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.

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 [6]. 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 for HMAC [2]. 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 [7]. This type of an asphalt mixture is designed not only considering empirical properties but also performance based properties (rut test, stiffness modulus and fatigue tests) (SPENS-Sustainable Pavements for EU New Member States).

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 EM. In Poland, the acronym is AC WMS. Possible application of weaker mineral aggregate is one of the advantages of EM. 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 was 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 Fraas breaking point. The test results are listed in table 2.

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 (SPENS) is permitted. The properties of dolomite aggregate are shown in table 1.

| 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/m3              | 2.80    | -                       | -                                       | LVS EN 1097-6 |
| Fines content, %                  | 1.0     | -                       | -                                       | LVS EN 933-1 |
| Freeze/thawing (MS), %            | 7       | ≤25                     | ≤25                                     | LVS EN 1367-2 |

Table 2. 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 |
|         | Fraas 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) | -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 |
|         | Fraas breaking point after aging, °C | -11.0 | -16.0 | -17.0 | LVS EN 12593 |
|         | Retained elastic recovery, % | - | > 50 | - | LVS EN 13398 |
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 [3]. 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).

![Experimental plan](image)

**Figure 2.** Experimental plan.

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

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

**Table 3.** Types and components of HMAC mixes.
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 at 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) Resistance to rutting, 60°C and 10000 cycles, according to EN 12697-22;
3) Fatigue resistance 4PB-PR, 10°C and 10 Hz, according to EN 12697-24;
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

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).

| Parameter                        | PMB 10/45 -65 | B20/30 | B70/100 | Reference |
|----------------------------------|----------------|--------|---------|-----------|
| Bulk density, kg/m³              | 2455           | 2457   | 2430    | 2457      | 2457      | 2550      |
| Maximum density, kg/m³           | 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       |
Table 5. Marshall test results.

| Mixtures          | PMB 10/45 -65 | B20/30 | HMAC-2/2 | HMAC-2/3 | Reference |
|-------------------|---------------|--------|----------|----------|-----------|
| 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   | Not tested | 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       |

4.2. 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.

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 rut 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 rut 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 (5.70%) have higher rut 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 rut 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. Table 7 shows results compliance with SPENS requirements.
Figure 3. Wheel tracking test results.

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

| Parameter                      | Unit         | Standard          | 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 (WTSₐir) | mm/10³ cycles | EN 12697-22       | 0.04     | 0.04     | 0.14     | 0.22     | 0.20 |
| Rut depth (RDₐir)             | mm           |                   | 1.8      | 1.8      | 3.8      | 5.7      | 5.3  |
| Proport. rut depth (PRDₐir)   | %            | B method          | 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 to 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. HMAC mixes compliance with the SPENS requirements are given in table 5.

Table 7. Compliance with SPENS requirements.

| Parameter                        | PMB 10/45 -65 | B20/30 |
|----------------------------------|---------------|--------|
| Voids content, %                 | 3.9           | 3.7    |
| Rut resistance, mm/1000cycles   | 0.04          | 0.04   |
| Stiffness (10°C, 10Hz), MPa      | 16700         | 16100  |
| Fatigue (10°C, 10Hz, 130μmm/mm)  | ε6-130        | ε6-130 |
| Water sensitivity, ITSR, %       | 100           | 98     |

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 AC16bin 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 rut und fatigue resistance. However, mixtures with hard grade bitumen B20/30 showed a little lower resistance to rutting. The reference mixture while having high rut resistance, proved that lower binder content results in shorter fatigue life. Rut resistance and stiffness of the reference mixtures do not meet SPEN 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).

6. References

[1] AFNOR – Association Française de Normalisation 1999 Enrobês Hydrocarbonês: Couches d’assises: enrobês a module élevé (EME): NF P 98-140 Paris
[2] Backer C, Visscher J, Glorie L, Vanelstraete A, Vansteenkiste S and Heleven L 2008 A comparative high – modulus experiment in Belgium Proc. of Transport Research Arena Europe 2008 (TRA 2008) Int. Conf. (Slovenia, Ljubljana, 21–24 April 2008)
[3] Rohde L, Ceratti J A P, Núñez P V and Vitorello T 2008 Using APT and Laboratory testing to evaluate the performance of high modulus asphalt concrete for base courses in Brazil. Proc. of the Third Int. Conf. on Accelerated Pavement Testing (APT ’08) (Spain, Madrid, 1–3 October 2008)
[4] Sivapatham P, Beckedahl H J and Jannsen S 2010 High stable asphalt for heavy loaded bus test lane sections Proc. of the 11th Int. Conf. on Asphalt Pavements ISAP 2010 (Japan, Nagoya, Aichi, 1–6 August 2010)

[5] Sustainable Pavements for European New Member States (SPENS) Document No. D8 [Available]: http://www.spens.fehrl.org

[6] Sybilski D, Bankowski W and Krajewski M 2010 High modulus asphalt concrete with limestone aggregate Int. J. of Pavement Research and Technology 3 (2) 96–101

[7] Sybilski D, Maliszewska D, Maliszewski M and Mularzuk R 2008 Experience with high modulus asphalt concrete in Warsaw street overlays Proc. of Transport Research Arena Europe 2008 (TRA 2008) Internationa Conf. (Slovenia, Ljubljana, 21 – 24 April 2008)

[8] Ėygas D, Laurinavičius A, Vaitkus A, Perveneckas Z, Motiejūnas A 2008 Research of asphalt pavement structures on Lithuanian roads (I) The Baltic J. of Road and Bridge Engineering 3 (2) 77–83

[9] Elliott R 2009 Implementing high modulus asphalt technology in The United Kingdom The Internation Seminar Maintenance Techniques to Improve Pavement Performance p 10

[10] Maupin G W and Diefenderfer B K 2006 Design of High-Binder- High-Modulus Asphalt Mixture Final Report VTRL 07- R15, Virginia Transportation Research Council p 28

[11] Vaitkus A, Laurinavičius A, Oginskas R, Motiejūnas A, Paliukaitė M, Barvidienė O 2012 The road of experimental pavement structures: experience of five years operation The Baltic J. of Road and Bridge Engineering 7 (3) 220–227

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