CETRA2020*
20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

BEHAVIOUR OF HIGH-MODULUS ASPHALT MIXTURES FROM THE PERSPECTIVE OF STRAIN CHARACTERISTICS (STIFFNESS)

Jan Valentin, Majda Belhaj, Pavla Vacková
Czech Technical University in Prague, Czech Republic

Abstract

High modulus asphalt concrete (HMAC) presents a concept of an asphalt mixture with advanced performance which is suitable mainly for heavy loaded pavement structures. The mix concept was developed more than 25 years ago in France and became a standard in many countries. In the Czech Republic this type of asphalt mixtures is used since the early years of this millennium, when original technical requirements have been set. After almost 20 years a volunteer technical assessment started to validate whether the technical requirement set mainly for stiffness values and partly also for flexural strength or resistance to crack propagation are still up-to-date or if some reasonable modification is needed like was done several years ago in France when high modulus asphalt concrete of so called EME II or GP5 generation were brought to the practice. Based on this a study with focus on stiffness determination for more than 40 different HMACs was started. The stiffness was tested at different temperatures. At the same time virgin and aged asphalt mixtures were compared. Results from this study are presented by the paper.

Keywords: asphalt mixtures, high modulus asphalt concrete, HMAC, EME, stiffness, SCB test

1 Introduction

High modulus asphalt concretes (HMAC) were firstly design and used in France nearly 40 years ago [1]. HMAC or interchangeable term of EME (Enrobé a Module Élevé) and are a special type of asphalt concrete with strong aggregate structure, slightly higher amount of binder and elevated stiffness usually balanced with good fatigue life. This type of mixtures is used in both heavy duty and structural rehabilitation projects where it is desirable to minimize the impact of grade change yet still ensure pavement longevity. Use of HMAC in base or potentially binder pavement layer can potentially lead to a reduction of thickness of asphalt layers in pavement structure in comparison to pavement structure with conventional asphalt concretes while the service life of such a construction remains unchanged. Effort to reduce the thickness of asphalt layer is related to reduction of construction costs and also later life cycle costs related to maintenance LCC optimization [2, 4]. In addition, the material resources can be saved. Some of the published papers or research outputs e.g. [5, 6] present a reduction in thickness between 25 and 30 percent in the pavement structure. In the case of long-life pavements, the overall costs have to be assessed not only from the perspective of construction costs but mainly from the view point of life cycle costs. Primary cost can be higher but the pavement shows less demand for repairs and rehabilitation actions and therefore the life cycle costs are significantly lower than for other types of asphalt mixtures. For these reasons it is necessary to focus on the life cycle cost assessment during selection of the right pavement design and not only on the lowest construction price as currently often happens. Espersoon [1] showed the results of the experimental research that has been done to calculate the reduction in thickness of the base layer with HMAC compare to a base layer with conventional paving grade bitumen for runway pavements at the different temperatures. Rys et al. [3] presented analysis of 80 selected road sections in Poland of total length of about 1300 km and compared low temperature cracking properties of pavements with HMAC mix type and conventional asphalt concrete base. It was revealed that pavements with high modulus asphalt bases have several times higher odds of cracked than pavements with conventional asphalt concrete base.

2 Assessed variants of asphalt mixture

For the assessment of further specified characteristics of high modulus asphalt concretes (denoted VMT 22 or HMAC) in total 47 variants were included. These mixtures were produced and tested in 2019-2020. The HMACs were divided in two groups depending on the used bituminous binder – either paving grade/hard paving grade or polymer modified bitumen (PMB). For the PMB set 5 variants containing PMB 10/40-65, 24 variants containing PMB 25/55-60 or -65 and 4 variants with commercial Polybitume EP were included. In total this group involved 33 variants of HMAC mixture. The “non-modified” set of asphalt mixtures contained 11 variants with 20/30 bitumen, on variant with hard binder 15/25 and two variants where 30/45 bitumen was used. In total there were for this set 14 variants.
Asphalt mixtures of HMAC type have generally similar grading (representation of particle size distribution) like asphalt concrete used for binder courses (AC_{bin}). The difference is in a closer grading envelope. In comparison with AC_{bin} 22 the HMAC 22 mixture do have a requirement for higher bituminous binder content. The national standard CSN 73 6121 (for the Czech Republic) specifies for AC_{bin} 22 of superior class a minimum bitumen content 4,0 % by mass. For HMAC 22 the required binder content interval is 4,1 to 5,4 % by mass depending on the coefficient of richness and the volumetric content of bitumen in the mixture (min. 10,5 % by vol.). These requirements have so far been defined by the technical specifications TP 151. According to the new standard CSN 73 6120 (in final review process) the bitumen content is even set between 4,4 and 5,6 % by mass. The requirement for coefficient of richness which is typical for French asphalt mix design as well as the minimum volumetric binder content will not be requested in the future.

