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Performance properties of asphalt mixes for rich bottom layers (RBL)

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Abstract. The binder content of asphalt mixes has an important influence on the performance properties. Higher binder content improves fatigue resistance. That is why the concept of RBL was developed in USA and applied for "perpetual pavements". However excessive binder content could lead to the decrease of the mix stiffness and to permanent deformations of asphalt pavement during hot summer. The advantages and limitations of RBL concept have been studied in research project CESTI. Fatigue tests of mixes with road bitumen and polymer modified bitumen and RBL were realised. Deformation behaviour of these mixes was also evaluated. The experience from the test section with RBL laid in 2015 will be presented. The results corresponded to expectations. However, low void content was obtained on one subsection. In spite of it, there were no permanent deformations during summer 2016. The analysis of methods for the prediction of the permanent deformation was also undertaken in research project CESTI. Some information about the results of these analysis related to the use of RBL will be also briefly mentioned.

1. Introduction

There is a tendency to increase a pavement life for roads with high traffic load. These pavements are often called long life pavements in Europe or "perpetual pavements" in USA. Pavement distresses due to the fatigue of asphalt mix are reduced or avoided. Higher fatigue resistance of the mix can be achieved either by the use of modified bitumen or by the increase of its binder content. The base course mixes with the higher binder content have been used recently in USA and Canada. They are called "Rich Bottom Layer" (RBL) or "Fatigue Resistant Layer" (FRL). The term RBL is used in this paper.

The RBL mixes have been tested in the Czech Republic in the framework of the research project CESTI carried out by Technical Universities of Prague (ČVUT) and Brno (VUT), Eurovia and other road companies. Stiffness and fatigue properties of some standard mixes and RBL mixes tested in the CESTI research are presented in this paper. Some test results on these mixes with road bitumen have been published in [1] and tests on mixes with polymer modified bitumen in [2] (both in the Czech language). The impact of measured fatigue test results on the pavement design was discussed in [3] written in the Hungarian language. This paper presents tests mentioned in [1], [2], [3] and other fatigue tests carried out at VUT laboratory in 2016 and their statistical evaluation. It discusses also some aspects not mentioned in quoted publications. As the fatigue behavior of asphalt mixes has a big impact on the pavement design, the research in CESTI was focused on fatigue properties. Thus fatigue behavior is mainly presented also in this text.

2. Composition and volumetric properties of tested mixes

Mixes for the base course with two binders were tested. One binder was road bitumen 50/70 another was PMB 25/55-60. RBL mixes had binder content 0,5 % higher than normal AC. All mixes were compacted with 2 x 50 blows of Marshall hammer. Mix with the road bitumen was compacted at 150°C and mix with PMB at 160°C. Aggregates from the quarry Litice (spilite) were used. Limestone filler was supplied by the lime company Hasit from Velké Hydčice. Gradation of the mixture is on Figure 1. Volumetric properties of these mixes are in Table 1.

