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EFFECT OF RAP ON THE PHYSICAL PROPERTIES OF ASPHALT MIXTURES WITH PMB

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Abstract

The aim of this paper is to describe the effect of dosing different amounts of RAP into asphalt mixtures with polymer modified binder on the change of physical properties of these mixtures. The changes in stiffness moduli, phase angles and low temperature properties of selected asphalt mixtures as a function of the amount of RAP dosed are described. The measurements were carried out on test specimens of laboratory produced asphalt mixtures AC 11 wearing course with different asphalt binders. The reference mix contained the most used road asphalt 50/70 in the Czech Republic. In addition, mixes with polymer modified binders 45/80-65, 45/80-80 and 45/80 RC were used. The dosage of R-material in the asphalt mixtures was chosen in the amounts of 0 %, 30 % and 50 %, thus describing the boundary conditions of the currently valid technical regulations and at the same time describing the physical properties of mixtures with an excess amount of RAP.

Keywords: RAP, asphalt mixtures with PMB, stiffness, phase angle, low temperature properties

1 Introduction

Recently, the civil engineering industry has been increasingly affected by the impact of global issues such as global warming, environmental protection, rising energy prices or limited financial resources. As a result, there is an increasing emphasis road construction on the development and use of new materials using secondary raw materials such as reclaimed asphalt pavement (RAP). RAP started to be used in the 1970s and is currently an environmentally and financially friendly way of producing hot-mix asphalt mixtures [1-3].

Based on data provided by the European Asphalt Pavement Association (EAPA), the total annual production of the 4700 European asphalt plants is approximately 282.5 million tonnes of hot mix asphalt [4]. On the other hand, literature [5] states that around 950 billion tonnes of asphalt mixtures are already installed in the entire European road network. Given the limited number of natural resources, it is therefore inevitable in the long term to use RAP as much as possible [6].

The RAP is most often obtained by crushing and sorting demolished asphalt slabs or milled reclaimed asphalt mixtures from completed traffic structures. The material obtained in this way contains aggregate coated with an asphalt binder which has aged to some extent because of long-term oxidation and exposure to climatic conditions. Aged binders are significantly harder and more brittle than fresh asphalt binders. The addition of RAP in the production of asphalt mixtures increases their stiffness. These mixtures are then more resistant to permanent deformation but are also more susceptible to cracking [7]. This leads to a distrust of government agencies to extend the specifications of asphalt mix production to allow the implementation of RAP in high quantities [1].

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One of the critical points in evaluating the increased stiffness and loss of ductility of an asphalt mixture is the degree of mixing between the original RAP binder and the newly proportioned binder during the production of the asphalt mixture [6]. Some researchers [1, 8-11] have been working to evaluate the degree of mixing that occurs during the production of asphalt mixtures with RAP; results suggest that partial mixing of binders does occur, but it depends on the specific material, mix type, and production characteristics. This topic was partly addressed in the research [6], in which the authors focused on the possibility of detecting RAP in hot-mix asphalt (HMA) mixtures in addition to the mixing rate of binders. The national authorities have developed various specifications for RAP that can be used in the production of HMA based on local experience [12].
In the Czech Republic, RAP can be dosed into asphalt mixtures only if the requirements laid down in the relevant standards are met [13-15]. RAP can be dosed into asphalt layers in a maximum quantity of up to 30 % by weight. However, the following conditions apply [13].
In practice, however, these requirements mean that many asphalt plants produce asphalt mixes with RAP only up to 15 %. This avoids the need for additional treatment of the RAP and subsequent testing of the properties of the recovered asphalt binders, for which stricter criteria apply if more than 15 % RAP is used.
The use of RAP in asphalt mixtures is also influenced by geographical and climatic conditions. In colder climates, asphalt mix failure due to cracking caused by exposure to cold temperatures is the most common problem that authorities must deal with. As the temperature drops, the stress in the asphalt mixture increases and the moment stress exceeds the tensile strength of the material, the material cracks. The temperature at which the pavement cracks is called the critical failure temperature. Due to the viscoelastic nature of the bituminous binder, the magnitude of the stress and the critical failure temperature depend on the initial temperature and the cooling rate. A higher initial temperature will affect the critical failure temperature. A higher cooling rate then means that stress accumulates in the material (the material does not have the ability to relax) and cracks occur at a higher temperature [12]. For this reason, the Thermal Stress Restrained Specimen Test (TSRST) was chosen to evaluate the low temperature properties of asphalt mixtures.
Asphalt mixtures with PMB are successfully used in places with excessive traffic loads such as highways, major streets in cities, intersections, airports, parking lots or racetracks. Increasingly, polymer modified styrene-butadiene-styrene (SBS) based binders are used worldwide, which are more resistant to permanent deformation and crack formation [16]. Despite the high use of SBS binders in the Czech Republic in asphalt mixtures, they are still investigated and so far considered high quality materials that should not be degraded by the addition of RAP. The aim of this paper is to demonstrate that asphalt mixtures with PMB are in contrary suitable materials for combination with RAP, and that the resulting asphalt mixes achieve very good low temperature properties. In other words, that material failure by cracking occurs at very low critical failure temperatures.

