Applying of energy-efficient asphalt concrete for road pavements

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Abstract. The piper observes experience of warm-mixture asphalt application. Ability of temperature decreasing realizes using chemical additive DAD-TA. Influence of the DAT-TA additive on organic binder properties is provided. Experimental results shows high mechanical characteristics and durability of the asphalt concrete preparing and compacting at low temperature comparing traditional hot asphalt mixtures. Information of warm asphalt mixture industrial application is provided, including work performance at low temperature. Economical and environmental effects of DAD-TA application are estimated.

1. Introduction
Recent years, large volume of the road construction alows significant amount of high quality construction materials. In spite of high-performance equipment utilization, building companies need to extend construction season. Also range of asphalt mixture delivery is restricted by cooling down. In this case application of traditional hot asphalt concrete mixtures creates limitations due to special aspects of this material. Disturbance of operating regime leads to insufficient density of the asphalt concrete during asphalt laying and compaction. As a result, key characteristics of the pavement (water resistance, mechanical strength, durability) are reduced and not meet requirement of national standards and technical specifications. Solution of the problem, described below, creates possibility for working range enlargement of asphalt concrete plants, allows to extend construction season and has a positive influence for economical development of road building companies[1].

From other point of view, application of temperature-reducing technology has positive influence on environment. At the asphalt concrete plants, liquid (diesel fuel, fuel oil) or gaseous (natural gas) fuel is used for mineral materials and bitumen heating. As usual, temperature of stone materials reaches temperature more than 180°C. Bitumen heats up to temperature 160°C. Decreasing of asphalt production temperature by 15-20°C is a positive factor for reducing of the environmental impact. Firstly, it is possibly to decrease fuel consumption. Secondly, low production temperature leads to reducing of carbon dioxide and others combustion gases emissions. Also, it is necessary to note direct economic profit, caused by the reduction of fuel consumption [2].

The last advantage of low-temperature asphalt production is positive influence on the asphalt pavement durability. Decreasing temperature of the asphalt mixture requires less intensity heating of the mineral materials. As a result, crushed stone is affected by high temperature impact in a less degree. Also, lower temperature of mixture creates good conditions for organic binder. Processes of bitumen aging accrue less intensive during asphalt mixture preparation and transportation. As a result
asphalt concrete pavements, produced of warm asphalt concrete mix, will have more resistance to aging under the influence of ultra-violet and infrared radiation, temperature and oxygen influence.

There are some technique, allowed to decrease temperature during production, asphalt laying and compaction. Water steam injection creates foamed bitumen which allow to reduce production temperature of asphalt concrete mixture. But, in this case, additional equipment for asphalt concrete plant modification is needed[3].

Another method is application of water-contained mineral filler. High porosity mineral filler adds to the hot bitumen, due to high temperature of bitumen water is released from pore spaces and creates foaming effect.

The most common technology of warm asphalt mixture production is temperature-reducing additives application. Special chemical compounds changes bitumen viscosity at high technological temperature range (from 90°C to 160°C) without any negative impact on mechanical properties of asphalt concrete][4,5].

Current research deals with DAD-TA warm-reducing additive for asphalt concrete produced by Russian company Selena.

2. Methods and materials
The study of the influence of temperature-reducing additives was divided into several stages. Physical and mechanical properties of bitumen after the introduction of additives were defined at the first stage. Stability of organic binding agent parameters after their modification is a key factor ensuring high physical and mechanical properties of composites made on the basis of such binding agents. The following indicators were chosen as control parameters:

- depth of needle penetration into bitumen at 25°C within 5 seconds and at 0°C within 60 seconds under 100 and 200 g load respectively, characterizing its viscosity ratio; measurements are made according to national standard GOST 33136-2014;
- melting point characterizing a temperature point of bitumen transition from elastoplastic to plastic state, defined at 5°C/min in a water bath of bitumen samples in rings loaded by standard balls; measurements are made according to national standard GOST 32054-2013;
- ductility at 25°C and 0°C characterizing elastic properties of bitumen, defined via bitumen ductility test at 5 cm/min in the ductility testing machine; tests are performed according to national standard GOST 33138-2014;
- Fraas brittle point characterizing transition of bitumen from a visco-elastic to brittle state, defined by cooling a thin layer of bitumen on a copper plate at 1°C /min until cracks in bituminous film appear when bending a plate; tests are performed according to national standard GOST 11507-78.

Bitumen marked as BND 60/90 produced at Moscow Oil Refinery was used as a organic binder. The DAD-TA temperature-reducing additive represents viscous dark liquid. According to fire danger and severity of exposure to humans, the additive belongs to low-hazardous substances. The optimal concentration established in earlier studies [6] made 0.4% of the bitumen mass. The additive was introduced into bitumen preliminary heated up to 140°C with forced mixing by a paddle mixer within 10 min.

