Asphalt mixture performance and testing

Verifying potentials of using stone mastic asphalt for binder layers containing up to 50 % reclaimed asphalt – lab and field experience

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Abstract

Asphalt pavements raise presently several challenges which force seeking for improved or even new solutions. For this reason in the Czech Republic it was started to think more seriously about the long-life pavement concepts, which we call in present stage as low-maintenance surfacing, i.e. focus is oriented on surface and binder layers where alternatives are sought. In case of surface layers asphalt mixtures which allow paving layers with max. thickness of 30 mm are under consideration looking at French concepts like BBTM 0/8 mm or on German concepts of noise reducing SMA 0/8 mm. Both types of mixtures have been repeatedly used for several years to proof their applicability. In case of binder courses the focus during last two years was oriented on analysing the concept of SMA mixtures which are applicable to these layers, i.e. their maximum particle size reaches 16 mm or even 22 mm. Additionally this was combined with use of RA to touch the first challenge as stated above. Mix designs of a SMA 0/22 mm mixture as well as of a BBTM 0/8 mm and SMA 0/8 mm following the national requirements on noise reducing surface layers were defined and experimentally verified. Based on that 2 km trial section was realized paving 3 options of SMA 0/22 mm with 0 % to 50 % RA and overlaid by either BBTM 0/8 mm or SMA 0/8 mm containing between 0 % and 30 % RA. Additionally for these mixtures it was required to have a voids content in the range 9-12 %-vol. Plant produced mixtures were collected during the paving and tested in laboratory. Visual control has been done after two winters to get feedback about the in-situ performance. Laboratory tests included moisture susceptibility, rutting, stiffness, frost cracking testing and for some mixtures even fatigue testing.

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1. INTRODUCTION

The investment in road infrastructure development and maintenance forms an important part of the state budget. Such investments are always planned in the long term as even small-scale construction projects amount to millions of CZK. The infrastructure funding comes from the taxpayers who, on their part, wish for the best quality and most durable roads possible. One of the crucial questions in budget compilation must surely be the aspect of lifecycle costs of construction structures, i.e. the funds invested in the construction and maintenance of the structure over its entire life. Unfortunately, only too often may we encounter situations in the construction practice where a repaired, or even new asphalt pavement demonstrates, after a relatively short period of time, a number of defects that certainly do not correspond with the amount of the investment. There might be various reasons for that – inappropriate pavement design, unsuitable bituminous binder application, poor quality of asphalt mixture preparation, insufficient quality of asphalt layer application etc. A broad range of influences affect the asphalt pavement structure. Very often, one of the causes is the investor's pressure to keep the cost low, or lack of readiness or willingness to abandon the established public work completion mode with one sole criterion, namely the project price.

In the case of pavement structure, there are two basic views of the investment – the price of construction works (initial investment, CAPEX) and lifecycle costs of the structure. The project costs are the initial price of the construction: the price includes the design, preparation and application of the asphalt layer; no additional costs are included once the pavement is used in operation. The lifecycle cost price includes not only the price of designing and construction works but also the maintenance and operation costs over the selected lifecycle. In the case of asphalt pavements, the theoretical design life of a structure is 25 years at least; this means that the lifecycle costs should include all pavement maintenance and repair costs over this time. Also, solutions capable of minimising such costs should be chosen as the most cost-effective ones.

The aforementioned problems might be solved by the adoption of a pavement design method that is completely different from the method used in the Czech Republic so far. This is the "*perpetual pavements*" or, in other terms, "*long life pavements*" concept. The concept was first formulated in the USA by the Asphalt Pavement Alliance in 2000. The principle of such structures involves the pavement design and completion with the aim of achieving at least 50 years' life of the asphalt layers with no need for major repair or reconstruction, with merely regular wearing course renovation as required by potential damage thereto. The perpetual pavement theory development was spurred by the fact that some sections of US asphalt pavements demonstrated excellent condition although they were built in the 1960's. A detailed examination determined that these pavements share some features which might be the reasons behind their long life: in most cases, they were "*full-depth"* or *"deep-strength"* structures, i.e. structures where the layers demonstrate good strength characteristics even over an extended lifecycle.

The completion of long life pavements envisages either three relatively thick asphalt layers with unbound subbase course, or the application of a modified design for the binder and base courses. Each course should be designed specifically to resist the load and strain occurring therein. At the same time, the correct design of the interaction of the individual layers must be borne in mind to prevent the courses from separating on the interface, causing defects. This paper focuses on the binding course type which is novel from the perspective of the Czech Republic.

The binder course should be the stiffest layer in the pavement structure. The main purpose of the binder course is to transfer the traffic loads, resisting the degrading of the pavement in the form of permanent deformation due to accumulated irreversible deformation. Therefore, the layer must be sufficiently resistant to permanent deformation while being flexible and frost crack-resistant. Asphalt layer stiffness may be achieved by designing the aggregate skeleton with a "*stone-on-stone"* contact between individual particles. Such skeleton is very well capable of transferring the load without failure. Asphalt layer flexibility may be achieved through modified bituminous binder application.

Stone mastic asphalt (SMA) has been used in the wearing courses of heavy duty pavements for over 30 years. Recently, it has been used even in binder courses, primarily in Germany, in a number of applications in high-load roads, with modified grading intervals and in forms with a maximum particle size of 16 mm or 22 mm. The concept has been worked with in the United Kingdom too.

SMA mixtures for binder courses are characterised by a gap graded curve and a higher content of bituminous binder if compared to the traditional asphalt concrete mixes. The gap gradation ensures a solid mineral skeleton of coarse aggregate which is bound by mastic asphalt, consisting of the bitumen, limestone filler and fine aggregate. Thanks to its composition, SMA has a very good resistance to traffic loading and permanent deformation (rutting). At the same time, there has been consistent evidence of improved durability.

