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High modulus asphalt concrete with dolomite aggregates

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Abstract

Dolomite is one of the most widely available sedimentary rocks in the territory of Latvia. Dolomite quarries contain about 1,000 million tons of this material. However, according to Latvian Road Specifications, this dolomite cannot be used for average and high intensity roads because of its low quality, mainly, its LA index (The Los Angeles abrasion test). Therefore, mostly the imported magmatic rocks (granite, diabase, gabbro, basalt) or imported dolomite are used, which makes asphalt expensive. However, practical experience shows that even with these high quality materials roads exhibit rutting, fatigue, and thermal cracks. The aim of the research is to develop a high performance asphalt concrete for base and binder courses using only locally available aggregates. In order to achieve resistance against deformations at a high ambient temperature, a hard grade binder was used. Workability, fatigue and thermal cracking resistance, as well as sufficient water resistance is achieved by low porosity (3-5%) and higher binder content compared to traditional asphalt mixtures. The design of the asphalt includes a combination of empirical and performance based tests, which in laboratory circumstances allow simulating traffic and environmental loads. High performance AC 16 base asphalt concrete was created using local dolomite aggregate with polymer modified (PMB 10/40-65) and hard grade (B20/30) bitumen. The mixtures were specified based on fundamental properties in accordance with EN 13108-1 standard.

Keywords: Dolomite aggregate; High Modulus Asphalt Concrete; performance evaluation

1. Introduction

If the local material does not fulfil the requirements, then one should seek the way for the improvement of its properties. If this is not possible, then one should seek the technological solution which will allow application of the weaker material (Sybilski et al., 2010). One of the proper solutions might be the use of dolomite as a component of High Modulus Asphalt Concrete (HMAC). Knowing that the binder courses situated between 5 and 12 cm below the road surface (Figure 1) are subject to the highest stresses, high stiffness is probably the most important requirement

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for HMAC (Backer C et al., 2008.). HMAC is a mixture of asphalt concrete designed for use in the base and binder courses of asphalt pavement. It has a closed structure with comparatively large content of bitumen. Hard road bitumen grades are applied, mainly 10/20, 15/25, 20/30 and polymer modified bitumen. Hard bitumen content ensures the mixture's resistance to rutting. Apart from workability, large content of bitumen assures fatigue durability and water resistance (Sybilski et al., 2008). This type of an asphalt mixture is designed not only considering empirical properties but also performance based properties (rutting test, stiffness modulus and fatigue tests) (SPEN-Sustainable Pavements for EU New Member States) (Bańkowski et al., 2013).