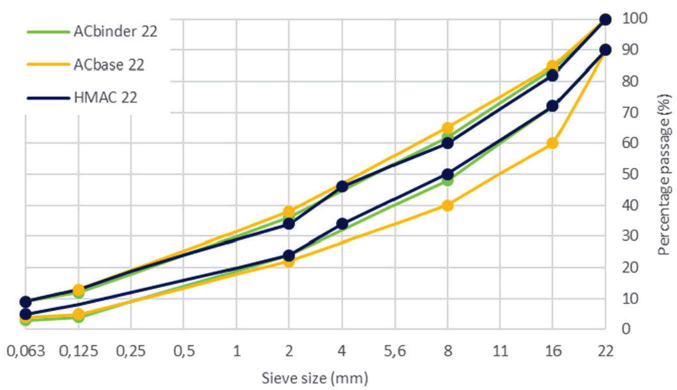

Figure 1 Comparison of grading envelopes for HMAC and asphalt concrete according to Czech specifications

For asphalt mixtures VMT 22 (HMAC 22) the interval of required voids content ins closer as well. The TP 151 specifications prescribe a voids content for mix designing of 3,0 to 5,0 % and for control testing 2,5 to 6,0 %. For common asphalt concrete AC_{bin} 22 for superior applica-

tions the voids content requirements are 4,0 to 6,0 % for type testing and 3,0 to 8,0 % for control testing.
One of the most fundamental characteristics for HMAC mix type is without any doubts its stiffness. In the case of the Czech Republic the stiffness modulus is determined at the test temperature of 15 °C (S15). This temperature is the most decisive according to the pavement design manual which is defined by specifications TP 170. In the so far still valid technical specifications TP 151 for HMAC mixtures the minimum required value of stiffness is $S_{15,min}$=9000 MPa. There is only on stiffness category. This limit is valid for determination of stiffness modulus either on trapezoidal test specimens according to EN 12697-26, annex A, or on cylindrical (Marshall) test specimens according to EN 12697-26, annex C. In the new standard CSN 73 6120 the minimum requirement has been already set depending on the used test method for its determination. For 2PB test using trapezoidal test specimens the minimum required stiffness value stays 9000 MPa, for IT-CY test method (repeated indirect tensile stress on cylindrical specimens) the minimum requirement has been increased to 9500 MPa. The reason for such differentiation is based on experience gained during the last 20 years. It has been repeatedly identified that if the identical HMAC mixture is tested using trapezoidal test specimens and in parallel cylindrical test specimens, in most case the results form 2PB test are lower. The common practice was then, that many asphalt mix producers to fulfil the criterion of stiffness after failing with 2PB test, ordered the IT-CY test to meet the minimum requirement. Such approach in general is technically not correct and therefore for both test methods different minimum required value has been proposed. The difference of 500 MPa between both test methods is still rather affable and less conservative. In general, this follows the ongoing issue existing in Europe where EN 12697-26 defines several test methods for stiffness but there isn´t any relevant functionality between the determined values of the particular methods.
The asphalt mixtures presented and compared in this paper were assessed from the viewpoint of their bulk densities, voids contents, stiffness values determined at temperatures of 0, 15, 27 and 40 °C on Marshall test specimens (IT-CY test method according to EN 12697-26, annex C) and the resistance to thermal induced cracking determined by modified test method based on CSN EN 12697-44 (semicircular bending test). The temperatures for stiffness testing are based on the established practice in the Czech Republic which is used for more than 30 years. The selected temperatures represent typical average conditions on a pavement during a year.

