6)	45	5	6	4	3	2	1
Stiffness modulus (MPa)	30	1	6	5	2	3	4
Low temperature behaviour (°C)	10	1	6	5	4	3	2
Rutting resistance (%)	10	4	1	2	3	5	6
Water sensitivity (%)	5	1	2	3	4	5	6
	Totals:	310	530	415	285	285	***275***

Based on the MCDM of binder course mixtures the job mix formula with 30 mass percent hydrated lime dosage was chosen to be built in the trial section.

Table 4. summarizes the determined weights and rankings of SMA 11 surface (mF) 25/55-65 asphalt mixtures.

Table 4. Multi criteria decision matrix of surface course mixtures examined in laboratory

Criteria	Weighting [%]	Asphalt mixtures					
		Basic	Hydrated lime dosage on filler part [%]				
			10	15	20	25	30
		Score					
Fatigue resistance (ε_6)	35	5	1	2	3	4	6
Stiffness modulus (MPa)	25	2	1	3	4	5	6
Low temperature behaviour (°C)	15	4	1	2	3	5	6
Rutting resistance (%)	15	4	3	2	1	5	6
Water sensitivity (%)	10	2	5	3	1	4	6
	Totals:	365	***170***	235	275	455	600

Based on Table 4. the SMA 11 surface (mF) 25/55-65 asphalt mixture with 10 mass percent hydrated lime showed the best performance under laboratory conditions. This job mix formula was chosen to be built in the trial section as surface course.

Table 5. and Table 6. summarize the laboratory test results of chosen asphalt mixtures, which were built in the trial section next to the reference section without added HL as filler.

Table 5. Laboratory test results of AC 22 binder (mNM) 10/40-65

Parameter	Hydrated lime content of filler part					
	0%	10%	15%	20%	25%	30%
Fatigue resistance (ε_6)	116	105	120	133	139	**143**
Stiffness modulus [MPa]	9974	8246	8393	9293	9108	**8852**
Water sensitivity [%]	87,8	86,1	85,7	85,2	84,9	**84,5**
Rutting resistance [%]	0,8	0,4	0,5	0,7	1,1	**1,4**
Low temperature behaviour [°C]	-23,2	-15,7	-17,4	-18,9	-19,2	**-19,6**

Table 6. Laboratory test results of SMA 11 surface (mF) 25/55-65

Parameter	Hydrated lime content of filler part					
	0%	10%	15%	20%	25%	30%
Fatigue resistance (ε_6)	165	**202**	183	176	168	154
Stiffness modulus [MPa]	5371	**5404**	5262	5008	4915	4863
Water sensitivity [%]	112,4	**108,7**	111,1	119,7	109,5	94,3
Rutting resistance [%]	3,4	**3,1**	3,0	2,8	3,7	4,3
Low temperature behaviour [°C]	-33,1	**-35,1**	-34,9	-34,0	-32,6	-31,3

6. TRIAL SECTION

After the laboratory tests a 100 meter-long trial section was built at an asphalt plant owned by Colas Hungary. The surface and binder asphalt mixtures were selected and described before. On half part of the trial section a reference pavement structure was built, without adding HL. At the beginning of the construction, the existent 11 cm thick pavement was milled off. Under the asphalt pavement a well-compacted 20 cm thick crushed gravel base laid, which ensured the base of the new pavement as well. After spraying emulsion on the top of the base layer, the binder and then the surface course were paved. The pavement structures are shown in Table 7.