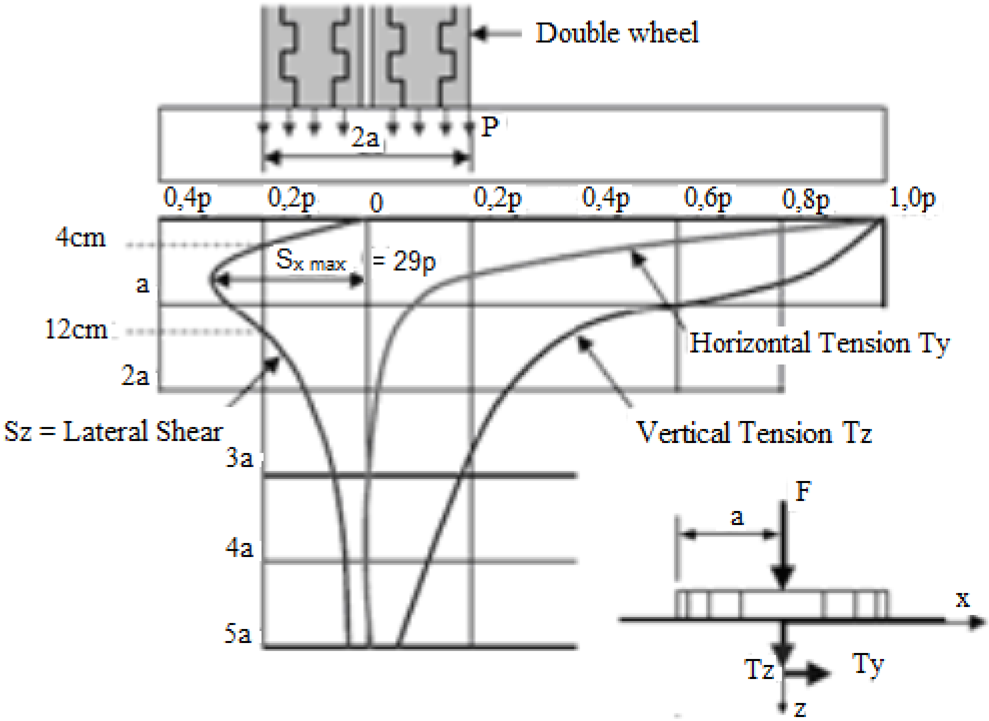

Fig. 1. Lateral force diagram of heavy vehicle tire (Sivapatham P. et al., 2010).

France was also one of the first countries in which mechanistic asphalt pavement design was introduced into the general practice (AFNOR – Organization of the French standardization system). In France, it is known under the acronym EME. In Poland, the acronym is AC WMS. Possible application of weaker mineral aggregate is one of the advantages of EME. Application of High Modulus Asphalt Concrete allowed for saving on asphalt pavement thickness thanks to higher stiffness modulus, which reduces tension strains in asphalt base layer. The aim of the paper is to develop high performance asphalt concrete for base and binder courses using only locally available aggregates – crushed dolomite. In order to achieve resistance to deformations at high ambient temperature hard grade binder was used.

2. Materials

The basic materials used in this study are fractionated crushed dolomite aggregate, unmodified hard grade bitumen B20/30 and SBS modified bitumen PMB 10/40-65 (B70/100 for reference mixture). Crushed dolomite aggregate were obtained from Pļaviņu DM ltd. (Latvia), and hard grade bitumen B20/30 from Grupa LOTOS S.A. (Poland).

2.1. Bitumen characteristics

The binder properties have been tested by means of conventional binder tests: needle penetration, softening point, aging and Fraass breaking point. The test results are listed in Table 1.

Table 1. Typical characteristics of the bitumens.

	Bitumen			
Parameter	B 20/30	PMB 10/40-65	B70/100	Standard
Penetration at 25 °C, dmm	25.3	35.0	80.0	LVS EN 1426
Softening point, °C	62.6	64.2	46.0	LVS EN 1427
Fraass temperature, °C	- 13.0	- 17.0	- 21.0	LVS EN 12593
Kinematic viscosity, mm2/s	1460	-	346	LVS EN 12595
Dynamic viscosity, Pa·s	3277	-	160	LVS EN 12596
Elastic recovery, %	-	85.0	-	LVS EN 13398
Ageing characteristics of bitumen under the influence of heat and air (RTFOT method)				
Loss in mass, %	-0.02	0.01	0.05	LVS EN 12607-1
Retained penetration, %	75.9	69.7	76.0	LVS EN 1426
Increase of a softening point, °C	6.9	5.5	5.4	LVS EN 1427
Fraass breaking point after aging, °C	-11.0	- 16.0	- 17.0	LVS EN 12593
Retained elastic recovery,%	-	> 50	-	LVS EN 13398

2.2. Properties of dolomite aggregate

The test results of dolomite main properties show very low flakiness index – 5, high frost resistance with average MS (Magnesium sulphate test) value of 7 and low fines content – 0.6%. However, LA value is only 33. These aggregates are suitable for use as a component of High Modulus Asphalt Concrete, where LA value up to 40 (SPEN) is permitted. HMAC granulometric composition designed based on dense grades asphalt concrete (AC 16) requirements in accordance with Road Specifications 2015 [Ceļu specifikācijas 2015]. HMAC gradations curve satisfy maximal and minimal target values. The properties of dolomite aggregate are shown in Table 2.

Table 2. Physical and mechanical characteristics of the dolomite aggregate.