3 Results for tested HMAC mixtures

3.1 Voids content

Results shown in this paper were grouped based on larger number of various commercial construction projects (sites). Not for each of the 47 available variants all characteristics were tested or determined.
The bulk density of test specimens has been determined for all available HMAC variants, however, the maximum density used for calculation of voids content was tested only for approx. 70 % of all mixtures. From the voids contents which were determined result that roughly in half of the cases does not fulfil the limits set for mix design (type testing). If more benevolent limit for control testing is used, that still about 20 % of tested variants shows voids content beyond this limit.
The problem with voids content has been detected mainly in the set of HMAC mixtures with polymer modified binders. This finding is crucial with respect to the workability of the asphalt mixtures, but might have influence on other properties as well. Voids content and in case of paved asphalt layer its compaction rate does significantly influence behavior and

performance of the asphalt layer as such. It is possible, that higher content of usually harder bituminous binder type and increased content of fines in the mixture can lead to partially worsened workability. On the other hand, voids content is the fundamental characteristic which can be influenced during the mix design. If an asphalt mix with inconvenient voids content is identified, it is necessary either modify the grading of the mixture or increase content of the used bituminous binder. In the case of utilizing hard bituminous binders it is necessary to mix and compact the mixture at sufficiently high temperatures. The specifications TP 151 define working (processing) temperatures in the interval between 170 °C and 195 °C depending on the type of used binder. Newly drafted national standard ČSN 73 6120 adjusts this interval for a range between 160 °C to 190 °C for paving grades and hard paving grades and between 155 °C to 180 °C for polymer modified binders. Reduction of the processing temperature is without any doubt beneficial with regard to environmental protection or cost efficiency of asphalt mix production. All the more it is important to care about an accurate asphalt mix design including requirements for voids content and further corresponding properties of HMAC. Last but not least the workability can be improved by using the warm mix asphalt concept as well.

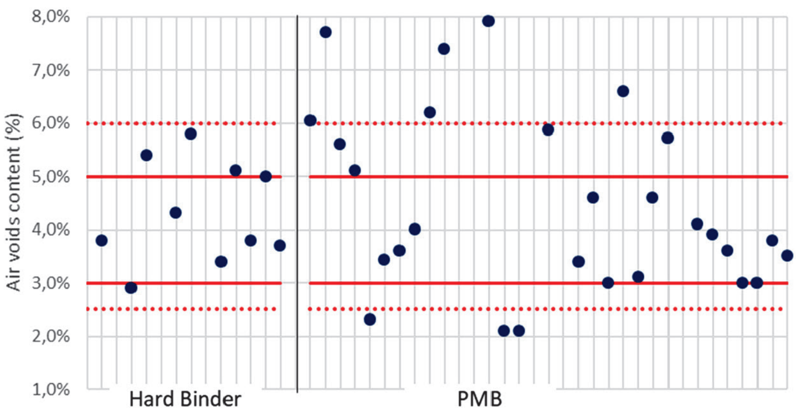

Figure 2 Voids content for assessed HMAC mixtures

Stiffness was determined by IT-CY test method at 4 temperatures: 0 °C, 15 °C, 27 °C and 40 °C. As has been mentioned earlier, the decisive temperature is 15 °C, for which the minimum required value of 9000 MPa is set (according to TP 151) and will be in the future 9500 MPa (according to the draft CSN 73 6120). The minimum value was in case on non-modified mixtures not fulfilled by one mixture containing 30/45 paving grade bitumen. For the set of modified asphalt mixtures the overall results are worse. From 32 tested variants 14 mixtures did not comply with was the existing minimum value, which is nearly half of all assessed variants. If the stricter limit would be considered, additional 2 variants would not fulfill the requirement since they showed a stiffness between 9000 MPa and 9500 MPa. This finding means that from all received and commercially used or designed HMAC mixtures the half in fact are not high modulus asphalt concretes but regular asphalt concretes for base or binder course containing just elevated content of bitumen.