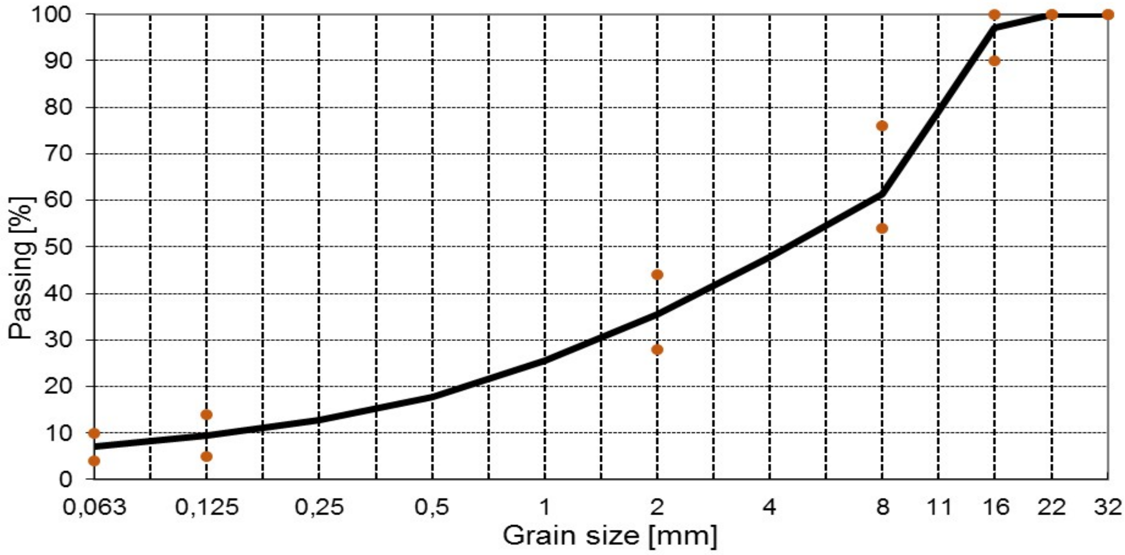

Figure 1. Gradation of the mixture.

Table 1. Volumetric properties of tested mixes.

Mix type			AC 16 base	AC 16 RBL	AC 16 base	AC RBL
Binder type			50/70		PMB 25/55-60	
Binder content	B_{mass}	%	4.100	4.600	4.100	4.600
Binder content	B_{vol}	%	9.700	11.100	9.700	11.000
Density	ρ_{bssd}	Mg/m^3	2.505	2.533	2.496	2.527
Maximum density	ρ_{max}	Mg/m^3	2.659	2.648	2.659	2.648
Void content	V_m	%	5.800	4.300	6.100	4.600
Bitumen filled voids	VFB	%	62.600	72.000	61.300	70.600

3. Stiffness properties

Indirect tensile stiffness tests on the cylindrical specimen after European standard [4] for the temperature range 0 to 30 °C were carried out in the road laboratory at the Technical University in Prague (ČVUT). Results are on Figure 2. Each point represents an average stiffness for 6 specimens. Both mixes with harder polymer modified bitumen had distinctly higher stiffness than mixes with road bitumen. However, there was a small difference in the stiffness (≈ 10 %) of the AC mixes and RBL mixes with the same binder.

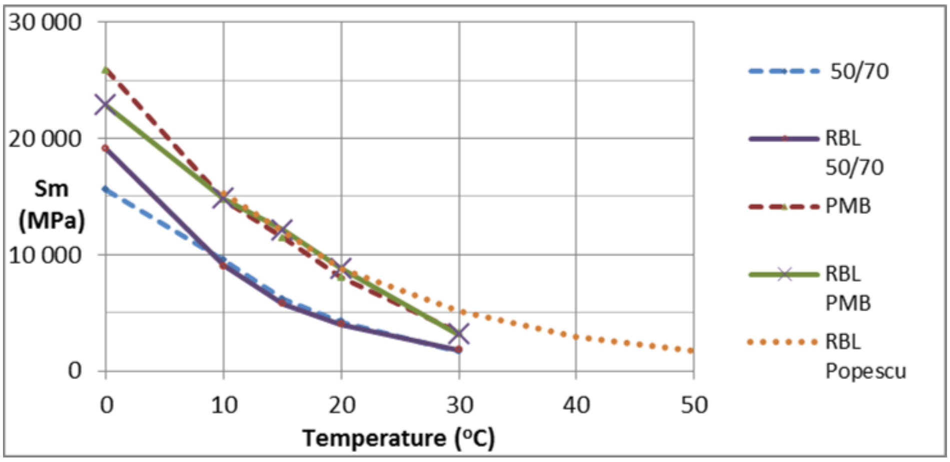

Figure 2. Stiffness IT-CY after EN [4].

Further increase in the binder content of RBL mixes would probably lead to the decrease of stiffness. Then the difference between AC and RBL will be important. This is illustrated by the test results on the other mix for the base course with the PMB 25/55-55 carried out also at ČVUT presented in [5]. The stiffness of the mix with the binder content B_{mass} 4.8, 5.1 and 5.4 % decreased with the increase of the binder content. The general relationship between binder content, void content and stiffness for the mix with road bitumen 50/70 was well illustrated in older French paper [6]. The Czech pavement design method, as well as the French one, uses the concept of equivalent temperature usually fixed at 15 °C. Thus the indirect tensile stiffness tests are usually carried out only for medium temperatures. It assures that the test conditions allow the evaluation of the stiffness modulus from the formulae based on elastic theory.