Physical and mechanical properties	Results	Requirement for HMAC-16	Requirement for reference mixture ACb-16	Standard
Los Angeles coefficient (LA), %	33	≤35	≤25	LVS EN 1097-2
Resistance to wear. Nordic test (AN), %	21	-	-	LVS EN 1097-9
Flakiness Index (FI), %	5	≤35	≤25	LVS EN 933-3
Water absorption, %	2	≤1	≤1	LVS EN 1097-6
Grain density, Mg/m^3	2.80	-	-	LVS EN 1097-6
Fines content, %	1.0	-	-	LVS EN 933-1
Freeze/thawing (MS), %	7	≤25	≤25	LVS EN 1367-2

3. Asphalt mix design

HMAC-16 asphalt concrete mixtures have been designed by using unconventional raw materials (bitumen - B20/30, PMB 10/40-65 and dolomite aggregate LA > 30) (Figure 2). The basic idea of HMAC is to design a mix with hard grade bitumen at high binder content (Rohde et al., 2008). The Marshall mix design procedure was used for the determination of the optimal bitumen content for the reference mixture, considering the mixture test results for Marshall stability and flow, as well as the volumetric values: air voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB).

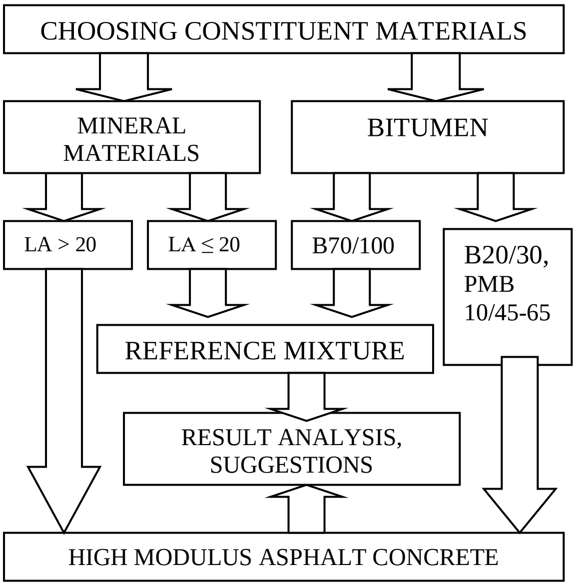

Fig. 2. Experimental plan.

Table 3 shows all the designed and laboratory produced asphalt mixtures with different bitumens and dolomite aggregates.

Table 3. Types and components of HMAC mixes.

Bitumen	Mixture
PMB 10/45-65	HMAC-1/1
	HMAC-1/2
B 20/30	HMAC-2/1
	HMAC-2/2
	HMAC-2/3
B 70/100	Reference

Test specimens for Marshall Test were prepared in the laboratory by impact compactor according to LVS EN 12697-30 with 2×50 blows of hammer 140 °C temperature (for mixes with conventional bitumen B70/100) and 150 °C (for mixes with hard grade bitumen B20/30 and PMB 10/40-65). Mixing temperature for HMAC-16 asphalt concrete with conventional bitumen was 160 °C and 170 °C for HMAC-16 asphalt concrete with hard grade bitumen B20/30.

The following physical and mechanical characteristics of HMAC were determined:
1) Stiffness modulus, 10 °C according to EN 12697-26 (4PB);
2) Rutting resistance, 60 °C and 10000 cycles, according to EN 12697-22;
3) Fatigue resistance 4PB-PR, 10 °C and 10 Hz, according to12697-24;
4) Asphalt concrete mixture density, according to EN 12697-5;
5) Asphalt concrete mixture bulk density, according to EN 12697-6;
6) Air voids content, according to EN 12697-8;
7) Stability and flow, 60 °C, according to EN 12697-34 (samples were prepared by 2×50 blows).

4. Results

4.1. Volumetric properties

Analysis of volumetric parameters of the different asphalt mixtures at different binder contents was performed. The results are presented in Table 4. The binder content was optimized according to HMAC requirements developed in the SPENS programme (Sustainable Pavement for European New Member States).

Table 4. Volumetric properties of HMAC mixtures.