2. DESCRIPTION OF THE TRIAL SECTION

This paper summarises the results of tests performed on asphalt mixtures in the surfacing of a rehabilited road section (binder and wearing course replacements) on a 2^{nd} class road No. II/236 Kačice - Směčno, located 30 km from Prague. According to data from the Czech National Traffic Census from 2010, the trial section was loaded by 987 heavy trucks passing in 24 hours in both directions; traffic intensity amounted to 5 817 vehicles per day on the section. According to the data from 2016, the intensity of heavy loaded vehicles increased to 1 009 in 24 hours, and traffic intensity rose to 6 111 vehicles per day. This regional road serves as a connection between motorways D6 and D7; if there are any traffic problems on either of the motorways, the road is used by heavy trucks as well.

The total length of the trial section was 1 784 m which was divided into three sub-sections in terms of the binder course, and into six sub-sections in terms of the wearing course. The binder course sub-sections measured 450 to 700 m, and the wearing course sub-sections approx. 300 m. These constitute sub-sections of a length allowing to monitor the quality and behaviour of the new technology over time. Three types of new technology SMA_{bin} 22 were applied in the binder course; the types differ by the quantities of reclaimed asphalt (RA) material added (0 %, 30 % and 50 % respectively). The thickness of the binder course applied was 100 mm while the application extended over the entire width of the road. Two types of asphalt mix (BBTM 8 LA and SMA 8 LA) were applied over each binder course sub-section – upon the investor's request, these were low-noise layers. The aforementioned mixtures differed from each other in terms of the reclaimed asphalt addition (0 %, 15% and 30% respectively), although the applicable technical specification of the Ministry of Transport (TP 259) prohibits the use thereof in this type of asphalt mixture. The wearing course was applied in a 30 mm thickness, i.e. as a thin wearing course.

3. STRUCTURAL PAVEMENT LAYERS

The binder course of flexible and semi-rigid pavements acts as a base for the wearing course; it is strained by shear forces, transfers load to the base layers and generally is the layer that should have a high shear strength and sufficient resistance to permanent deformation. In summer, rather high temperatures climbing up to over 50 °C are commonly measured in the binder course even in Central Europe. This often causes permanent deformation in the form of ruts in asphalt mixtures of insufficient load-bearing capacity and stiffness applied in the binder courses. These courses are thicker than the wearing courses, and more prone to deformation for that reason.

The modern trend in the pavement surfacing concept involves the application of a binder course with extended life and durability while applying a thinner wearing course. This means that, in view of the pavement structure life cycle, the binder course life is extended and the thinner wearing course (20 to 30 mm) is periodically replaced.

SMA_{bin} 22 or SMA_{bin} 16 mixtures for binder courses are aphalt mixtures based on asphalt mortar and coarse aggregate skeleton principle. The mixture consists of aggregate with a high proportion of coarse particles and, usually, polymer modified bitumen (PMB). Due to the higher binder content and gap graded curve, additive avoiding bitumen drainage is recommended (cellulose, mineral fibre etc.). The high proportion of coarse aggregate particles forms the asphalt mixture skeleton which acts positively against permanent deformation. The voids in the aggregate skeleton are filled with the mastic mortar (fine aggregate particles, filler, bituminous binder).

The recommended thickness of the alternative asphalt binder course, type SMA_{bin} is 5 to 12 cm. Asphalt mixtures with 22 mm maximum particle size are used for structural layers of 9 to 12 cm thickness. The requirements for evenness of the surface should reflect the higher requirements for smoothness of the thin asphalt wearing course. The application of this type of asphalt mixtures should use, particularly in large-scale road projects, a homogeniser to achieve improved uneveness of the layer wherein compaction has a more homogeneous effect thanks to even cool-down.

SMA_{bin} mixtures are designed with lower void contents within the range of 3 to 4 %-vol. The lower void content limits water absorption in the asphalt binder course, thus extending its life and durability.

The wearing course is the top layer in the pavement structure and remains in permanent contact with the weather environment and tyres of the vehicles. The layer must be designed to resist high traffic loads and remain free from defects (cracks, plastic deformation or loss of anti-skid properties) in changing weather conditions.

The wearing course is the only course in the "perpetual" or "low-maintenance" pavement concept which requires regular maintenance (replacement) over shorter time cycles. If regular maintenance and repair actions are performed in a timely manner with sufficient technological discipline, protection of the remaining pavement structure layers is ensured which provides the advantage of extending the life of the entire structure. Visual checks of the surface and, should superficial cracks appear, adequate repair must be proposed in a timely manner. Once the wearing course fails, water penetrates the bottom layers and these degrade faster, particularly if such phenomena are not prevented.

4. ASPHALT MIXTURE TESTING

For evaluation of influence of selected variants the following tests were performed and evaluated:

- **grading analysis** (EN 12697-2) and **bituminous binder content** (EN 12697-1)
- **volumetric characteristics** (EN 12697-5, EN 12697-6, EN 12697-8);
- **water and freeze susceptibility** according to European standard EN 12697-12 and modified American method AASHTO T283-3;
- **stiffness** (EN 12697-26, method IT-CY) at test temperature of 0 °C, 15 °C a 27 °C;
- **resistance to permanent deformation** (EN 12697-22) on small test device in air bath at test temperature of 50 °C;
- **flexural strength** determined by three point bending beam test at a test temperature of 0 °C (Czech Technical Conditions TP 151);
- **fracture toughness** determined according to SCB test (EN 12697-44) performed on 100 mm diameter semi-cylindrical specimens with a loading rate of 2.5 mm/min.