2 Used materials

Within the framework of this paper, an asphalt mixture AC 11 with the addition of RAP was designed and produced in the laboratory. Four different bituminous binders were used to produce this mix: Pavement grade bitumen 50/70, PMB 45/80-65, PMB HIMA (Highly Modified Asphalt) 45/80-80 and PMB 45/80 RC. The RAP was proportioned into these mixes at rates of 0 %, 30 % and 50 %. These asphalt mixtures were used to produce specimens for the measurement of stiffness moduli, phase angles and determination of low temperature properties.

3 Test methods used

The methods of measuring the stiffness modulus of asphalt mixture are described in the standard ČSN EN 12697-26 [17]. In the framework of this research, the stiffness modulus was determined using the two-point bending test on trapezoidal shaped specimen - 2PB TR. The sinusoidal stress is applied to the free end of the specimen glued at the bottom base to a backing plate fixed to a rigid frame. The deflection should not exceed a deflection of $\varepsilon \leq 50 \cdot 10^{-6}$. Based on the force, deflection and phase angle, complex modulus is determined, which is made up of a real and an imaginary part. The stiffness moduli and phase angles were measured at temperatures of (- 5, 10, 15, 25 and 40) °C with loading frequency of 10 Hz. Methods for measuring the low temperature properties of asphalt mixtures and crack formation in them are described in ČSN EN 12697-46 [18]. The characteristics were determined using the Thermal Stress Restrained Specimen Test TSRST, which maintains a constant length of the test body while its temperature decreases with time. As a result of the prohibited thermal contraction, the test body is subjected to (cryogenic) tensile stress. The test was started at an initial temperature of +15 °C and cooling was carried out at a rate of 10 °C /h.

4 Test results

This chapter presents the results of tests mentioned in the section 3 to determine the stiffness modulus, phase angle and low-temperature properties of laboratory-mixed asphalt mixtures.

4.1 Stiffness

The values of the complex modulus determined at temperatures of (-5, 10, 15, 25 and 40) °C and a frequency of 10 Hz for asphalt mixtures are represented in Table 1 and Fig. 1. The complex modulus determined at a temperature of 15 °C and a frequency of 10 Hz, which is highlighted in the table, is the determining value listed in the Czech standard TP 170.

Table 1 Complex moduli [MPa] measured at a frequency of 10 Hz and T = (-5 to 40) °C

Asphalt Mixture	**Temperature** [°C]				
	- 5	10	**15**	25	40
0 RAP 50/70	15150	10446	**8370**	4815	1338
30 RAP 50/70	15964	11664	**9821**	6474	2587
50 RAP 50/70	17661	13388	**11662**	8305	3749
0 RAP PMB 45/80-65	14371	8958	**6849**	3672	1038
30 RAP PMB 45/80-65	14817	10137	**8210**	5065	1765
50 RAP PMB 45/80-65	13979	10189	**8606**	5847	2426
0 RAP PMB HIMA 45/80-80	12727	8839	**7323**	4746	2112
30 RAP PMB HIMA 45/80-80	15043	10573	**8759**	5585	2088
50 RAP PMB HIMA 45/80-80	14083	10648	**9225**	6598	3336
0 RAP PMB 45/80 RC	14657	9036	**6919**	3791	1140
30 RAP PMB 45/80 RC	14762	9975	**8120**	4909	1701
50 RAP PMB 45/80 RC	12982	9555	**8218**	5805	2723

