Towards high-performance materials for road construction

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Abstract. Due to constant increase of traffic, modern road construction is in need of high-performance pavement materials. The operational performance of such materials can be characterized by many properties. Nevertheless, the most important ones are resistance to rutting and resistance to dynamical loads. It was proposed earlier to use sulfur extended asphalt concrete in road construction practice. To reduce the emission of sulfur dioxide and hydrogen sulfide during the concrete mix preparation and pavement production stages, it is beneficial to make such a concrete on the base of complex sulfur modifier. In the present work the influence of the complex modifier to mechanical properties of sulfur extended asphalt concrete was examined. It was shown that sulfur extended asphalt concrete is of high mechanical properties. It was also revealed that there as an anomalous negative correlations between strain capacity, fatigue life and fracture toughness.

1. Introduction

Due to the growth of load on automotive roads, modern construction industry needs efficient materials for pavements. Advantages of the concretes that are based on sulfur–extended asphalts (SEA) are the natural effects caused by physicochemical properties, availability and low cost of technical sulfur [1]. Because of numerous alterations in chemical and phase composition of bitumen, and also due to relatively intensive interaction at the phase interface, SEA–based pavements are characterized by improved operational properties. However, widespread use of ordinary SEA is not possible because of environmental impacts. The emission of hydrogen sulfide and sulfur dioxide takes place both during the concrete mix preparation and pavement production stages. The complex modifier that is based on sulfur and contains special mineral phases was earlier proposed to mitigate such emission [1-5]. The objective of the present work is to examine influence of such complex modifier to the mechanical properties of sulfur extended asphalt concrete.

2. Materials and methods

The specimens of SEA concrete were prepared from gabbro–diabase chipping of fraction 5–20 mm (77% by mass in mineral part), granite screenings of fraction 0.315–5 mm (11% by mass in mineral part), diatomite powder of average particle size 7 μm (12% by mass in mineral part), bitumen and sulfur modifier in form of pellets (figure 1). The amount of sulfur in complex binder ranges from 0 to 40% by mass (table 1).

Cylindrical specimens of diameter 150 mm and height 75 mm (for AASHTO TP 63 test) and 65 mm (for AASHTO T 324 test) were compacted. Six specimens of each composition of asphalt concrete were tested. The value of rut depth for each composition is calculated as an average for six specimens.
Table 1. Mixtures of complex binder

| Component                  | Mix #1 | Mix #2 | Mix #3 | Mix #4 |
|----------------------------|--------|--------|--------|--------|
| Bitumen, % above mineral part | 5.50   | 4.87   | 4.49   | 4.05   |
| Sulfur modifier, % above mineral part | 0      | 1.37   | 2.21   | 3.18   |
| Amount of sulfur in binder, % | 0      | 20     | 30     | 40     |

Figure 1. Pellets of the modifier

We have performed two tests according to AASHTO TP 63 “Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer” and AASHTO T 324 “Hamburg Testing”. Modified APA asphalt pavement analyzer (Pavement Technology Inc, Covington, GA, USA) that allows to carry out both tests is used. The APA is a thermostatically controlled device designed to determine the properties of hot mix asphalt by applying repetitive linear loads to compacted test specimens through a loaded wheel.

The measurements of fatigue life parameters were performed according to the EN 12697–24 “Bituminous mixtures. Test methods for hot mix asphalt. Resistance to fatigue,” and “Pavement Technology” (hereafter PT) methods. Both these methods are adequately representing loads of the real traffic flow. In addition, fracture toughness (splitting tensile strength) was determined in accordance with RU GOST 12801–98.

The EN 12697–24 indirect tensile tests were carried out with Dynapave 78-B7130 servo-hydraulic dynamic testing system (Controls Group, Milan, Italy). Cylindrical SEA concrete samples with diameter of 150 mm and height of 70 mm were tested at 20 °C. The samples were exposed to repetitive sinusoidal load; such load is causing tensile stress in the direction that is perpendicular to the load axis. The test completes at the moment of vertical crack growth. The fatigue limit is determined as the total number of load cycles that precede the destruction of the sample. Total horizontal deformation is also registered during the test.

The PT fatigue test method was designed by Pavement Technology, Inc to be performed also by asphalt pavement analyzer. The samples for the test are beams of 75 mm by 125 mm by 300 mm in size (during the test, three beams are simultaneously examined). After compaction, test specimens were aged for 120 hours at a temperature of 85 °C. The test itself consists of repetitive wheel tracking. The wheel load was 1113 N, test temperature was 20 °C. The test completes if at least one of the following conditions is met: some predefined number of cycles is reached; the beam breaks; beam deflection rate of change in vertical direction is above 1.0 mm after 10 cycles.