5. RESULTS OF PERFORMED TESTING

5.1. Particle size distribution and bitumen content

There are no regulations covering the particle size distribution and bituminous binder content in SMA_{bin} 22 mixtures in the Czech Republic. The asphalt mixture was designed according to the principles as described in the German technical specification, *„Forschungsgesellschaft für Straßen- und Verkerhrswesen. Arbeitsgruppe Asphaltbauweisen, Hinweise für die Planung und Ausführung von alternativen Asphaltbinderschichten 2015".*

The bituminous binder content in SMA_{bin} 22 ranged from 4,9 to 5,3 %. The version with 50 % RA had the least bituminous binder; it is likely to have contained a lower percentage of binder in total than expected (insufficient homogeneity of the reclaimed asphalt).

Table 1. Bituminous binder content in asphalt mixtures

	0 % RA	15 % RA	30 % RA	50 % RA
SMA_{bin} 22	5.1%	-	5.3%	4.9%
BBTM 8 LA	4.6%	4.6%	4.6%	-
SMA 8 LA	6.0%	5.8%	6.6%	-

All versions of the BBTM 8 LA asphalt mixture are identical as to the bituminous binder content (determined by extraction). TP 259 stipulates the threshold for minimum bituminous binder content in this type of mixture at 5,3 %. Unfortunately, the mixtures did not get over the threshold. If the asphalt mixtures were viewed as BBTM 8B S according to Czech standard ČSN EN 13108-2, the requirement of a minimum content of soluble binder would not be met either.

The SMA 8 LA asphalt mixtures had 5,8 to 6,6 % bituminous binder. The biggest differences were between the mixtures containing reclaimed asphalt.

5.2. Volumetric properties

The void contents of the SMA_{bin} 22 mixtures differ from one another distinctively. The version with 30 % RA had almost double air void content if compared to the reference mixtures with no reclaimed asphalt (RA). That is a rather surprising result, considering the fact that the 30 % RA version had the highest proportion of bituminous binder and a finer particle size distribution than the remaining two versions. This suggested that the void content should be lower, rather than higher. The void contents of the BBTM 8 LA mixtures on test are very similar to one another (ranging from 13,1 % to 13,6 %), as depicted by Fig. 1. The mixtures meet the test limits as highlighted in the diagram, and conform to the requirements of technical specification TP 259.

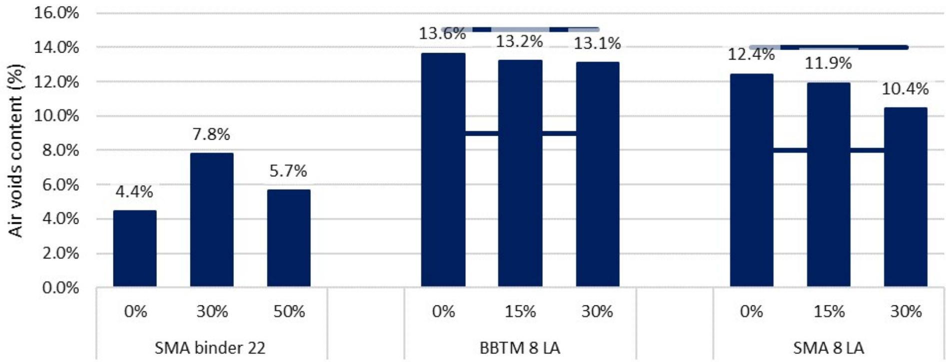

Figure 1: Air voids content of asphalt mixtures

The void contents of SMA 8 LA mixtures differ from one another slightly. The figures range from 10,4 to 12,4 %. The air voids content decreases with the increasing quantity of RA in the mixtures. All versions of the mixture meet the requirements for the air voids test limit according to TP 259.

5.3. Stiffness

The stiffness modules were determined at three selected test temperatures – commonly tested in the Czech Republic – of 0 °C, 15 °C and 27 °C. Thermal susceptibility as ratio between the stiffness at lowest and at highest temperature was calculated as well. After the test on virgin test specimens, half of the test specimens were subject to simulated laboratory ageing according to prEN 12697-52, wherein the compacted specimens were stored at 85 °C in an oven with forced ventilation for 5 days. Then, the stiffnes modulus was determined again. This was performed at all three test temperatures for the binder course and at 0 °C and 15 °C for the wearing course.

The ageing index (AI) was calculated from the measurements taken. This is the ratio of the scores of the aged to the unaged test specimen groups. The results obtained by aged test specimens are marked “aged”.

Table 2. Stiffness of asphalt mixtures

	SMA_{bin} 22			BBTM 8 LA			SMA 8 LA		
RA content	**0 %**	**30 %**	**50 %**	**0 %**	**15 %**	**30 %**	**0 %**	**15 %**	**30 %**
0 °C	16600	13506	20561	8607	9900	11212	12993	12646	11750
0 °C (aged)	18895	17067	19883	10157	10290	12206	11589	11405	11219
15 °C	7914	9233	10220	3904	4686	6183	4685	5374	5602
15 (aged)	9012	11443	11380	5133	5645	7200	5497	6415	6045
27 °C	3196	4919	4221	1306	1710	2574	1632	1972	1977
27 °C (aged)	3935	6833	5534	-	-	-	-	-	-
Thermal susc.	5.2	2.7	4.9	6.6	5.8	4.4	8.0	6.4	5.9
Thermal susc. (aged)	4.8	2.5	3.6	-	-	-	-	-	-

The SMA_{bin} 22 mixtures demonstrate a noticeable effect of stiffness modulus rise with the increasing proportion of RA in the mixture – by roughly 15 %, or 30 % relative to the reference mix at 15 °C (the determining temperature from the point of view of the design method according to TP 170). The bituminous binder in the RA has oxidised due to ageing in the pavement, which causes it to harden. The resulting bituminous binder in the mixture with RA is a combination of the new and the re-activated aged binder. In the cases of all asphalt mixtures with RA, the degraded binder was treated by a recycled mineral oil-based rejuvenator. Despite the rejuvenation, the degraded bituminous binder still demonstrates a certain effect on the overall behaviour of the asphalt mixture.