Figure 3 is split in two parts. First part shows all stiffness results for non-modified HMAC variants whereas the second part contains only modified variants. The asphalt mixtures are in each group ordered according to the reached stiffness S_{15} and this order is kept for all presented graphs. First five "PMB variants contain harder PMB 10/45-65 binder. All remaining modified variants are just ranked according to S_{15} values without any further division according to the used PMB. In the case of HMAC mixtures with paving grades or hard paving grade binders the correlation for 15 °C and for other temperatures works quite well (R^2 = 0,82 to 0,94). For these mixtures it is therefore with some accordant caution be stated and forecast what will be the stiffness for other temperatures as well. Such statement is nevertheless not valid unconditionally and it is necessary to accentuate that for the evaluation only 14 variants have been included. This is rather a smaller number of determinations and the correlation results need to be considered with providence.

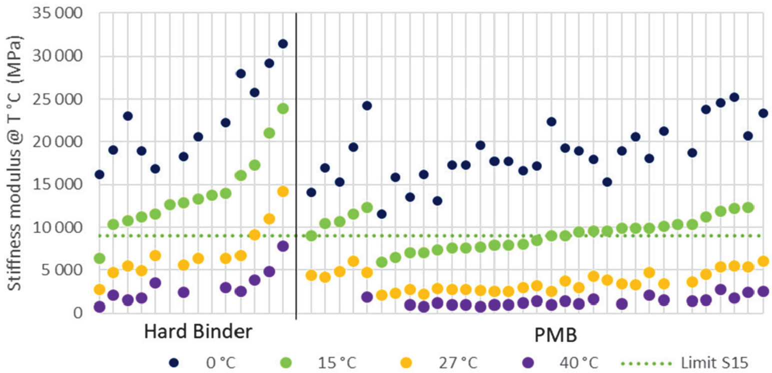

Figure 3 Stiffness of assessed HMAC mixtures

For the HMAC mix variants with polymer modified binders the variance of analyzed characteristics is higher. At elevated test temperatures there is obvious similar trend like in the case of paving grades and hard binders – the tilt of the tangent for the regression curve is very similar, but the coefficient of determination is lower (R^2 0,79, resp. 0,66).

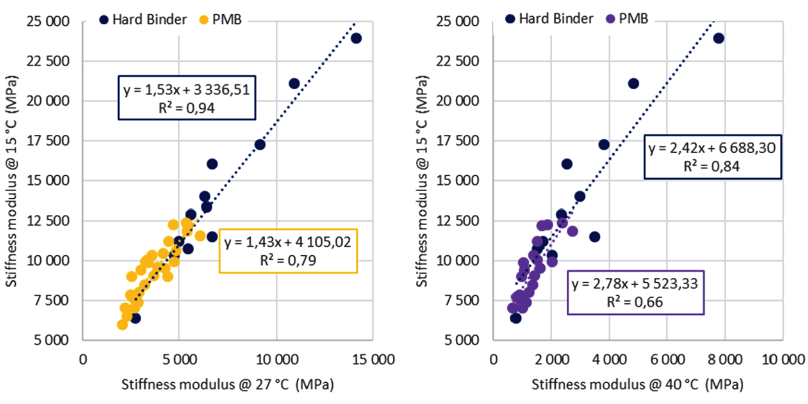

Figure 4 Comparison of stiffness S_{15} and S_{27}, as well as S15 and S_{40} for assessed HMAC mixtures

At the test temperature of 0 °C there is fully apparent a different impact of particular modifications. The coefficient of determination in case of the PMB mixture group reaches only a value of 0,54, which indicates some dependence between the parameter, but it is only medium strong. The tilt of the regression curve tangent is completely different from the tilt for non-modified mixtures showing a gentler progress. This means that there is a slower accrual of stiffness with decreasing test temperature. If the set of HMAC mixtures containing PMBs is further divided in sub-groups following the particular binder types (PMB 10/40-65 and PMB 25/55-60 or -65 including Polybitume EP) a higher variability for “softer” PMBs can be induced from the results. This can be entrained by the fact that binders commercially offered by different producers have the same PMB category, but the source including production processing, original bitumen master-batch and used type of modifier is different which results in dissimilar properties even if fulfilling the standard requirements for the bitumen as prescribed by EN 14023 and national requirements. That might be also one of many explanations why it is not as simple to interchange same type of a PMB coming from different producers. This works quite well for a paving grade but shall be followed with caution in case of modified bituminous binders.

