The use of high-performance asphalt mixtures in heavy traffic road structures

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Abstract. Asphalt mixtures are being used in road construction more and more, to the deficit of concrete surfaces. Due to the additives as well as the new technologies being used to obtain asphalt mixtures, the results are vastly improved which can lead to a better behavior in day to day situations, even under heavy traffic. This study means to show the way in which changing the binder influences the properties of the mixture. So, the chosen binder course, type BAD 22.4, will use different types of binder (bitumen), more specifically: a 50/70 pen bitumen; a 50/70 pen bitumen modified with flexible semi-rigid polymers and a PmB 45/80-65 bitumen, modified with polymers by crosslinking. The asphalt mixtures will be characterized by their volumetric properties, Marshall Characteristics and their behavior to dynamic tests. The results presented in the form of charts and tables were obtained in the Road Laboratory of the Technical University of Civil Engineering of Bucharest. The conclusion that can be drawn is that depending on the type of binder used, the results obtained differ with a noted improvement of the resistance to permanent deformation and creep, in the mix which uses the binder modified with polymers by crosslinking technology.

1. Introduction

Due to the rapidly growing pace of the industry lately, traffic development can be observed, as it regards intensity and load. This also determines an increase in the pollution of the environment (meaning, more damaging conditions for people, as well as road life expectancy). Thus, the manufacturing of more effective and durable asphalt mixtures becomes a necessity.

The most common road pavement structures are those that use as components asphalt mixtures (flexible road pavements).

Asphalt mixtures are mainly made of aggregates and binder (bitumen). Additionally, depending on the local materials available, traffic loads, weather conditions, other materials may become necessary (additives).

Taking into account manufacturing process and their behavior when in use, road pavement structures can be classified as following:

- flexible pavements – made of a series of layers that consist of incohesive materials stabilized mechanically or/and with carbohydrate binders, the surface course and the base course consisting of asphalt mixtures (or exceptionally, the base course being a bituminous macadam base or a macadam base);
- rigid pavements – made of a series of layers stabilized (or not) with binders, the surface course here being a concrete slab;
- semi-rigid pavements – made of layers consisting of natural aggregates mechanically stabilized with hydraulic or puzzolanic binders, layers which in time develop cracks due to contraction, while the surface course and maybe the base course are made of asphalt mixtures.

By intervening on the composiing materials, properties of the asphalt mixtures can be improved. In this paper, the study will mainly focus on treating bitumen with different materials and the performance of the asphalt mixtures using the resulting types of bitumen. Bitumen has a diverse range of applications – from roads (streets and highways alike), parking lots and roofing material to insulation material (reservoirs) and airplane runways. [1][2]

The criteria for selecting the type of asphalt mixtures are diverse and of various nature, depending on traffic, available materials and climate. The process of selecting the final mix recipe for asphalt mixtures include tests for determining water sensitivity as well as, more recently, performance tests. [2]

The majority of roads are built using the hot mix asphalt (HMA) technology. This process involves heating the binder (160° - 170°C, 4-6% of asphalt mixture mass) before mixing it with the aggregates (94-96% of asphalt mixture mass). A type of binder for asphalt mixture can be bitumen, being a thermoplastic material and having both viscous and elastic properties. Seeing as environment conditions (higher temperatures make it more malleable and when low temperatures are present, it freezes) have a greater influence on bitumen as opposed to aggregates, using it as a binder can vastly affect asphalt mixture behavior. [3]

Road pavements are influenced by temperature, their performance depending on the climate their exposed to. To reduce the impact of temperature on asphalt mixtures, the concept of modifying bitumen with polymers was entertained and researched [4]. Though these binders allow a stable response from the road pavement, as well as better mechanical performances, the added price for obtaining them can sometimes be a drawback when compared to traditional bitumen [5].