From the perspective of thermal susceptibility (the ratio of stiffness modulus determined at 0 °C to that of 27 °C), the best results by far were achieved by the version with 30 % RA. This version has a thermal susceptibility amounting to half the value of the remaining two mixtures. This suggests that the incorporation of an adequate quantity of RA may help reduce the susceptibility to temperature changes, or the effect of temperature changes on variations in the characteristic on test.
Contrastingly, from the perspective of ageing of the asphalt mixture (results expressed by the ageing index), it is far from obvious how the presence of RA deteriorates or improves susceptibility to ageing. At least in the case of the SMA_{bin} 22 mixtures on test, there is no clear conclusion on that matter.

The same trend appears in the BBTM 8 LA mixtures wherein the stiffness modulus determined at 15 °C grows with the increasing content of RA in the mixture. However, this increase is more distinctive than in the binder course type of asphalt mixture – when 15 % RA is used, the increase amounts to roughly 20 % while with double the RA quantity, the increase amounts to almost 40 %.

From the point of view of thermal susceptility, the version with 30 % RA scores better yet again; the reclaimed material, if the quantity is adequate, seems to have a positive influence on this characteristic. A similarly beneficial effect is obvious in the ageing index test, too, where the higher proportion of reclaimed asphalt in the mixture pushes the ageing index down, i.e. the asphalt mixture is less susceptible to the effects of laboratory-simulated ageing.

Even SMA 8 LA demonstrates a noticeable increase in the stiffness modulus due to the application of reclaimed material although the increase is not as dinstictive as in cases where a low-maintenance surfacing was implemented with a BBTM type of asphalt mixture. The addition of 15 % RA to SMA 8 LA resulted in a 15 % improvement in strength, while the improvement only amounted to approx. 20 % when the RA quantity was doubled. However, the decreasing thermal susceptibility due to higher RA proportions in the SMA LA mixtures was demonstrated again, while lower ageing index values were achieved as well. This indicates a good potential of a well chosen RA percentage in an asphalt mixture.

As has been mentioned above, the ageing index is the ratio of values of the aged to the unaged specimens. The closer the value gets to one, the less effect ageing has on the bituminous binder in the mixture. Ageing usually results in increased stiffness as the aged bituminous binders have lower penetrations and higher softening points which increases the strength characteristics to a certain degree.

Table 3. Ageing index of stiffness modulus of asphalt mixtures

	SMA_{bin} 22			BBTM 8 LA			SMA 8 LA		
RA content	**0 %**	**30 %**	**50 %**	**0 %**	**15 %**	**30 %**	**0 %**	**15 %**	**30 %**
0 °C	1.14	1.26	0.97	1.18	1.04	1.09	0.89	0.90	0.95
15 °C	1.14	1.24	1.11	1.31	1.20	1.16	1.17	1.19	1.08
27 °C	1.23	1.39	1.31	-	-	-	-	-	-

The version of SMA_{bin} 22 with 30 % RA demonstrated the poorest (highest) values in its group while the version with 50 % RA scored very good results at the two lower temperatures (below 10 %). Contrastingly, as has been mentioned above, the increasing proportion of RA in BBTM 8 LA reduced the ageing index which means that, in this case, the asphalt mixtures with RA are less affected by any further ageing.

5.4. Water and frost susceptibility

Susceptibility of asphalt mixes to water was tested according to ČSN EN 12697-12, determination to water and frost susceptibility was tested according to the modified method of the US standard, AASHTO T283-3. A set of 9 Marshall specimens compacted by 2x25 impacts according to ČSN EN 12697-30 was prepared for each mixture. The specimens were divided into three groups where each group was exposed to a different tempering method. The “dry” specimens were stored dry in air, at a laboratory temperature and common relative humidity. The “EN” test specimens were subjected to the saturation method according to ČSN EN 12697-12, wherein they were saturated and stored at a water bath at 40 °C for 72 hours. The last set of test specimens, “AASHTO”, was saturated and stored at a plastic bag for at least 18 hours in a freezer at -18 °C, followed by 24 hours in a water bath at 60 °C.

The test specimens, treated and strained by the different environmental influences, were subsequently tempered for at least four hours at 15 °C (in water in the case of “EN” and “AASHTO” and dry in the case of “dry” specimens) and tested for indirect tensile strength according to ČSN EN 12697-23.

The dry specimens were expected to demonstrate an increase in indirect tensile strength with higher RA contents in the mixture. Similarly to the stiffness characteristic, the indirect tensile strength of dry specimens should increase due to the use of aged bituminous binder in the RA.

For the SMA_{bin} 22 mixtures, there is an obvious increase in strength between 0 % and 50 % RA (approx. 10 %); however, there was an uncharacteristic drop in the mixture with 30 % RA. In the BBTM 8 LA group, the mixture with the highest RA proportion had higher dry strengths although the specimens with 15 %-wt. of RA recorded a significant drop, almost by one half in BBTM 8 LA (while it was “only” 20 % in SMA_{bin} 22). This is a noticeable decrease; nonetheless, according to the design standards, the decisive aspect is not the indirect tensile strength but its ratio to the strength measured for specimens loaded according to ČSN EN 12697-12 wherein the specimens are stored in a water bath at 40 °C for 72 hours.

In the case of SMA 8 LA, all the partial figures of the dry specimens are almost identical although a slight increase in the characteristic is still obvious.