Table 7. Pavement structures of trial section

Reference section		Trial section with hydrated lime	
Thickness [mm]	**Layer**	**Thickness [mm]**	**Layer**
40	SMA 11 surface (mF) 25/55-65	40	SMA 11 surface (mF) 25/55-65 + 10%HL
70	AC 22 binder (mNM) 10/40-65	70	AC 22 binder (mNM) 10/40-65 + 30% HL
200	crushed gravel	200	crushed gravel
-	soil	-	soil

The two structure was analysed with ALIZE pavement design software. ALIZE works based on French national design method, which includes the following steps:

- Load has to be defined from the equivalent standard axel.
- Type of the pavement, materials, their thickness, mechanical properties (Young's modulus, Poisson ratio), foundation class, has to be determined. The structure is represented by isotropic, linear elastic layers bonded to each other.
- Pavement behaviour, such as strains and stresses under the reference load, are estimated in the structure. This provides the mechanical criteria.
- Allowable values from the mechanical behaviour of the materials under repeated loads, adjusted with several factors, are calculated.
- During the service lifetime of the road the characteristic of the materials and the pavement thicknesses have to be optimized until the following criteria is fulfilled:

  Mechanical criteria calculated from the pavement modelling < Allowable values

In this study as the conditions of the test section were bounded, the thickness of the asphalt pavement is given. The aim was to determine the equivalent axel load, which the pavement can endure.

The trial section was selected based on an estimated service lifetime, which is short enough to allow the observation of the asphalt pavement deterioration within a reasonable time.

Table 8. and Table 9. represent the mechanical properties of the HL and reference pavement, also the strain and stresses arisen under 100 kN standard axel load. As ALIZE requires 2 point bending test result for stiffness modulus, the test was performed accordingly. The critical value is the horizontal strain under the asphalt binder course and the vertical strain at the top of the soil.

Table 8. Mechanical properties of HL section's asphalt mixtures under laboratory conditions

Layer	Thickness [mm]	Stiffness modulus [MPa]	Poisson ratio [-]	Horizontal strain [µstrain]	Vertical strain [µstrain]
SMA 11 surface (mF) 25/55-65 + 10%HL	40	8280	0,35		
AC 22 binder (mNM) 10/40-65 + 30% HL	70	11460	0,35	141,4	
crushed gravel	200	400	0,35		
soil	infinite	120*	0,35		500,4

*E_2 bearing capacity of soil

Table 9. Mechanical properties of reference section's asphalt mixtures under laboratory conditions

Layer	Thickness [mm]	Stiffness modulus [MPa]	Poisson ratio [-]	Horizontal strain [µstrain]	Vertical strain [µstrain]
SMA 11 surface (mF) 25/55-65	40	7940	0,35	-	-
AC 22 binder (mNM) 10/40-65	70	12020	0,35	136,6	-
crushed gravel	200	400	0,35	-	-
soil	infinite	120*	0,35	-	499,8

*E_2 bearing capacity of soil

Based on these laboratory test results the number of equivalent standard axle loads (ESAL) were determined, where the allowable strain is equal to the strain estimated in the pavement design model. The estimated standard axle loads are shown in Table 10.

Table 10. Estimated standard axle load at the end of service lifetime based on calculation of ALIZE pavement design program

Section	No. ESAL
HL section	325000
Reference section	130000

Due to the decreasing of the stiffness modulus of AC 22 with 30 m% HL content in the filler part the strain under load is slightly higher than that of the reference pavement. However, the fatigue resistance of the HL mixture is higher, so it can endure more traffic.

The pavement design and the necessary performance tests were also performed on the asphalt sample from the asphalt plant in order to check the production. The fatigue, the stiffness (IT-CY) and the wheel tracking test results are presented in Table 11, where, for a better comparison, the results from laboratory mixtures are also shown.

Table 11. Performance parameters of asphalt mixtures sampled from laboratory mixing and from production at mixing plant

Sampling site, asphalt type		HL mixtures			Reference mixtures		
		Stiffness modulus [MPa]	Fatigue resistance [µstrain]	Rutting resistance [%]	Stiffness modulus [MPa]	Fatigue resistance [µstrain]	Rutting resistance [%]
Asphalt plant	SMA 11 surface	3560	161	2,8	3220	182	3,3
	AC 22 binder	5800	148	2,9	8350	137	3
Laboratory	SMA 11 surface	5404	202	3,1	5371	165	3,4
	AC 22 binder	8852	143	1,4	9974	116	0,8

It can be noticed that the mixtures produced at asphalt mixing plant have lower stiffness. The stiffness of the SMA increases as 10% hydrated lime is added.