	PMB 10/45 -65		B20/30			B70/100
Parameter	HMAC-1/1	HMAC-1/2	HMAC-2/1	HMAC-2/2	HMAC-2/3	Reference
Bulk density, kg/m^3	2455	2457	2430	2455	2457	2550
Maximum density, kg/m^3	2555	2551	2586	2555	2551	2680
Voids content, %	3.9	3.7	6.0	3.9	3.7	4.85
VMA	17.8	18	18.3	17.8	18	17.6
VFB	78.2	79.6	67.2	78.2	79.6	72.4
Bitumen content, %	5.67	5.83	5.06	5.67	5.83	5.0

4.2. Marshall test

Table 5 contains Marshall test results at different binder contents for the mixtures that passed the requirement of having less than 5% air voids. The results show that HMAC mixtures have higher Marshall Stability compared to the reference mixture.

Table 5. Marshall test results.

	Mixtures					
	PMB 10/45 -65		B20/30			B70/100
Parameter	HMAC-1/1	HMAC-1/2	HMAC-2/1	HMAC-2/2	HMAC-2/3	Reference
Bitumen content, %	5.67	5.83	5.06	5.67	5.83	5.0
Specimen height, mm	64.2	64.0		63.6	62.9	63.3
Stability at 60 °C (kN)	16.5	15.8	Not tested voids content > 5%	16.6	15.4	12.0
Flow at 60 °C (mm)	2.8	3.4		3.8	5.9	4.2

4.3. Wheel Tracking test

A wheel tracking apparatus was used to simulate the effect of traffic and to measure the plastic deformations of the asphalt concrete samples. Tests were performed according to standard EN 12697-22 method B (wheel tracking test with small size device in air). This test method is designed to repeat the stress conditions observed in the field and therefore can be categorized as simulative. The resistance of asphalt mixture to permanent deformation is assessed by measuring the rutting depth and its increments caused by repetitive cycles (26.5 cycles per minute) under constant temperature at 60 °C. The rut depths are monitored by means of two linear variable displacement transducers (LVDTs), which measure the vertical displacements of each of the two wheel axles independently as rutting progresses. The obtained results after 20,000 wheel passes demonstrate the highest rutting resistance depth of 5.7mm for the HMAC 2/3 mixture with 5.83% bitumen content. However, the results show that HMAC 2/2 with a little lower bitumen content (5.67%) have higher rutting resistance than HMAC 2/3. This can be explained by increasing of mixture stiffness due to decrease of bitumen content (see Table 7). The reference mixture demonstrates similar result having 5.3mm rutting depth. HMAC 1/1 and HMAC 1/2 mixture having 5.67% polimermodified bitumen PMB 10/45-65 content shows the highest rutting resistance with 3.8mm. This can be explained by high modified bitumen PMB 10/45-65 elastic properties when there is no difference between bitumen content 5.7% and 5.8%. Figure 3 and Table 6 summarize the wheel tracking test results. HMAC 2/1 is not for performance characters due too very high voids content. Voids value for HMAC 2/1 exceed requirements based on SPENS specifications. Table 7 shows results compliance with SPENS requirements.

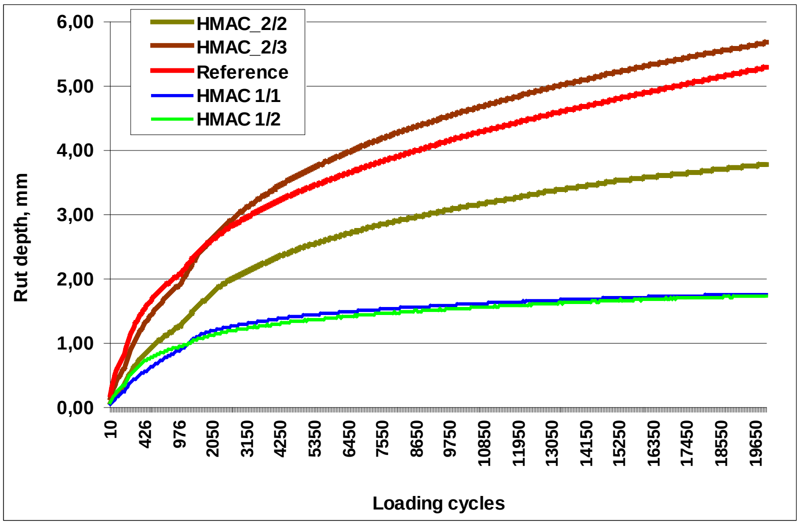

Fig. 3. Wheel tracking test results.