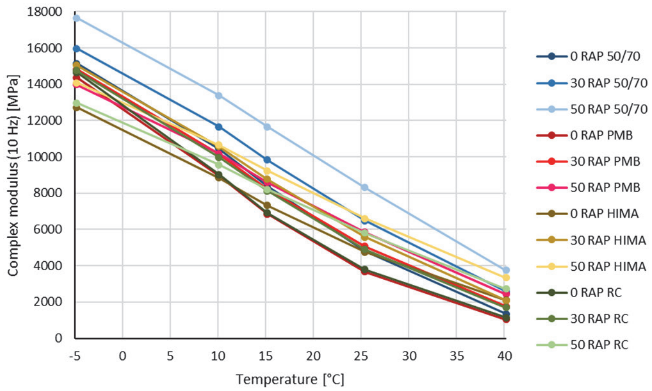

Figure 1 Temperature dependence of the complex modulus at a frequency of 10 Hz

Stiffness of the asphalt mixture increases with decreasing temperature. The stiffness of the asphalt mixture also increases with the amount of RAP dosed. Thus, RAP increases the resistance of asphalt mixtures to the formation of permanent deformations. The results show that the highest complex modulus determined at a frequency of 10 Hz was demonstrated by the asphalt mixtures with 50/70 road asphalt. On the other hand, the lowest complex modulus was declared by the asphalt mixtures containing modified RC binder. Mixtures containing modified SBS based binders do not achieve very high complex modulus values (as in the case of the 50/70 pavement grade bitumen), as the modification makes the binders more elastic.

In the past, the national standard EN 13108-1 required a minimum design value of the complex modulus for the asphalt mixture used in wearing and base course of 7000 MPa. This condition would not be met by AC 11 PMB 45/8065 + 0 % RAP (6849 MPa) and AC 11 PMB 45/80 RC + 0 % RAP (6919 MPa). This requirement has been removed with a new revision of this standard specifically with respect to asphalt mixtures containing PMB. Asphalt mixtures are currently not limited by their designed stiffness.

4.2 Phase angles

Phase angles of the asphalt mixtures were also measured as part of the determination of the complex modulus. The values of measured the phase angles as a function of temperature are represented in Table 2 and Fig. 2.

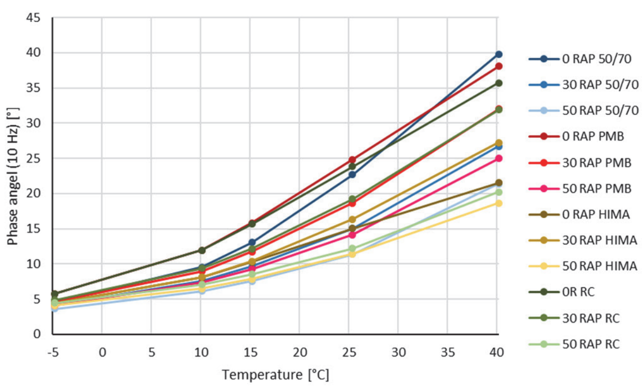

Figure 2 Temperature dependence of the phase angles at frequency of 10 Hz

Table 2 Phase angels [°] measured at a frequency of 10 Hz and T = (-5 to 40) °C

Asphalt mixture	**Temperature [°C]**				
	- 5	10	**15**	25	40
0 RAP 50/70	4,5	9,6	**13,1**	22,7	39,8
30 RAP 50/70	4,1	7,5	**9,6**	15,1	26,7
50 RAP 50/70	3,6	6,2	**7,6**	11,4	21,4
0 RAP PMB 45/80-65	5,8	11,9	**15,8**	24,9	38,1
30 RAP PMB 45/80-65	4,6	9,0	**11,7**	18,6	32,0
50 RAP PMB 45/80-65	4,1	7,3	**9,3**	14,1	25,0
0 RAP PMB HIMA 45/80-80	4,4	8,1	**10,2**	15,0	21,6
30 RAP PMB HIMA 45/80-80	4,4	8,1	**10,4**	16,3	27,2
50 RAP PMB HIMA 45/80-80	4,1	6,5	**7,9**	11,4	18,7
0 RAP PMB 45/80 RC	5,8	12,0	**15,7**	23,8	35,7
30 RAP PMB 45/80 RC	4,9	9,4	**12,2**	19,2	31,9
50 RAP PMB 45/80 RC	4,5	7,1	**8,6**	12,2	20,2