In order to get an approximate idea about the possible decrease of the stiffness of RBL for higher temperatures, the results of the test on RBL mix for the temperature 10 – 50 °C given in [7] were added to the graph in the Figure 2, as that mix had similar stiffness as our mix with PMB for the temperature range 10 – 20 °C.

The repeated loading at higher temperatures and for longer loading time could lead in some cases to distinctly higher permanent deformation for RBL mixes. This was demonstrated by the results of the shear test with the constant height (RSST-CH) used in USA at 50 °C in [7]. RBL mix with binder content B_{mass} = 5.2 % and void content m = 3 % had about 50 % higher permanent deformation after 5000 cycles than AC with B_{mass} = 4.7 % and m = 6.0 %. The impact of higher binder content on permanent deformations in the triaxial cyclic compression test (TCCT) after European standard EN 12697-25 [8] is shown for example in [9]. Creep rate f_c for 2 mixes with B_{mass} = 4.8 % and one mix with B_{mass} = 4.9 % was higher than for the same mix with B_{mass} = 4.5 %. Even steeper decrease of stiffness was observed for tested mixes for binder content ≥ 5 %. According to [9], the optimum binder content derived from the TCCT test is about 0.3 to 0.1 % lower than the optimum binder content found by the traditional Marshal mix design method

Repeated triaxial load tests are normally not realized in our country. Some repeated load tests on different mixes are now under way at the VUT Brno in the framework of CESTI research. The results will be presented when more experience with this test will be obtained.

4. Fatigue properties

4.1. Fatigue properties of mixes with road bitumen 50/70

Fatigue tests according to European standard EN 12697-24 [10] on trapezoidal specimens (2 PB) were carried out with the frequency 25 Hz at 10 °C in the laboratory of VUT Brno in 2015 on specimens with bitumen 50/70 fabricated in the laboratory of Eurovia. The fatigue properties of RBL were much better than for AC base, as it is illustrated in Table 2.

Table 2. Fatigue parameters for mixes with bitumen 50/70 tested in 2015.

		AC base 50/70	RBL 50/70
Binder content	(%)	4.1	4.6
Slope B = - 1/b	(-)	4.7	5.0
ε_6	(μs)	81.5	107.9
$\gamma_{úp} = \varepsilon_{6,50} / \varepsilon_{6,5}$ after Czech TP 170	(-)	1.47	1.22
$\Delta\varepsilon_6$ after EN12697-24	(μs)	14.3	8.5
$\varepsilon_{6min} = \varepsilon_6 - \Delta\varepsilon_6$	(μs)	67.2	99.4
Standard error $SN_{N/\varepsilon}$		0.481	0.267
Coefficient of determination R^2		0.796	0.918
Number of specimens		16	17

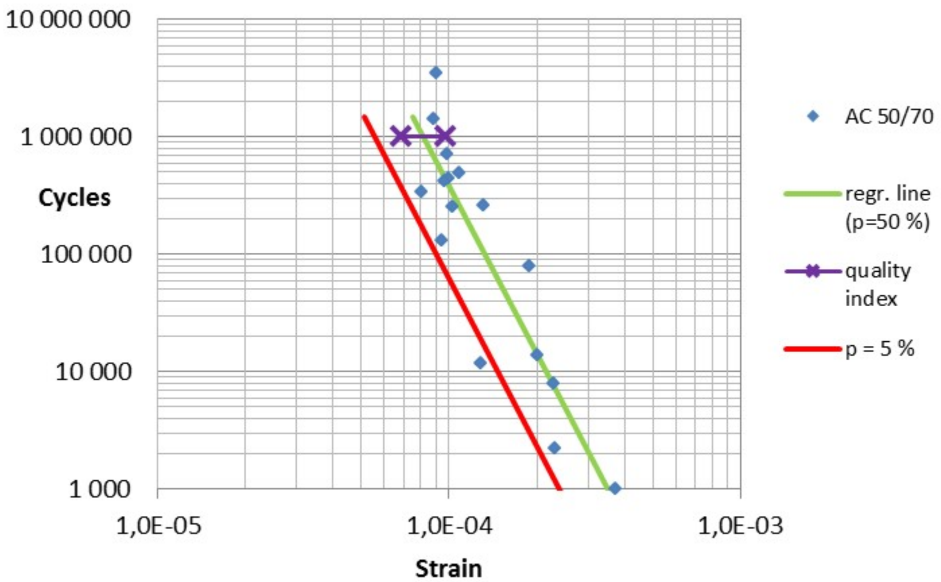

Figure 3. Shift of the fatigue line after TP 170 for *AC base* with 50/70.