Seeing as rheology involves the study of deformation and flow of materials, the most popular method to characterize a bitumen is by analyzing its rheological behavior. A change in the bitumen’s rheology can be achieved by a change in either/both their chemical composition or/and in the physical structures of the molecules, the two aspects determining the rheological properties of a bitumen at certain temperatures. [5]

Improvement of physical and rheological properties of bitumen can be achieved by using different type of materials (as additives) [4][6][7], such as:
- organic additives (different types of wax: Fischer-Tropsch, Montan, amide waxes, etc.);
- chemical additives;
- adhesive agents;
- rejuvenating agents;
- flux oils.

The polymers used for bitumen modification are plastomers and elastomers.

One of the first types of plastomers used to modify bitumen is polyolefin. Other polyolefin materials used as modifiers for bitumen are: linear low-density polyethylene, low-density and high-density polyethylene. [5]

When it comes to thermoplastic elastomers, styrene-butadiene-styrene (SBS) copolymers and styrene-isoprene-styrene (SIS) copolymers are used the most, the two having similar structures (chemically). The structures of the SBS copolymers are made of SBS triblock chains which have two phases of morphology, more specifically the continuous phase, characterized by a matrix of flexible polybutadiene (PB) in which can be found the rigid domains of polystyrene (PS), representing the dispersed phase. The PB blocks contribute to elasticity, while the PS blocks offer strength, for normal service temperatures for paving bitumen. [5]

2. Materials and mix designs used
The experimental part of this study took place in the Road Laboratory on four different mix designs for the BAD 22.4 type of asphalt mixture (one mix design used a simple bitumen, another used a modified bitumen and two mix designs were for modified asphalt mixtures) to determine the physical
and mechanical characteristics for the binder course according to the national norm AND 605-2016 [8] and the series of norms SR EN 12697 [9-15]

The following types of bitumen were used during the experimental stage:
- 50/70pen bitumen (bitumen “A”) – 4.5% of the asphalt mixture mass;
- PmB 45/80–65 bitumen, obtained by the use of crosslinking technology (bitumen “B”) – 4.5% of the asphalt mixture mass;
- 50/70pen bitumen (bitumen “C”) – 4.6% of the asphalt mixture mass.

The mix designs used were, as follows:
- mix design BAD 22.4 – 1, asphalt mixture BAD 22.4, obtained with bitumen “A”;
- mix design BAD 22.4 m – 2, asphalt mixture BAD 22.4, obtained with bitumen “A”. This asphalt mixture was modified by using a mix of flexible semi-rigid polymers;
- mix design BAD 22.4 – 3, asphalt mixture BAD 22.4, obtained with bitumen “B”;
- mix design BAD 22.4 m – 4, asphalt mixture BAD 22.4, obtained with bitumen “C”. This asphalt mixture was modified by using a mix of flexible semi-rigid polymers.

In the mix designs previously described, aggregates from two quarries were used (one quarry for the mix designs BAD 22.4 – 1, BAD 22.1 m – 2 and BAD 22.4 - 3 with andesite rocks, the other quarry for the mix design BAD 22.4 m – 4 with dacite rocks).

The granulometric curves used for the BAD 22.4 asphalt mixtures are shown below in figure 1.

![Granulometric curves](image.png)

**Figure 1.** Granulometric curves used for the asphalt mixtures studied.

### 3. Tests performed

The following characteristics for the binder course were determined, according to the norms valid, to show the performance of the asphalt mixtures using different types of bitumen:
- stiffness modulus at 20°C – Indirect Tension Test on cylindrical samples – IT-CY, according to norm SR EN 12697-26/2018, annex C [9];
- deformation and rate of deformation at 40°C, 200 kPa and 10000 impulses – Triaxial cyclic compression Test – dynamic creep, according to norm SR EN 12697-25/2016, method B [10];
- air voids content through the use of the gyratory compactor, 120 gyrations, according to norm SR EN 12697-31/2007 [11];
- fatigue resistance, number of cycles until cracking at 15°C – Indirect Tension Test on cylindrical specimen – IT-CY, according to norm SR EN 12697-24/2012, annex E [12];
- bulk specific gravity, according to norm SR EN 12697-6/2012 [13];
- fatigue resistance, four-point bending test, prismatic samples (4 PB-PR), according to norm SR EN 12697-24/2012, annex D [12].
4. Results

Based on the tests performed (described in the previous section), the results obtained are showed in the following figures (figures 2-9). In figure 2, the results for the bulk specific gravity for the studied asphalt mixture can be seen. The greatest value was obtained for the BAD 22.4 – 3 mix design.