Table 6. Numerical values of Wheel Tracking Test of HMAC mixtures with dolomite aggregate.

Parameter	Unit	Standard	Mixture				
			HMAC 1/1	HMAC 1/2	HMAC 2/1	HMAC 2/3	Ref
Bitumen content	%	EN 12697-1	5.7	5.8	5.7	5.8	5.0
Wheel tracking slope (WTS_{air})	mm/10^3 cycles	EN 12697-22 B method	0.04	0.04	0.14	0.22	0.20
Rutting depth (RDair)	mm		1.8	1.8	3.8	5.7	5.3
Proport. rutting depth (PRDair)	%		3.6	3.6	7.6	11.4	10.6

4.4. Fatigue

To determine the fatigue life of the prepared asphalt concrete mixes, a four point bending beam fatigue test was conducted. The test was run at 10 °C, using 10Hz frequency at 130 µm/m strain level. The beams were compacted in the laboratory using roller compactor. They were saw cut to the required dimensions of 50mm width, 50mm height and 400mm length. The failure criterion used in the study is the traditional 50% reduction from initial stiffness. The obtained results indicate that HMAC mixtures have high resistance to fatigue, compared to the results of reference mixture made with conventional bitumen. HMAC mixes fatigue resistance corresponds to standard category ε6-130. HMAC mixes compliance with the SPENS requirements are given in Table 5.

4.5. Water sensitivity

Water sensitivity test value ITSR give information about asphalt concrete durability with a respect ti ingress of water. The water sensitivity test were performed according to EN 12697-12 standard method A on the base of indirect tensile strength of dry and wet Marshall specimens. All results are in accordance with the requirements of SPENS, but mixtures with used PMB show higher results. HMAC mixes compliance with the SPENS requirements are given in Table 5.

Table 7. Compliance with SPENS requirements.

	Mixtures				
	PMB 10/45 -65		B20/30		
Parameter	HMAC-1/1	HMAC-1/2	HMAC-2/2	HMAC-2/3	Requirement
Voids content, %	3.9	3.7	3.9	3.7	3.0 – 5.0
Rutting resistance, mm/1000cycles	0.04	0.04	0.14	0.22	0.03 – 0.25
Stiffness (10 °C, 10Hz), MPa	16700	16100	17900	17100	S_{min} 14000
Fatigue (10 °C, 10Hz, 130µmm/mm)	ε_6-130	ε_6-130	ε_6-130	ε_6-130	ε_6-130 (≤ 50%)
Water sensitivity, ITSR, %	100	100	98	94	ITSR 80

5. Conclusions

Use of relatively weak dolomite aggregate in High Modulus Asphalt Concrete was evaluated. This mixture was designed to have less than 5% air voids using Marshall compactor, and had high hard (B20/30) and polymer modified (PMB 10/45-65) bitumen content. Testing was performed to compare this mix with reference mixture that was produced using conventional bitumen B70/100 and granite aggregate. Test results demonstrated that with optimum mix design HMAC mixture can provide high rutting und fatigue resistance. However, mixtures with hard grade bitumen B20/30 showed a little lower resistance to rutting. The reference mixture while having high rutting resistance, proved that lower binder content results in shorter fatigue life. Rutting resistance and stiffness of the reference mixtures do not meet SPENS project recommendations.

These results provide confidence that the weak Latvian dolomite may be applied in High Modulus Asphalt Concrete for base and binder courses. HMAC mixtures fulfil the HMAC asphalt concrete requirements in accordance with SPENS project recommendations (SPENS).

Acknowledgements

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