The results show that the magnitude of the phase angle is dependent on the temperature and the amount of RAP dosed. The phase angle increases with increasing temperature. On the other hand, the value of the phase angle decreases with increasing proportion of RAP in the asphalt mixture, mainly caused by the aged binder contained in the RAP. An exception is the asphalt mixture AC 11 PMB HIMA 45/80-80 with 30 % RAP, which has higher phase angle values than the mixture AC 11 PMB HIMA 45/80-80 without RAP.
The highest phase angle (39,8°) was measured for the asphalt mixture AC 11 with pavement grade bitumen 50/70 at 40 °C. In general, the highest phase angles across the entire temperature spectrum were determined for the AC 11 PMB 45/80-65 asphalt mixture. Contrary to the asphalt mixture with the lowest phase angle, which is AC 11 PMB HIMA 45/80-80 with 50 % RAP and the very lowest single value of phase angle (3,6°) was measured for AC 11 asphalt mixture with pavement grade bitumen 50/70 and 50 % RAP at -5 °C.

4.3 Low temperature properties

The results of the TSRST test are represented in Table 3 and Fig. 3.

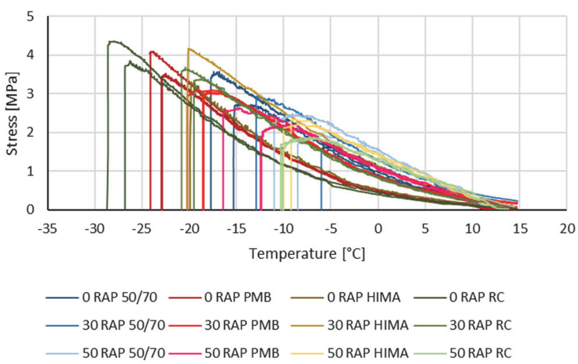

Figure 3 Low temperature properties of asphalt mixtures with RAP

Table 3 Low temperature properties of asphalt mixtures with RAP

Asphalt mixture	Critical temp. [°C]	Critical load [kN]	Critical stress [MPa]
0 RAP 50/70	-16,5	7,64	3,06
30 RAP 50/70	-12,7	7,43	2,97
50 RAP 50/70	-9,8	4,86	1,94
0 RAP PMB 45/80-65	-23,6	9,38	3,75
30 RAP PMB 45/80-65	-19,4	7,38	2,96
50 RAP PMB 45/80-65	-14,4	5,39	2,26
0 RAP PMB HIMA 45/80-80	-19,8	8,27	3,31
30 RAP PMB HIMA 45/80-80	-20,1	10,42	4,17
50 RAP PMB HIMA 45/80-80	-9,5	5,58	4,17
0 RAP PMB 45/80 RC	-27,7	9,97	3,99
30 RAP PMB 45/80 RC	-20,2	8,66	3,47
50 RAP PMB 45/80 RC	-10,2	4,10	1,64

The critical temperature of the asphalt mixtures ranged from -10 °C to -30 °C. The critical force and critical stress ranged from (4.1 to 10.42) kN and (1.64 to 4.17) MPa. In terms of critical temperature, it can be concluded that the asphalt mixtures with pavement grade bitumen 50/70 exhibit the worst low temperature properties. These asphalt mixtures had the highest critical temperature, in all cases regardless of different amounts of RAP contained in them (0; 30 and 50) %. On the other hand, the asphalt mixtures containing modified RC binder showed the best low temperature properties (up to 50 % RAP when PMB samples ended up better).

5 Conclusion

Based on the evaluation of the laboratory tests carried out to determine the complex modulus, phase angle and low-temperature properties of AC 11 asphalt mixtures with different binders and different RAP contents, the following can be stated.
The values of the complex modulus determined at a temperature of 15 °C and a frequency of 10 Hz ranged from approximately 7000 MPa to 12000 MPa. The complex modulus was mostly influenced by the type of binder used. The asphalt mixtures containing SBS PMB generally achieved lower modulus than the mixtures with pavement grade bitumen 50/70. From the resulting phase angles can be concluded, that mixtures with a higher proportion of RAP exhibit higher elasticity than mixes without RAP.
Based on the resulting low temperature properties determined by the TSRST method, it appeared that asphalt mixtures with PMB and RAP in the amount of up to 30 % show higher resistance to cracking than mixtures with the most used binder in the Czech Republic, pavement grade bitumen 50/70. In case of the 50 % RAP dosage, the type of binder no longer influences the crack failure and all asphalt mixtures failed at approximately the same critical temperature of -10 °C. The standard [13] maximum limit for the dosage of RAP in asphalt mixtures used in a wearing course is optimally 30 % in terms of low temperature properties. It has been confirmed that the addition of RAP into asphalt mixtures with PMB is not undesirable, but on the contrary very advantageous. The best overall performing binder used in combination with RAP in this project is PMB 45/80 RC. However, all asphalt mixtures with PMB showed better properties than the mixtures with pavement grade bitumen 50/70.