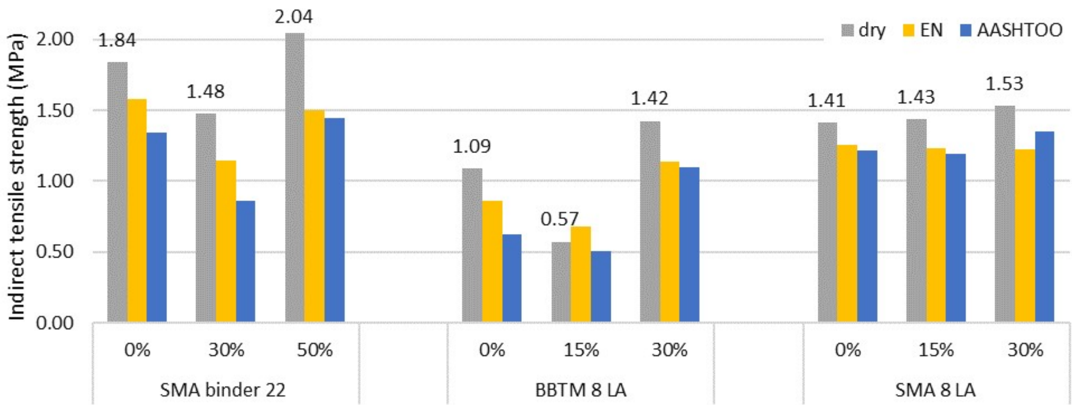

Figure 2: Indirect tensile strength (ITS) of asphalt mixtures

The indirect tensile strength ratio (ITSR) has a limit value of $ITSR_{min}$ = 80 % stipulated by TP 259. There is no limit stipulated for the SMA_{bin} 22 type of asphalt mixtures. In both mixtures on test, the ITSR tended to decrease with increasing percentages of RA in the mixture. Although the SMA 8 LA mixture with 30 % RA recorded a 9 % drop relative to the reference mixture (0 % RA), it still complied with the limit as stipulated by TP 259.

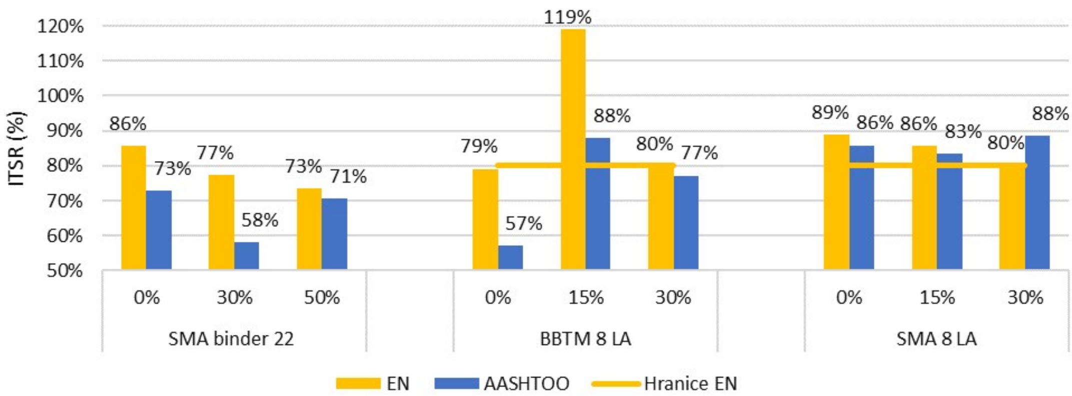

Figure 3: Indirect tensile strength ratio (ITSR) of asphalt mixtures

No such trend was obvious for BBTM 8 LA. The worst results were scored by the reference mixture which, in this case, is even below the limit stipulated by TP 259. Although just by one percent, the value is short of the required 80 %. An interesting phenomenon occurred in the mixture with 15 % RA, namely an ITSR value exceeding 100 % which means that the water cycle has a positive effect on asphalt mixture properties. This is quite unlikely and it might have been a measurement error. After 72 hours in a water bath at 40 °C, the compacted asphalt specimens are conditioned again to the test temperature, 15 °C. As is generally known, even a 1 °C difference has a significant impact on asphalt mixture properties. In the case of water susceptibility, this fact is notoriously known. Therefore, the test specimens were probably not well tempered to the test temperature as needed.

With respect to the results of SMA_{bin} 22 mixtures, we can note that the increasing proportion of reclaimed asphalt would probably require an appropriate type of adhesion promoter which should improve the water susceptibility characteristic with increasing quantity of reclaimed asphalt.

5.5. Resistance to crack propagation

In the Czech Republic, asphalt mixture behaviour in the low temperature range has been an underestimated aspect in the overall mixture characterisation despite the summer/winter weather cycle. However, it is impossible to clearly determine the effect of RA application on the mixture based on the results obtained for fracture toughness (resistance to thermal induced crack propagation). The parameter is influenced by a number of factors involved in the evaluation and, therefore, there is no way the characteristic might be estimated beforehand.

An overly high stiffness modulus is usually expected to affect the characteristic negatively – the higher the modulus the lower the fracture toughness usually is although this is not a rule of tomb that would always apply.

Table 4. Asphalt mixture resistance to frost crack propagation

	RA content	Fracture toughness [N/mm$^{3/2}$]	Fracture energy till max. F [J]	Fracture energy till [J]
SMA$_{bin}$ 22	0 %	45.2	2.2	3.1
	30 %	39.2	1.8	2.6
	50 %	28.3	1.3	1.9
BBTM 8LA	0 %	21.8	1.1	2.2
	15 %	22.9	1.4	2.3
	30 %	28.4	1.4	2.1
SMA 8LA	0 %	34.3	1.9	3.4
	15 %	33.4	1.8	2.5
	30 %	32.1	1.8	3.0

SMA$_{bin}$ 22 shows a noticeable drop in fracture toughness with increasing percentages of RA in the mixture. Out of the aged asphalt specimens, the 30 % RA version recorded a drop in fracture toughness. This particular mixture defies the envisaged trends in a number of tests.