Parameters ε_6 , $\Delta\varepsilon_6$, b in Table 2 are defined in EN 12697-24 [10]. The slope of the fatigue line B and the coefficient $\gamma_{úp}$ are used in the Czech pavement design method after TP 170 [11] and [12]. The coefficient $\gamma_{úp}$ represents the shift of $\varepsilon_{6,50}$ on the fatigue line obtained from the regression analysis of the test results (which corresponds to the probability p = 50 %) to the value $\varepsilon_{6,5}$ (lower values than $\varepsilon_{6,5}$ have the probability of p = 5 %). It is represented by the red line on Figure 3. Thus the shift is calculated in a similar way as in the French pavement design method in [13]. This shift in both methods corresponds to the prediction interval for the regression line in the terminology of statistical analysis. The strains $\varepsilon_6 \pm \Delta\varepsilon_6$ are also shown in Figure 3 (They are marked with the crosses).

Table 2 shows that RBL mix has a distinctly higher value of ε_6 than *AC base*. The standard error for RBL is lower and coefficient of determination is higher. That is why the “quality index” $\Delta\varepsilon_6$ for

RBL is lower (the term used in EN 12697-24 is somewhat misleading, as lower "quality index" for RBL corresponds to a better homogeneity of measured mix fatigue resistance).

However, even for RBL calculated value of $\gamma_{úp}$ was higher than preliminary design value in TP 170. Higher values of $\gamma_{úp}$ than in TP 170 were obtained also for the other asphalt mixes tested during the last few years at VUT. It indicates that the value of $\gamma_{úp}$ recommended in TP 170 (published in 2004) which was based on a few tests realized about 15 years ago, was too optimistic for all mixes. The dispersion is often larger, especially for mixes with binder content close to minimum binder content given in asphalt mix specifications. This is important observation as these mixes are frequently used due to economic reasons. However, there are some pessimistic assumptions in the pavement design method after TP 170 which might compensate optimistic value of $\gamma_{úp}$. The explication of these problems is out of the scope of this paper. These discrepancies can be adjusted during the next novelization of TP 170 which is planned in the future.

The first test section where these AC and RBL were laid was realized in autumn 2015. Some samples of the mixes produced in the mixing plant were taken. Test specimens were prepared at Eurovia laboratory. The fatigue tests were realized in 2016 at the laboratory of VUT on the same testing equipment as in 2015. Fatigue parameters of RBL were worse than measured in 2015. The reason for this difference might be due to the natural dispersion and due to the fact that the mixes tested in 2016 had to be reheated in the laboratory before the fabrication of the specimens. It can be supposed that the short term aging of the binder was more important than in 2015. The binder extracted from the specimen after fatigue test in 2016 had the penetration at 25 °C only pen=26. The softening point *R&B* was 59,6 °C (fresh binder 50/70 has *R&B* = 46 – 54 °C). Values for extracted binder correspond to parameters of 50/70 bitumen after 3 times RTFOT test. This confirms that aging of the road bitumen was important on this job site.

It is worth to mention that the differences between laboratory prepared specimens, samples of mixtures produced in the mixing plants and samples taken from pavements were observed in a huge German research project finished in 2015. Comprehensive evaluation and analysis of the data from 21 road sections showed large spans of the results that can be explained only in part by material properties or by the installation quality, as stated in [14].

4.2. *Fatigue properties of mixes with PMB 25/55-60*

Fatigue parameters for mixes with PMB were also better for RBL mix than for AC. Results are in Table 3. Due to various reasons, only 14 specimens of RBL with PMB were tested in 2016, even if EN 12697-24 demands at least 18 specimens. The value of $\varepsilon_{6min} = \varepsilon_6 - \Delta\varepsilon_6$ for 2016 RBL mix was only slightly lower than $\varepsilon_{6max} = \varepsilon_6 + \Delta\varepsilon_6$ for 2015 RBL mix. However, confidence limits for two regression lines for the probability of 95 % distinctly overlapped, especially for very low and very high strains levels (The graph is not presented here). That is why fatigue parameters for all 32 specimens were also calculated. They are presented in table 3 as well as the design parameters after TP 170 for *AC base* and on the Figure 4.