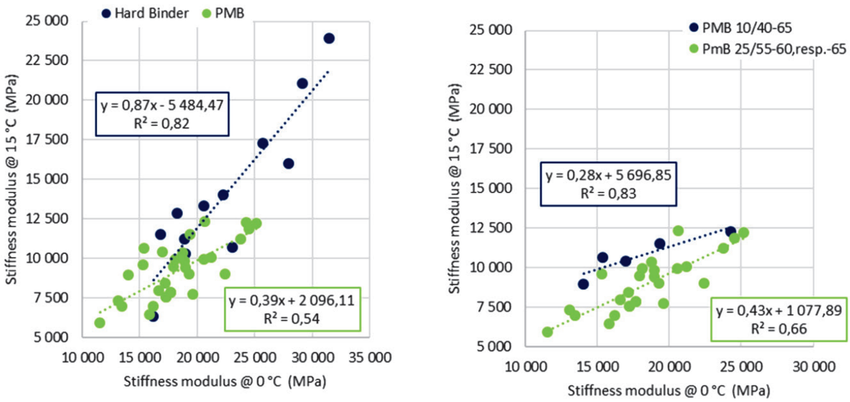

Figure 5 Comparison of stiffness modules S_{15} and S_0 of HMAC mixtures

Variability of the results for HMAC set of mixtures containing PMB is apparent also for the comparison of stiffness S15 and bulk density. In this respect we are aware of the fact that the comparison to bulk density and not voids content which was not determined for all mix variants presented by this study might be partially misleading and not fully predicative.

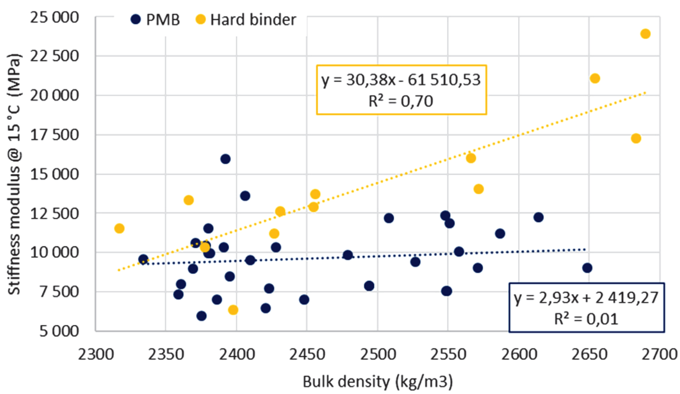

Figure 6 Comparison of stiffness S_{15} and bulky density of HMAC mixtures

Table 1 Statistical quantities for stiffness modules of assessed HMAC mixtures

Statistical quantity	0 °C			15 °C			27 °C			40 °C	
	HB	PMB 10	PMB 25	HB	PMB 10	PMB 25	HB	PMB 10	PMB 25	HB	PMB 25
Mean	22445	17994	18607	13932	10770	9410	6992	4841	3456	3076	1377
Stand. error	1465	1798	655	1203	557	420	888	332	215	584	117
St. deviation	5074	4020	3403	4502	1245	2259	3077	743	1119	1938	562
Minimum	16213	14036	11533	6345	8976	5951	2739	4165	2030	778	693
Maximum	31426	24254	25164	23930	12271	15932	14159	6085	5981	7790	2732
Range	15213	10218	13630	17585	3296	9981	11420	1920	3952	7012	2039
Count	12	5	27	14	5	29	12	5	27	11	23

HB = Hard bituminous binders; PMB 10 = PMB 10/40-65; PMB 25=PMB 25/55-60 or PMB 25/55-65 or Polybitume EP

