Performance evaluation of high modulus asphalt concrete mixes

V Haritonovs, J Tihonovs, M Zaumanis

Riga Technical University, Faculty of Building and Civil Engineering, The Institute of Transportation, Department of Roads and Bridges, Riga, Latvia Russia

E-mail: viktors.haritonovs@rtu.lv

Abstract. Dolomite is one of the most available sedimentary rocks in the territory of Latvia. Dolomite quarries contain about 1000 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, LA index). Therefore, mostly 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 to EN 13108-1 standard.

1. Introduction

If the local material does not fulfill 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 [1-2]. One of a proper solution 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, are subject to the highest stresses, high stiffness is probably the most important requirements for HMAC [3-4]. HMAC is a mixture of asphalt concrete designed for use in base and binder course of asphalt pavement. It has 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 assures the mixtures resistance to rutting. However large content of bitumen assure workability, fatigue durability and water resistance [5-6]. This type of an asphalt mixture is designed not only by empirical properties but also by performance based properties (rut test, stiffness modulus and fatigue tests) [7-8].

France was also one of the first countries in which mechanistic asphalt pavement design was introduced into the general practice [9]. 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 (in English HMAC). Application of High Modulus Asphalt Concrete allowed for saving on asphalt pavement’s 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 with 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 Fraas breaking point. The test results are listed in Table 1.

| 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) |
| 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       |
| Fraas 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 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 permitted LA value up to 40 (SPENS). 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 | Standard          |
|-----------------------------------------|---------|-------------------|
| Los Angeles coefficient (LA), %         | 33      | LVS EN 1097-2     |
| Resistance to wear. Nordic test (AN), % | 21      | LVS EN 1097-9     |
| Flakiness Index (FI), %                 | 5       | LVS EN 933-3      |
| Water absorption, %                     | 2       | LVS EN 1097-6     |
| Grain density, Mg/m³                    | 2.80    | LVS EN 1097-6     |
| Fine content, %                         | 1.0     | LVS EN 933-1      |
| Freeze/thawing (MS), %                  | 7       | LVS EN 1367-2     |

3. Max design

The basic materials used in this study are fractionated crushed dolomite aggregate, unmodified hard grade bitumen HMAC-16 asphalt concrete mixtures have been designed by using unconventional (bitumen - B20/30, PMB 10/40-65 and dolomite aggregate LA > 30) raw materials (Fig. 1). The basic idea of HMAC is to design a mix with high grade bitumen at high binder content [10-11]. 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) [12]. 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 150°C temperature.

Figure 1. Experimental plan
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 3. The binder content was optimized according to HMAC requirements developed in the SPENS programme (Sustainable Pavement for European New Member States).

4.2. Marshall test
Table 4 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.

| Parameter                      | Mixtures                        |
|--------------------------------|---------------------------------|
|                                | PMB 10/45 -65                  |
|                                | HMAC-1/1                        |
|                                | HMAC-1/2                        |
|                                | B20/30                          |
|                                | HMAC-2/1                        |
|                                | HMAC-2/2                        |
|                                | HMAC-2/3                        |
|                                | Reference                       |
| Bulk density, kg/m³            | 2455                            |
| Maximum density, kg/m³         | 2555                            |
| Voids content, %               | 3.9                             |
| VMA                            | 17.8                            |
| VFB                            | 78.2                            |
| Bitumen content, %             | 5.67                            |

| Parameter                      | Mixtures                        |
|--------------------------------|---------------------------------|
|                                | PMB 10/45 -65                  |
|                                | HMAC-1/1                        |
|                                | HMAC-1/2                        |
|                                | B20/30                          |
|                                | HMAC-2/1                        |
|                                | HMAC-2/2                        |
|                                | HMAC-2/3                        |
|                                | Reference                       |
| Bitumen content, %             | 5.67                            |

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 that the highest rut depth of 5.7mm for the HMAC mixture with 5.83% bitumen content. The reference mixture demonstrates a similar result having 5.3mm rut depth. HMAC mixture having 5.67% bitumen content shows the highest rutting resistance with 3.8mm. Figure 2 summarizes the wheel tracking test results.

![Figure 2. Wheel tracking test results](image)

### 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 both HMAC mixtures have high resistance to fatigue, compared to the results of reference mixture made with conventional aggregates and bitumen. HMAC mixes fatigue resistance corresponds to standard category ε6-130. However, the reference mixture did not pass the fatigue test. HMAC mixes compliance with the SPENS requirements are given in Table 5.

| Parameter                        | PMB 10/45-65 | B20/30 |
|----------------------------------|--------------|--------|
| Voids content, %                 | 3.9          | 3.7    | 3.9 | 3.7 | 3.0 – 5.0 |
| Rut resistance, mm/1000cycles    | 0.04         | 0.04   | 0.14 | 0.22 | 0.03 – 0.25 |
| Stiffness (10°C, 10Hz), MPa       | 16700        | 16100  | 17100 | 17900 | Smin 14000 |
| Fatigue (10°C, 10Hz, 130μm/mm/mm) | ε6-130       | ε6-130 | ε6-130 | ε6-130 | ε6-130 (≤ 50%) |
| Water sensitivity, ITSR, %       | 100          | 100    | 98   | 94   | ITSR 80    |

Table 5. Compliance with SPENS requirements
5. Conclusion
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 AC16 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.

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

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