Measured values of B and ε_6 of all mixes in table 3 are distinctly higher than the design values in TP 170. It is well known that fatigue parameters of mixes with PMB are normally better than for the same mixes with road bitumen of similar stiffness. However that difference is considered only for high modulus mixes (HMAC) in the Amendment of TP 170 [12]. HMAC have $\varepsilon_6 = 125\ \mu s$ for mixes with road bitumen and $\varepsilon_6 = 135\ \mu s$ for mixes with PMB in [12]. The difference between the design value of ε_6 for the mixes with road bitumen and PMB is not considered for ordinary mixes for the base layer in [12]. It is supposed that this difference will be considered in the future version of the design guide.

Table 3. Fatigue parameters for mixes with PMB.

	ACP PMB 2015	RBL PMB 2015	RBL PMB 2016	RBL 2015+2016	AC base TP 170
B	5.7	6.0	6.2	6.1	5.0
ε_6 (10^{-6})	112.6	119.1	129.5	123.6	100
$\gamma_{úp}$	1.31	1.15	1.16	1.17	1.15
$\Delta\varepsilon_6$ (10^{-6})	11.4	6.4	6.7	4.9	
$\varepsilon_{6min} = \varepsilon_6 - \Delta\varepsilon_6$	101.2	112.7	122.8	118.7	
$SN_{N/\varepsilon}$	0.399	0.227	0.244	0.25	
R^2	0.878	0.885	0.926	0.89	
Number of spec.	20	18	14	32	

Results for 32 specimens of RBL with PMB, confidence and prediction limits are on the Figure 4.

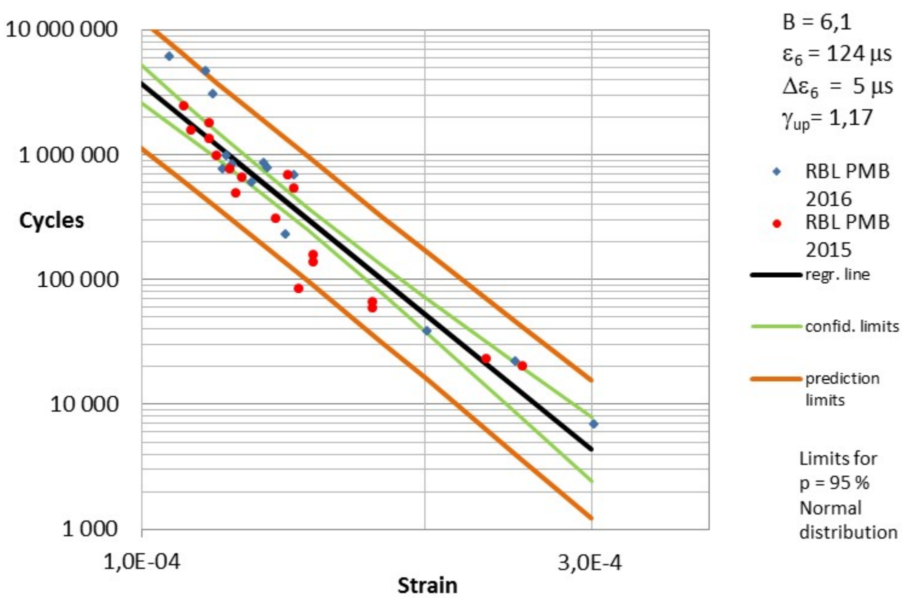

Figure 4. Statistical evaluation of the results of fatigue tests for RBL with PMB.

The application of laboratory measured values of fatigue parameters for the pavement design is allowed in TP 170 with some restrictions which lead to similar limitations as in the French pavement design method in [13]. Different way of the limitation on the application of the laboratory fatigue tests is considered in the new Austrian pavement design method which will be published this year. Differences in these 3 approaches are out of the scope of this text. Paper devoted to this is under preparation for the Czech conference Asphalt pavements AV 17 in November 2017.