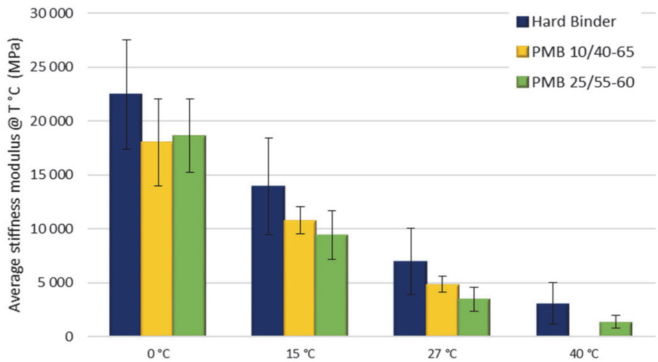

Figure 7 Mean value of stiffness modulus of HMAC mixtures

The highest mean stiffness moduli were determined for asphalt mixtures with hard binders. This is expected phenomena due to lowered penetration and increased stiffness of the binder. For modified mixtures, the stiffness modulus determined at temperate of 15 °C and 27 °C is higher for mix variants with PMB 10/40-65, which again confirms the influence of penetration of binder to mixture‘s stiffness. At the temperature of 0 °C the asphalt mixtures with PMB 25/55-60, resp. 65 + Polybitume EP reached higher stiffness.

Behaviour in the range of low temperature is crucial for HMAC mixture. The mixtures are very stiff and usually more susceptible to low temperature cracking. Technical conditions of Czech ministry of transportation TP 151 defines the minimum flexural strength determined by three-point bending test 6 MPa. This requirement was left out from the new standard CSN 73 6120 which is actually in final approval process. For this research study the SCB test according to modified method was used, instead of three-point bending test. The modified method is based on standard EN 12697-44. The modified method is elaborately described e.g. in [7]. The important modifications in the methodology are e.g. smaller diameter of test specimens (ø100 mm), different compaction of test specimens (according to EN 12697-30), lower loading rate (2.5 mm/min), new test parameters (e.g. fracture energy) etc.

The SCB test performed at temperature of 0 °C, 15 °C and 25 °C. The higher test temperatures relate to ‘fatigue’ cracking.

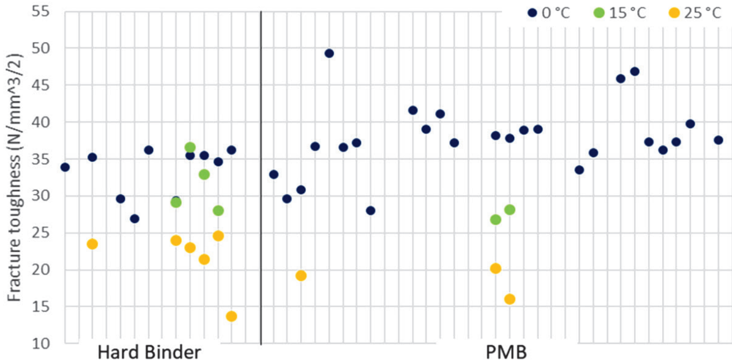

Figure 8 Fracture toughness of HMAC mixtures

In figure 8, there are results for both groups of HMAC mixtures. The individual variants are still in the same sequence according to the stiffness modulus determined at 15 °C. From the results, it might be deducable, that there is a certain trend between stiffness modulus at 15 °C and fracture toughness, but it is actually very low. From the coeffients of determination (Figure 9) it can be seen, that these two parameters do not relate to each other. For fracture parameters the opposite trend is apparent in comparison to stiffness modulus – with higher penetration and modification of binder, the fracture parameters increase, Table 2.

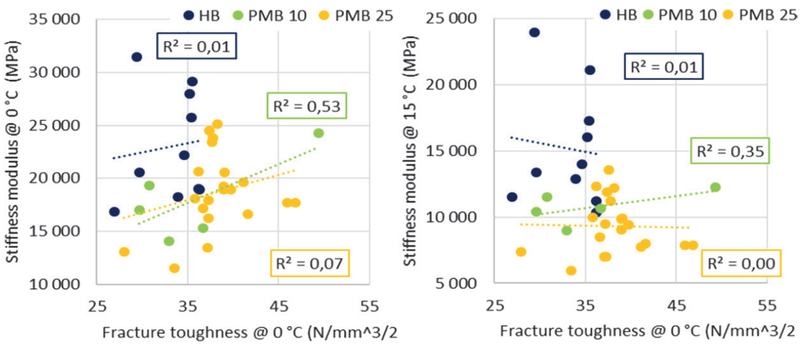

Figure 9 Comparison of fracture toughness determined at 0 °C and stiffness modulus determined at 0 °C a 15 °C