3. Results
Six specimens for each composition of asphalt concrete were tested. The value of rut depth for each composition is calculated as an average for the six specimens. The experimental dependencies are presented on figures 2 and 3.
As it can be seen from figures 2 and 3, resistance to rutting of the SEA concrete is significantly higher than for ordinary asphalt concrete (control sample, binder #1). For the AASHTO TP 63 test method, rutting resistance is 1.7, 2.4 and 3.7 times higher for the binders from #2 to #4, respectively.

According to AASHTO TP 63, the allowable rut depth should be no more than 12 mm after 8000 wheel cycles. For the control specimen such rut depth has reached after the 7800 wheel cycles. For the SEA concrete such rut depth does not reached even after the 10000 wheel cycles. Maximum depths are 7.38, 5.58 and 3.64 mm for the binders from #2 to #4, respectively.

For the AASHTO T 324 test, rutting resistance of the SEA concrete is 1.3, 1.7 and 3.0 times higher if compared with the value for control samples. AASHTO T 324 states that rut depth should be no more than 12 mm after 12000 wheel cycles. For the control specimen of asphalt concrete such rut depth has reached after the 14000 wheel cycles. For the SEA concrete such rut depth does not reached even after 20000 wheel cycles: the maximum depths are 10.8, 8.1 and 4.5 mm, for the binders from #2 to #4, respectively.

During operation of asphalt pavements the gradual decline of their strength and other physical and mechanical properties takes place. Such decline is because of the irreversible destruction process of the material structure. The destruction of asphalt concrete under repeated cyclic loading is caused by the fatigue processes, i.e. formation and accumulation of micro-scale defects and the subsequent

![Figure 2. AASHTO TP 63 results: rut depth for binders from #1 to #4.](image)

![Figure 3. AASHTO T 324 results: rut depth for binders from #1 to #4.](image)
The formation of macroscopic defects [6-10]. Experimental results related to fatigue life parameters are summarized in table 2.

**Table 2. Fatigue life parameters of SEA concretes**

| Property                           | Mix #1 | Mix #2 | Mix #3 | Mix #4 |
|------------------------------------|--------|--------|--------|--------|
| EN 12697–24 cycles                 | 1066   | 1280   | 4123   | 6315   |
| EN 12697–24 deformation, mm        | 1.96   | 0.63   | 0.60   | 0.54   |
| PT cycles                          | 933    | 814    | 2807   | 4620   |
| PT beam deflection, mm             | 7.6    | 2.98   | 2.45   | 1.395  |
| Splitting tensile strength, MPa    | 3.21   | 3.89   | 3.82   | 3.71   |

The formation of spatial cross-linked network may take place when the amount of sulfur in complex binder is in range from 20% to 40%. Such a network contributes the increase of almost all operational properties, including fatigue strength.

As it can be seen from table 2, fatigue life parameters increase together with the amount of sulfur in SEA concrete. Starting from binder #2, for both test methods there are linear dependencies between amount of sulfur and number of load cycles before failure. The corresponding regression models are:

\[
N_1(c) = -3646 + 252c, \\
N_2(c) = -2962 + 190c,
\]

where \(N_1\) and \(N_2\) are numbers of load cycles before failure for EN 12697–24 and PT methods, respectively; \(c\) is the amount of sulfur in complex binder, %.

These models can only be used for \(c \in [20; 40]\). The corresponding parameters of both models are near to each other; this reflects the fact that both methods give consistent results. For series #4, the number of cycles preceding the start of irreversible deformation and main crack growth, if compared with values for reference sample #1, is about 5 and 6 times higher, depending on the test method. Both methods are also indicating that increase of the content of sulfur leads to decrease of deformability. Deformations at the failure point are lowered in 3.3 and 3.6 times (EN 12697-24) and in 3.1 and 5.4 times (PT method), for binder #3 and #4, respectively.

However, as it follows from the last row of table 2, the excess of sulfur may also lead to negative effects. In particular, the values of low-temperature properties (e.g., tensile strength at 0 °C) of SEA concretes slightly decline. Yet, this decline is relatively small (about 5% for series #2 and #4) and even for binder #4 the absolute value of tensile strength is still higher than for control sample. Thus, whilst most materials demonstrate positive correlation between strain capacity and fracture toughness, SEA concrete demonstrate negative one. The correlation between fatigue life and strain capacity is also negative.

**4. Conclusions**

Prolonging the service life of the roads reduces the consumption of natural resources. Both advantages and drawbacks of SEA concretes are currently well known; from the ecological point of view, the primary drawback is the emission of toxic gases during production and placement. Such emission can be almost eliminated if complex sulfur binder with suppressors of toxic gases is used for production of SEA concrete.

In the present work we have examined mechanical properties SEA concrete that is based on complex modifier. It was shown that admixture of this modifier contributes the increase of almost all operational properties, including resistance to rutting and fatigue limit. Resistance to rutting can be increased in 1.3...3.7 times. The anomalous (negative) correlations between strain capacity, fatigue life and fracture toughness are also revealed; such correlations are quite beneficial for building material.

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