Studying figure 3, which shows the values for the stiffness modulus, it can be observed that the highest value is obtained for the BAD 22.4 m – 2 mix design.

The results for deformation at 40°C, 200 kPa and 10000 impulses for the triaxial cyclic compression test are drawn in figure 4. It shows that the maximum value of the deformation can be reached in the asphalt mixture with the BAD 22.4 – 3 mix design.

Figure 5 shows the values obtained for the deformation rate that were achieved during the triaxial cyclic compression test.

During the indirect tension test on cylindrical specimens (IT-CY) certain fatigue resistance values were reached for the asphalt mixture samples tested. There results can be seen in figure 6; the BAD 22.4 – 3 mix design has a better resistance to fatigue (when it comes to a minimum number of cycles), the difference between this mix design and the other three (BAD 22.4 – 1, BAD 22.4 m – 2 and BAD 22.4 m - 4) being a considerable one.

The last test presented in this study is the four-point bending test (4 PB-PR) on prismatic samples. Different levels of amplitude were used for the imposed deformation during the test (150 μdef, 250 μdef, 350 μdef). The fatigue lines that result are shown in figure 7, while the equations for these lines (y = Ax + B type of equation) can be determined by using the parameters shown in table 1.
Figure 6. Fatigue resistance (IT-CY Test).

Figure 7. Fatigue lines – fatigue resistance on prismatic samples (4 PB-PR).

Table 1. Equation parameters for the fatigue lines (4 PB-PR).

| Mix recipe         | Parameters |
|--------------------|------------|
|                    | A          | B          |
| BAD 22.4 - 1       | -5.7445    | 41.9910    |
| BAD 22.4 m - 2     | -4.5926    | 37.0650    |
| BAD 22.4 - 3       | -2.1818    | 25.4950    |
| BAD 22.4 m - 4     | -4.6242    | 37.3930    |

By observing the fatigue lines in figure 7, the mix design with the best behavior to fatigue is the BAD 22.4 – 3 mix design, having not only the highest values for resistance to fatigue, but also the highest number of load cycles until that limit is reached (smaller slope). The values for the specific deformations of the four mix designs can be found in figure 8.

Figure 8. Specific deformation – fatigue resistance on prismatic samples (4 PB-PR).

5. Conclusions

Several conclusions can be drawn from this study. When it comes to using a modified asphalt mixture (BAD 22.4 m – 2), there is an improvement of the stiffness modulus as well as an improvement in behavior when talking about fatigue and dynamic creep. From the results obtained, the addition of flexible semi-rigid polymers to the asphalt mixture (BAD 22.4 m – 2 mix design) leads to the asphalt mixture having admissible values for a binder course, according to national norm AND 605-2016.

By comparing the two asphalt mixtures BAD 22.4 m – 2 and BAD 22.4 – 3, it can be observed, from the results obtained after testing, that using a bitumen modified with polymers is vastly preferable to using a simple bitumen. The one characteristic of the BAD 22.4 – 3 that has a lower
value is the stiffness modulus (5000 MPa), but the advantages of using a modified bitumen can be seen when analyzing the asphalt mixture’s resistance to fatigue.

From the results described previously, the physical and mechanical characteristics vary depending on the type of bitumen used. Overall, better results are seen when using the bitumen modified by crosslinking. Even though, the stiffness modulus for the asphalt mixture modified with a mix of flexible semi-rigid polymers has a greater value than the one obtained when using the bitumen modified by crosslinking, the higher value for the resistance to fatigue and permanent deformation is higher in the BAD 22.4 – 3 mix design, facts which lead to the conclusion that this mix design will have a better performance in real life conditions of climate and traffic.

The choice of technology used to manufacture asphalt mixtures, specifically, the type of bitumen used, clearly depends on the properties and performance that the asphalt mixture has to fulfill in the road pavement structure.

6. References
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