Table 2 Statistical quantities for SCB test parameters of assessed HMAC mixtures determined at 0 °C

Statistical quantity	Fracture toughness (N/mm$^{3/2}$)			Fracture energy till Fmax (J/m²)			Total fracture energy (J/m²)		
	HB	PMB 10	PMB 25	HB	PMB 10	PMB 25	HB	PMB 10	PMB 25
Mean	33	36	38	835	1052	1111	1193	1295	1416
Stand. error	1	4	1	87	176	72	148	209	82
St. deviation	3	8	4	276	392	313	467	467	358
Minimum	27	30	28	492	704	733	583	1004	998
Maximum	36	49	47	1257	1668	2169	2171	2114	2389
Range	9	20	19	765	964	1436	1588	1110	1392
Count	10	5	20	10	5	19	10	5	19

HB = Hard bituminous binders; PMB 10 = PMB 10/40-65; PMB 25=PMB 25/55-60 or PMB 25/55-65 or Polybitume EP

4 Conclusions

The presented study offered a comprehensive preview of the commonly gainable characteristics of HMAC mixtures as used in the Czech Republic. It was possible to collect more than 40 variants representing different types of aggregates and different binders as they are regularly used for pavement structures. It provided also a better understanding about the stiffness values ant potential weaknesses. It is true – and was supported by the results – that harder binder, especially if applied as paving grades provide usually high values of stiffness. This must necessarily not correspond with appropriate resistance to cracking and fracture behavior, which is critical especially in the case that HMAC is used in a binder course.

It has been shown that usually PMBs do result in slightly lower stiffness and in general there are more variants which do not meet the minimum required stiffness, mainly if PMB 25/55-60 or -65 is used. It might be well explainable by a higher elasticity of such bitumen. On the other hand it was demonstrated that HMAC mixtures with modified binders result in better fracture characteristics and higher resistance to cracking. If such finding would be compared with the fact that binders do continuously age, then the option with slightly softer PMB might result in an overall better long-term performance.

It has been also analyzed if there is some stronger relation between stiffness and either bulk density or the characteristics used for assessment of behavior in low-temperature range and resistance to cracking. In case of bulk density there was a moderate dependency between this characteristic and stiffness for hard paving grades. For fracture characteristics or flexural strength there is more or less no clear relation, even if the characteristics have been tested at same test temperature.

Remark

This paper was funded by the research project TE01020168, within the program Competence centres of Czech Technological Agency.

References

[1] Espersson, M.: Effect in the high modulus asphalt concrete with the temperature, Construction and Building Materials, 71 (2014), pp. 638-643

[2] Miró, R., Valdés, G., Martinez A., Segura P., Rodriguez, C.: Evaluation of high modulus mixture behaviour with high reclaimed asphalt pavement (RAP) percentages for sustainable road construction, Construction and Building Materials, 25 (2011) 10, pp. 3854-3862, doi: 10.1016/j.conbuildmat.2011.04.006

[3] Rys, D., Judycki, J., Pszcola, M., Jaczewski, M., Mejlun, L.: Comparison of low-temperature cracks intensity on pavements with high modulus asphalt concrete and conventional asphalt concrete bases, Construction and Building Materials, 147 (2017), pp. 478-487

[4] Corté, J.-F.: Development and uses of hard-grade asphalt and of high-modulus asphalt mixes in France, Perpetual Bituminous Pavements, Transportation Research Circular, 2001, pp. 12-31

[5] Newcomb, D.: Perpetual Pavements - A Synthesis. Asphalt Pavement Alliance, 2002.

[6] Geng, H., Clopotel, C.S., Bahia, H.U.: Effects of high modulus asphalt binders on performance of typical asphalt pavement structures, Construction and Building Materials 44 (2013), pp. 207-213

[7] Vacková, P., Valentin, J.: What information can be provided by the asphalt crack propagation test done on semicylindric specimens, World Multidisciplinary Civil Engineering - Architecture - Urban Planning Symposium 2020.