5. Information about the test section realized in 2015

The first test section (composed of 4 sub-sections) was laid on one road near the town Pilsen in autumn 2015 during its reconstruction. Pavement design was carried out according to TP 170. Parameters used for RBL were based on detailed review of foreign literature in the framework of CESTI project, as own fatigue tests had not been finished at that time. The same slope of the fatigue line for AC and RBL B=5,0 was used. The same difference between ε_6 for AC and RBL (10 μs) was used for both binder types. This corresponds well to the difference between ε_6 for AC and RBL for 32 specimens tested in 2015 and 2016 as presented in the Table 3.

Fabrication and placement of RBL mixture was realized generally without problem, in spite of some complications related to the fact that it was a fragmented reconstruction of the main road in urban area without allowance for any interruption of the traffic (This led to rest periods between the realization of individual sub-sections, partial closure of one direction, etc.) Void content measured on cores and by nuclear asphalt density gauge was generally in the range 3 to 6 %. Unfortunately low void content 2 % was measured in one relatively small part of RBL section both by Eurovia laboratory and independent laboratory engaged by the investor.

Some risk of permanent deformation during the short period of very hot summer days could not be excluded in this subsection, especially as the trucks sometimes stop before crossings or due to the traffic jam. After an intensive review of the foreign literature on permanent deformations of RBL, some preliminary evaluation and discussion with partners on the project, it was decided to let this subsection in place and observe the behavior.

No permanent deformation of the pavement surface has been observed in 2016, in spite of quite warm summer. According to the results obtained at the state meteorological station in the region, there were 4 subsequent tropical days in August 2016 with air temperature over 30 ^{o}C and maximum air temperature 32,4 ^{o}C. Authors used the database from the continuous measurements of air and pavement temperature on one PPP project in Slovakia some years ago to estimate the surface temperatures on test section with RBL in 20016. The surface temperatures were probably in the range 50 – 57 ^{o}C for a couple of hours for some days. It has to be kept in mind that such analogy is approximate as the temperature on the surface of the pavement depends not only on air temperature, but also on the wind conditions, etc. Anyway, it was higher than the temperature of 50 ^{o}C which is specified for rutting test in the framework of initial type test according to the present Czech AC specifications.

Distinctly higher temperatures were observed in that region in extremely hot summer 2015 (before the reconstruction of the road). There were 17 tropical days during summer with maximum temperature 38 ^{o}C. The maximum pavement surface temperature could be under these conditions around 60 ^{o}C. The suitable temperature for rutting test in the Czech conditions could be 55 ^{o}C in our opinion, but European standard for rutting test [15] specifies only test temperature 50 or 60 ^{o}C.

6. Evaluation of shear stress and elastic and permanent deformation for the design axle load

French pavement design program Alize was used to calculate elastic shear stress and strains for various temperature distributions in the pavement. This program is very user-friendly and permits to present horizontal and vertical stress and strains distribution in various points in a graphical form. The surface temperature and the distribution of the temperature in the pavement have a big impact on calculated elastic strains. The temperature distribution given in the German pavement design method [16] was used for a couple of selected surface pavements temperatures. Permanent deformations of the pavement were calculated from elastic strain by the method proposed in [17]. As we had no own test results from repeated cyclic tests in 2016, we made only preliminary calculations for a pavement similar to the test section with parameters given in [17].

7. Conclusions

Tests of performance properties of AC and RBL showed the differences in their behaviour. The stiffness of RBL was similar to AC, but the fatigue properties of RBL were much better. Valuable experience was obtained from the first test section. Some care had to be taken to avoid a too low void content of RBL in the pavement. It is planned that calculations of permanent deformations by different methods given in the literature will be carried out. Some cyclic loading tests are now under way.

The review of the literature and preliminary calculations showed that any forecast by the methods presented in the literature is very approximate due to the sensitivity of the results to the temperatures in asphalt layers and difficulties of its forecast. However, the back-analysis of permanent deformations observed on real pavements during hot summer period by these methods is possible. Based on laboratory cyclic loading tests results of used materials and temperature measurements obtained from meteorological stations the back-analysis could lead to the detection of the probable source of deformations. It could be useful in cases that the causes of observed damage are not evident from classic empirical tests and/or judgment based on experience.

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