From the perspective of fracture toughness, BBTM 8 LA mixtures copy the trend of SMA$_{bin}$ 22, although the differences in the individual values are not too distinctive. All mixtures recorded almost identical figures.

The exact opposite occurred for mixture SMA 8 LA, i.e. the fracture toughness increased with the increasing percentage of RA in the mixture. The softer, polymer-modified binder applied to this type of wearing course mixture type might be the trend-changing factor. However, this is no more than a speculation unsupported by any in-depth analysis. The difference between the reference mixture and the 15 % RA mixture is negligible; the mixture with twice as much RA scored a 30 % increase.

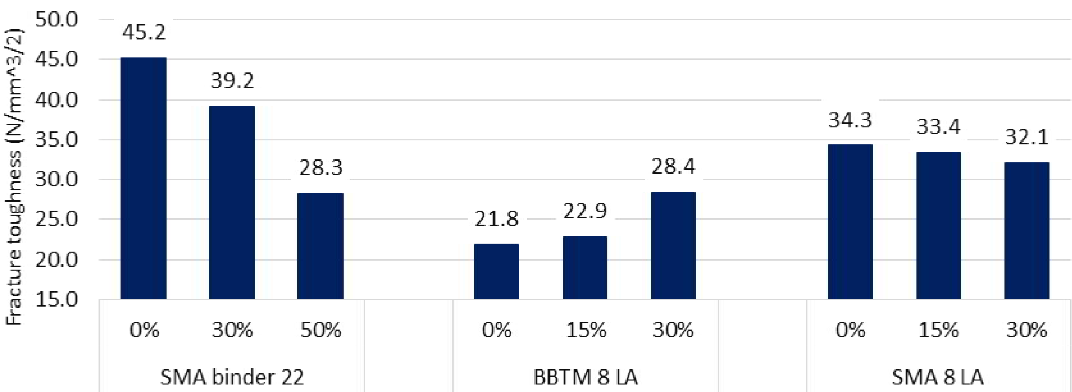

Figure 4: Fracture toughness of asphalt mixtures

5.6. Resistance to Permanent Deformation

This is, in the conditions of the Czech Republic, one of the crucial characteristics required and monitored for a number of types of asphalt mixtures for wearing and binder courses. For SMA$_{bin}$ 22, the increasing percentage of RA in the mixture was associated with a drop in the rut depth and increment thereof. There are no requirements regulating the resistance to permanent deformation (rutting) in the Czech Republic as of now. Using the German technical regulations, governing the characteristics and limits for this type of asphalt mixture, the only requirement concerns PRD$_{AIR}$ with the limit value of 5,0 %. This is safely met by all SMA$_{bin}$ 22 mixtures; the result of the mixture with 50 % RA can be considered rather low from this perspective.

In asphalt mixtures for low-accustic wearing layers, the limit for PRD$_{AIR}$ amounts to 6,0 %. The limit for WTS$_{AIR}$ has been set to 0,07 mm.

Amongst the BBTM 8 LA mixtures on test, the mixture with 15 % RA recorded a significant increase in the characteristics concerned. Both values obtained will meet the limit parameters according to TP 259, although such an increase is uncharacteristic and inexplicable. When 30 % RA was applied, both characteristics on test decreased as expected, i.e.

there should be higher stiffness and, therefore, improved resistance to permanent deformation in the presence of reclaimed asphalt.

In SMA 8 LA, the increasing proportion of RA in the mixture is associated with an obvious drop in the characteristics of resistance to permanent deformation, as same as in SMA_{bin} 22. This trend correlates with the results of stiffness modulus measurements at higher temperatures where the modulus grew depending on the RA content in the mixture. The WTS_{AIR} limit was exceeded by the mixture with no reclaimed asphalt which does not correspond with the results in the ITT protocol where the mixture failed to meet this requirement. The value is significantly higher relative to the mixtures with RA. The drop in WTS_{AIR} when 30 % RA is used is more than four-fold.

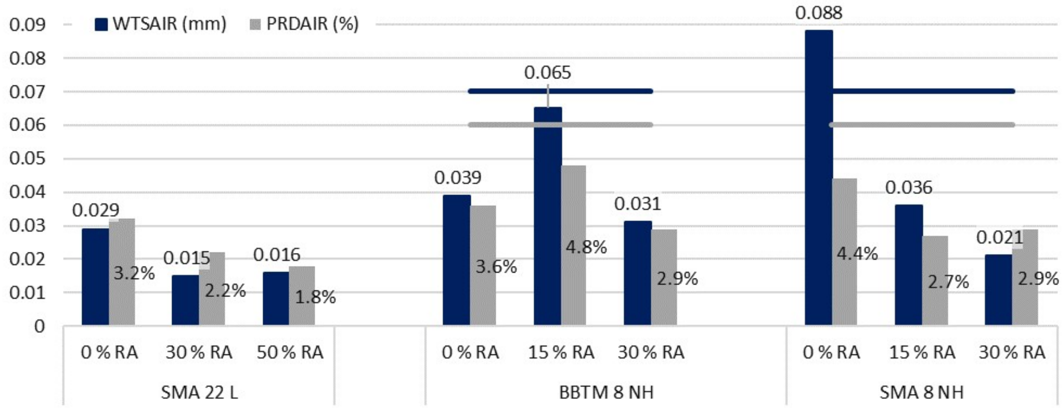

Figure 5: Results of permanent deformation test of asphalt mixtures

5.7. Flexural strength

Flexural strength was tested by 3-point bending beam test. The test specimens were obtained from the plates used for the rutting test, and divided into beams; four beams were left at laboratory temperature ("virgin") and four others were exposed to an ageing cycle according to prEN 12697-52, i.e. stored at 85 °C for five days ("aged"). No test was performed with the BBTM 8 LA mixture with 30 % reclaimed asphalt, because of unintentional disposal of the plates before the cutting process.