With these results from the production the ALIZE analyses were carried out again. Table 12. and Table 13. present the pavement characteristics, the strains under load and Table 14. presents the number of equivalent standard axle load, which the pavement can endure during its service lifetime.

Table 12. Mechanical properties of HL section's asphalt mixtures sampled on asphalt mixing plant

Layer	**Thickness** [mm]	**Stiffness modulus** [MPa]	**Poisson ratio** [-]	**Horizontal strain** [µstrain]	**Vertical strain** [µstrain]
SMA 11 surface (mF) 25/55-65 +10% HL	40	7940	0,35		
AC 22 binder (mNM) 10/40-65 +30% HL	70	12020	0,35	136,6	
crushed gravel	200	400	0,35		
soil	infinite	120*	0,35		499,8

*E_2 bearing capacity of soil

Table 13. Mechanical properties of reference section's asphalt mixtures sampled on asphalt mixing plant

Layer	**Thickness** [mm]	**Stiffness modulus** [MPa]	**Poisson ratio** [-]	**Horizontal strain** [µstrain]	**Vertical strain** [µstrain]
SMA 11 surface (mF) 25/55-65	40	8056	0,35		
AC 22 binder (mNM) 10/40-65	70	12450	0,35	136,4	
aggregate base	200	400	0,35		
soil	infinite	120*	0,35		500,6

*E_2 bearing capacity of soil

Table 14. Estimated standard axle load at the end of service lifetime

Section	No. ESAL
HL section	315000
Reference section	340000

Due to a slight decrease of stiffness and in addition a decrease of horizontal strain of the asphalt mixtures sampled on asphalt mixing plant, according to ALIZE model the HL section can endure slightly less ESAL than the earlier ESAL, which was calculated based on from laboratory sampled asphalt mixtures performance parameters.

7. KUAB FALLING WEIGHT DEFLECTOMETER (FWD) RESULTS

Falling weight deflectometer measurements were performed at the trial section to determine the surface modulus. Table 15. presents the average modulus of the two different section. The HL section has a higher surface modulus.

Table 15. Surface modulus measured with KUAB FWD

Section	Surface modulus [MPa]
HL section	568
Reference section	479

8. SENSORS

In order to observe the mechanical behaviour of the asphalt pavement, several sensors were built in. They were arranged in the approximate line of the wheel path. Figure 4. shows the arrangement of the sensors.