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References

[1] Mogawer, W., Bennert, T., Daniel, J.S., Bonaquist, R., Austerman, A., Booshehrian A.: Performance characteristics of plant produced high RAP mixtures, Journal of Road Materials and Pavement Design, 13 (2012), pp. 183-208

[2] Behnood, A.: A review of the warm mix asphalt (WMA) technologies: Effects on thermo-mechanical and rheological properties, Journal of Cleaner Production, 259 (2020) 120817

[3] Guo, M., Liu, H., Jiao, Y., Mo, L., Tan, Y., Wang, D., Liang, M.: Effect of WMA-RAP technology on pavement performance of asphalt mixture: A state-of-the-art review, Journal of Cleaner Production, 266 (2020), DOI: 10.1016/j.jclepro.2020.121704

[4] EAPA data; http://www.eapa.org/asphalt.php

[5] EAPA Position paper; Asphalt the 100 % recyclable construction product; European Asphalt Pavement Association, Brussels, Belgium, June 2014, http://www.eapa.org/userfiles/2/Publications/EAPApaper_Asphalt_the%20100%20_recyclable_construction%20product.pdf

[[6] Sachr, J., Dasek, O., Hyzl, P.: Detection of Reclaimed Asphalt Pavement Presence in Asphalt Mixtures Using a Method of Successive Asphalt Binder Extraction, Key Engineering Materials, 904 (2021), pp. 458-463

[7] Sungho, K., Sholar, G.A., Byron, T., Kim, J.: Performance of Polymer-Modified Asphalt Mixture with Reclaimed Asphalt Pavement, Journal of the Transportation Research Board, 2126 (2009) 1

[8] Bonaquist, R.: Laboratory evaluation of hot mix asphalt (HMA) mixtures containing recycled or waste product materials using performance testing, Pennsylvania Department of Transportation, Harrisburg, 2005.

[9] Daniel, J.S., Pochily, J., Boisvert, D.: Can more reclaimed asphalt pavement be added? Study of extracted binder properties from plant produced mixtures with up to 25% reclaimed asphalt pavement, Transportation Research Record: Journal of the Transportation Research Board, 2180 (2010), pp. 19–29

[10] McDaniel, R., Shah, A., Huber, G.: Investigation of low- and high-temperature properties of plant produced RAP mixtures, Federal Highway Administration, 2012.

[11] Daniel, J.S., Gibson, N., Tarbox, S., Copeland, A., Andriescu, A.: Effect of long-term aging on RAP mixtures: Laboratory evaluation of plant produced mixtures, Journal of Road Materials and Pavement Design, Special Issue: Papers from the 88th association of asphalt paving technologists annual meeting, 2013.

[12] Mensching, D., Daniel, J., Bennert, T., Medeiros, M., et al.: Low-temperature properties of plant-produced RAP mixtures in the Northeast, Journal of Road Materials and Pavement Design, 15 (2014), pp 1-27

[13] ČSN 73 6141, Requirements for the use of RAP in asphalt mixtures, Office for Standards, Metrology and Testing, 2023.

[14] ČSN 736120, Road construction - Other asphalt layers - Implementation and compliance check, Office for Standards, Metrology and Testing, 2021.

[15] ČSN 73 6121, Road construction - Compacted asphalt layers - Implementation and compliance check, Office for Standards, Metrology and Testing, 2023.

[16] McDaniel, R., Shah, A.: Use of Reclaimed Asphalt Pavement (RAP) Under Superpave Specifications, Journal of the Association of Asphalt Paving Technologists, 72 (2003), pp. 226–252

[17] ČSN EN 12697-26+A1, Asphalt mixtures - Test methods - Part 26: Stiffness, Office for Standards, Metrology and Testing, 2023.

[18] ČSN EN 12697-46, Test methods - Part 46: Low temperature properties and crack formation using uniaxial tensile testing, Office for Standards, Metrology and Testing, 2021.