Table 5. Results of flexural strength test of asphalt mixtures

	RA content	Flexural stregth (MPa)	Flexural modulus (MPa)	Fracture energy (J)
SMA_{bin} 22	0%	9.2	1467	2.5
	30%	9.2	1521	2.3
	50%	7.9	2042	1.3
BBTM 8 LA	0%	4.0	676	0.9
	15%	3.1	688	0.7
	30%	-	-	-
SMA 8 LA	0%	3.8	451	1.3
	15%	4.1	544	1.3
	30%	3.8	457	1.4

A slight drop (15 %) in the flexural strength was noticed in the SMA_{bin} 22 mixtures when 50 % RA was applied. The application of a lower percentage resulted in the same strength as in the reference mixture. The higher brittleness of the bituminous binder in the mixture with 50 % might have been due to the higher proportion of aged binder in the RA. The same drop is seen also in the case of fracture energy which characterises the amount of energy necessary for the test beam to break (fracture). A beam with 50 % RA only needed half of the energy necessary to fracture a reference mixture beam. This characteristic thus requires a correct dose of the rejuvenator, as it could be significantly improved by further optimisation of the rejuvenator quantity.

There is no limit value for this asphalt mixture in Czech specifications. The only document determining the limit value of flexural strength determined at 0 °C is the TP 151 technical specification concerning asphalt mixtures with high stiffness modulus (HMAC). The specification stipulates a 6,0 MPa limit for flexural strength for HMAC mixtures. All of the SMA_{bin} 22 mixtures would have met this limit comfortably.

The effect of the reclaimed asphalt material was noticeable in BBTM 8 LA mixtures, too, notably by a drop in the flexural streght although the difference in fracture energy was not as significant as in the preceding case. Due to the aforementioned reason, the only comparison available is for the mixture with 15 % RA.

The SMA 8 LA mixture achieved stable results in the flexural streght. The application of reclaimed material did not have a significant effect; the fracture energy results are even, with no distinctive variations among the individual mixture versions.

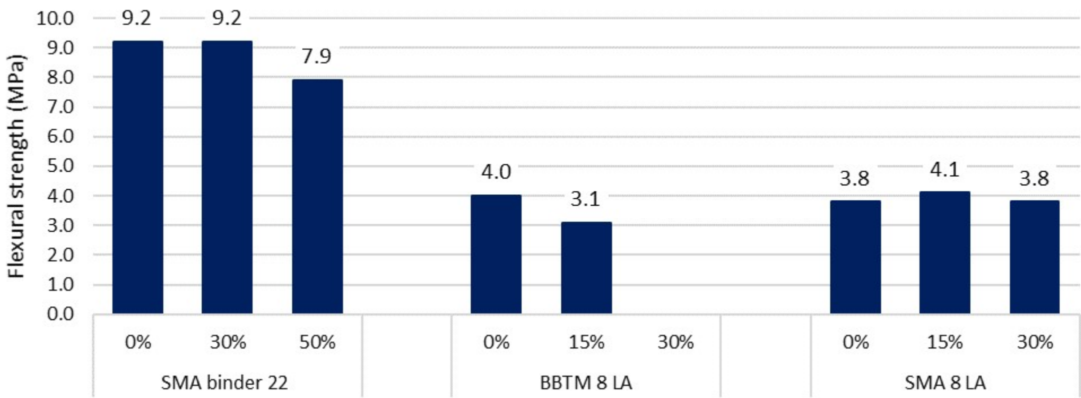

Figure 6: Flexural strength of asphalt mixtures

6. SUMMARY

Based on the extended performance tests of asphalt mixtures used in the surfacing of the test section of road II/236 Kačice – Směčno, the evaluation suggests that the selected asphalt mixture design and application of reclaimed asphalt material even in mixtures where the technical regulations do not currently permit such application had no negative impact on the quality and performance based behaviour of the mixtures.

The binder course used mixture SMA_{bin} 22, which was the only application thereof in the Czech Republic so far – this type of asphalt mixture has not been used in any other road yet. The asphalt mixture was prepared in two sub-versions with 30 % and 50 % recycled asphalt material, respectively, to tests the impact of RA content on the ultimate characteristics of the mixture. The findings for SMA_{bin} 22 were as follows:

- The asphalt mixture with no reclaimed material had the lowest air void content within the group on test – SMA_{binder} type of mixture should be designed with a lower air void content relative to common asphalt concrete for binder courses. A more compact structure will provide increased stiffness, increased resistance to rutting and resistance to fatique. Within the group, the reference asphalt mixture (no reclaimed asphalt material added) demonstrated the best properties in the low temperature range and even achieved relatively high strength characteristics, depending on the source of aggregate.
- The design of the asphalt mixture with 30 % RA was probably not optimal. This mixture contained a slightly higher quantity of bituminous binder and had finer particle sizes than the other two mixtures. On the other hand, the impact of air voids content was manifested, which rather contradicts the higher bituminous binder content and finer grading curve. The asphalt mixture had a lower indirect tensile strength than expected, although the ITSR value conforms to the expected trend.
- The aged binder in the reclaimed material within the mixture with 50 % RA caused an increase to the strength and deformation characteristics; the stiffness modulus at 15 °C was 30 % higher relative to the reference mixture with no reclaimed material. This subsequently caused a slight deterioration in the properties tested in the low temperature range wherein the fracture toughness determined at 0 °C decreased by almost 50 %. The asphalt mixture properties in the low temperature range could be improved by optimising the doses of the rejuvenator, where a higher quantity of rejuvenator could have a positive impact on the characteristics. Any addition of rejuvenator should primarily check the resistance to permanent deformation characteristic as this particular version did very well but an increased concentration could deteriorate this performance.
- From the perspective of higher significance, no negative effect of reclaimed material in the mixture on the characteristics on test was established for SMA_{bin} 22 mixtures. There were naturally deteriorations in some mixtures in comparison to the reference value although this never went below the stipulated, or analogously determined, limit that would jeopardise the quality of the pavement structure.