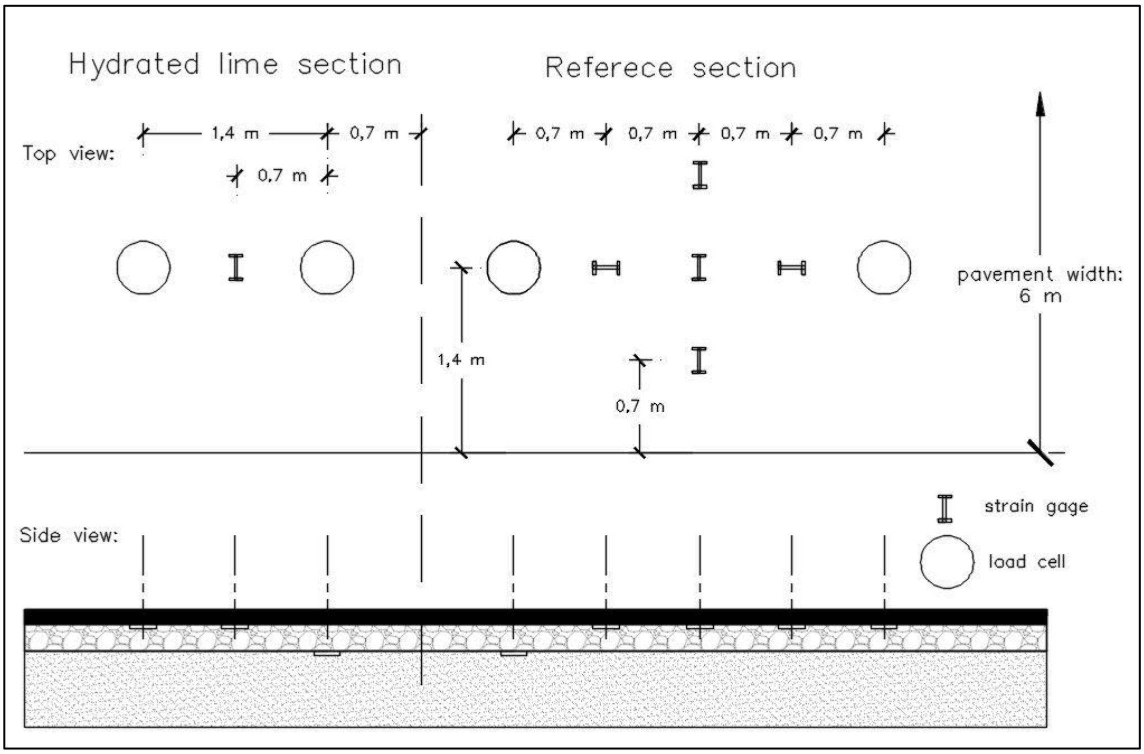

Figure 6. Arrangement of the sensors, top and side view

The aim of this arrangement is to record as many parameters of the deflection bowl as possible and the distribution of the vertical stress under the asphalt pavement.

The sensors are connected to a datalogger unit, which records the data in a given intervals. Though the shorter the recorded interval, the more detailed the results are, the data file will therefore become large and the battery can run down faster. It was set up to record the data every 50 msec.

So far, no significant deviation between the HL and reference section has been noticed. The thorough analyses of the sensors will take part in a future research.

9. CONCLUSION

The aim of the study was to examine the effect of hydrated lime on asphalt mixtures. Thus, 10 asphalt mixtures with 6 different hydrated lime dosage were tested in laboratory. After choosing a surface and a binder asphalt mixture with the optimal hydrated lime content, a trial section was built with stress and strain gauges in the pavement in order to monitor the behaviour of the pavement construction.

The bitumen tests showed that the softening point increases and the penetration decreases parallel as the hydrated lime content is increased. Fraass breaking point slightly decreases as hydrated lime is added to the asphalt mixtures.

At asphalt tests the best fatigue behaviour, rutting resistance, water sensitivity were measured at 10-20 m% hydrated lime content of the filler. Stiffness moduli decreased as the hydrated lime content increased. At low temperature behaviour no general conclusion was made.

Based on the tests results a multi criteria decision matrices were established in order to determine the optimal hydrated lime content of the two asphalt mixtures, which were selected to be built in a trial section. The SMA 11 surface and the AC 22 binder mixtures were produced with 10 % and 30% hydrated lime content respectively.

Before construction, the mechanical behaviour of the pavement were modelled with ALIZE pavement design software. It was shown that based on the laboratory results the pavement section with hydrated lime could endure 2,5 times higher traffic as the reference section without hydrated lime.

After producing the mixtures at asphalt mixing plant, it was observed that the fatigue behaviour of the hydrated lime mixes improved less than under laboratory conditions, so the pavement design analysis showed less capacity during the service lifetime.

Although, based on the laboratory test selected hydrated lime contents showed an optimal behaviour, on the asphalt mixing plant produced asphalt mixtures could not verify the before expected difference in the service lifetime. Different hydrated lime dosages or optimisation algorithms can be considered as a future task.

Based on the strain and stress gauges no significant difference between the mechanical behaviour of the hydrated lime and reference section have been observed so far. The analyses of the sensors is a part of a future research.

As a further research it is recommended to examine the exact mechanical properties of asphalt mixtures produced at asphalt mixing plant. The effect of hydrated lime on the adhesion between the binder and the aggregate is also to be investigated on various Hungarian raw materials.

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