The individual versions of the BBTM 8 LA mixture were designed with almost identical grading curves and with the identical quantities of bituminous binder. However, the binder content fell short of the minimum limit stipulated by the TP 259 technical specification (the minimum limit is 5,3 % while the mixtures only had 4,6 %). The volumetric properties of all the mixtures were also almost identical.

- If compared to the other mixtures, the asphalt mixture with 15 % RA scored very low in the indirect tensile strength test (almost 50 % lower relative to the reference mixture). In contrast to that, the measurement taken of the saturated specimens (3 days in a water bath at 40 °C) was 20 % higher. In the case of this test, the specimens may have been insufficiently tempered or there might have been measurement error. Even a certain lack of homogeneity caused by the reclaimed material could be considered although this is less likely with respect to the quantity of the material in the mixture. The asphalt mixture scored well in the low temperature range (values comparable to the reference mixture) but the performance in the resistance to permanent deformation test was weaker. That might be partially linked to the lower strength. Although the asphalt mixture met the requirements of TP 259, the stipulated values are significantly higher than those of the remaining two mixtures.
- The asphalt mixture with 30 % RA had the lowest thermal susceptibility value which might be of great significance for a wearing course. The lower the thermal susceptibility, the less susceptible the asphalt mixture is to sudden temperature changes which are rather frequent in wearing courses. The asphalt mixture also scored well in fracture toughness (highest score in the group on test); again, this is a very important parameter for a wearing course even if it is not required or checked in the Czech context.
- In the BBTM 8 LA type group, the mixture with 30 % RA had very good results, better even than the reference mixture with no RA in a number of tests. Contrastingly, the asphalt mixture with 15 % RA content demonstrated deteriorated results. The results show how important it is to adopt an individual approach to every single design of asphalt mixture with reclaimed material rather than working just with assumptions of how the asphalt mixture should perform.

The SMA 8 LA asphalt mixtures were designed with the identical grading curve but the binder content in the individual mixtures differed. The mixture with 30 % RA had a 0.6 % higher binder content than the reference mixture and 0.8 % higher than the mixture with 15 % RA. This may influence the results of the tests presented wherein the increased binder content should have a positive effect on water susceptibility and fatigue resistance although, on the other hand, it might affect resistance to permanent deformation slightly negatively.

- In terms of resistance to permanent deformation, the reference mixture with no reclaimed material performed the worst. The WTS_{AIR} was almost one quarter above the standard limit. When compared to the mixture with 30 % RA, the WTS_{AIR} of the reference mixture was four times worse.
- The asphalt mixture with 30 % RA had a slightly lower air voids content than the remaining mixtures. This was probably caused by the higher content of bituminous binder which has a positive effect on asphalt mix workability. The content of RA and lower air void content had no effect on the stiffness modulus (at 15 °C). These two factors were expected to make the stiffness increase significantly. The evaluation of water and freeze susceptibility showed that when 30 % RA was applied, the $ITSR_{EN}$ deteriorated – it is at the minimum limit according to the requirements of the currently valid TP 259. On the other hand, when the US method of assessing water susceptibility (employing the freeze cycle) was employed, this mixture scored the highest (best).
- From the perspective of behaviour in the low temperature range, all SMA 8 LA mixtures scored almost the same. There had been a concern that the aged bituminous binder in the reclaimed material might have a negative effect on brittleness of the asphalt mixtures in the low temperature range but the results refute such concerns.

7. CONCLUSION

In a number of cases, the application of reclaimed material contributed towards an improvement in the complex properties of the asphalt mixtures on test. We can generally state that the RA content was demonstrated by an increase in the stiffness which, in turn, meant a consequent rise in resistance to permanent deformation. The test of resistance to permanent deformation clearly showed that – the depth of the rut decreased by one half in some cases. On the other hand, this higher stiffness caused a rise – although not in all cases – in brittleness of the specimens which were then more susceptible to crack initiation and propagation. This was obvious from the crack propagation test in semi-cylindrical specimens as well as beams. A faster crack initiation at a low temperature (lower fracture energy) means that the asphalt layer of the pavement might fail sooner even if the traffic load remains the same.

Despite some slight deteriorations in the properties, the application of reclaimed asphalt material in asphalt mixtures where it is not permitted by national standards or technical specifications of the industry at the moment appears promising and the applications should be further researched. Extended use of reclaimed asphalt even in asphalt mixtures other than asphalt concrete (where the current standards permit the application thereof nowadays) is a direction the society should follow. It is not possible to keep using natural resources exclusively; new solutions which will be beneficial both environmentally and economically must be pursued. Moreover, the generally applicable axioma that behaviours using resources infinitely are impossible in the long term in any system with limited resources, shall be kept in mind. We may choose to ignore this fact but the consequences thereof cannot be undone.

Focusing on the issue of viability of a combination of the aforementioned two types of asphalt mixtures for wearing courses, and a new type of asphalt mixture for a binder course, the results show that the combination of the relevant wearing course and binder course could deliver a good quality surfacing from the perspective of the results achieved; according to the findings available so far from the design as well as practical verification by the trial section, the surfacing in question champions and supports the idea of low-maintenance asphalt pavement surfacing concept.

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