The composition of the dense fine-grained asphalt concrete mix (B type) was chosen for the study. B-type of asphalt mixture was applied as more easy for compaction compare with other types of the asphalt concretes. Upon selection, the amount of bitumen in the mix was accepted as 5.5% relative mineral material weight. Maximum specific density is 2,380 g/cm³, residual porosity is 2.5%. The particle size distribution of the mix was selected to ensure that the grain-size distribution curve passes in the middle of a range stipulated in the requirements of the Technical Specifications for Asphalt Concrete - GOST 9128-2013. This allowed receiving a relatively dense-graded mix with an optimal structure, but without an excessive amount of crushed stone, which could hamper the estimation of influence of bitumen characteristics on compaction. Table 1 shows particle size distribution of the mix.
Asphalt concrete samples are tested according to the testing methods at national standard GOST 12801. Test samples are applied force by axial loading configuration with rate of strain equal 5 mm/min.

**Table 1.** Distribution of particle size of dense fine-grained asphalt concrete mix (B type).

| Cell diameter, mm | 40  | 20  | 15  | 10  | 5   | 2.5 | 1.25 | 0.63 | 0.315 | 0.14  | 0.071 |
|------------------|-----|-----|-----|-----|-----|-----|------|------|------|------|-------|
| Actual composition | 96.0| 81.0| 75.6| 65.7| 54.6| 40.1| 33.2 | 25.4 | 19.2 | 13.3  | 6.2   |
| Technical specification requirements | 90  | 76  | 68  | 60  | 50  | 38  | 28   | 20   | 14   | 10   | 6     |
| max              | 100 | 100 | 80  | 72  | 60  | 48  | 37   | 28   | 22   | 16   | 12    |

For the wheel tracking test stone mastic asphalt was used, as most common type of the surface. Granulometric size composition of the stone mastic asphalt SMA-15 is listed in the table 2. Except mineral materials and organic binder, stone mastic asphalt SMA-15 includes stabilizing additive Nanobit. The amount of bitumen in the mix was accepted as 6.5% relative mineral material weight. Maximum specific density is 2,360 g/cm³, residual porosity is 2.0%.

**Table 2.** Distribution of particle size of stone mastic asphalt mix SMA-15.

| Cell diameter, mm | 15  | 10  | 5   | 2.5 | 1.25 | 0.63 | 0.315 | 0.14  | 0.071 |
|------------------|-----|-----|-----|-----|------|------|------|------|-------|
| Actual composition | 98.8| 52.0| 31.1| 26.4| 21.5 | 18.4 | 15.1 | 12.3  | 10.1  |
| Technical specification requirements | 90  | 40  | 25  | 18  | 15   | 12   | 10   | 9     | 9     |
| max              | 100 | 60  | 35  | 28  | 25   | 22   | 20   | 16    | 14    |

The asphalt concrete mix was prepared at 135°C (140°C for SMA-15) with bitumen modified by DAD-TA and at 150°C (165°C for SMA-15) with a bitumen test sample and was then exposed to temperature control in a drying cabinet without convection until it reached the required compaction temperature.

Compaction was studied via Cooper CRT-GYR gyratory compactor. A small gyrator form with a diameter of 100 mm was used to check the compaction. Based on the full density of asphalt concrete for the selected mix, the mass of one sample made 1,870 grams. The pressure of sample formation made 0.6 MPa; rotation speed of the gyrator form was 30 rpm; the inner inclination angle of the gyrator form reached 0.81 degrees.

Wheel tracing test is provided via using Infratest "Hambur wheel" system. Following conditions are chosen: rubber wheels, 20000 crossing, air test environment, temperature of test 60°C. All parameters confirm EN 12697-22.

3. **Results and discussion**

The first part of research includes bitumen characteristics measurements. Additive ratio is 0.4% relative mass of bitumen. All parameters are shown at table 3.

Received data show stability of the bitumen properties after modification via DAD-TA additive. Special attention should be given to following parameters: Fraas brittle point, softening point and penetration debit at 0°C. According to the results, needle penetration depth at 0°C does not change after DAD-TA application, as well as ductility at 0°C and softening point. This fact means that temperature interval of bitumen workability does not change after modification. It seems clear that asphalt concrete, based on modified bitumen, will have similar mechanical properties as traditional material including thermal stability and crack resistance.
Table 3. Physical and mechanical properties of bitumen modified by DAD-TA additive compared to test bitumen sample

| Parameter                          | Test sample | Modified sample |
|-----------------------------------|-------------|-----------------|
| Needle penetration depth, 0.1 mm, at 25°C | 70          | 73              |
|                                   | 25          | 25              |
| Ductility, cm, at 25°C             | 90          | 94              |
|                                   | 3.6         | 3.6             |
| Softening point, °C                | 47          | 47              |
| Fraas brittle point, °C            | -19         | -18             |

Following step of work is a asphalt concrete mixture research. It consist of two stages. The first one includes compactability research via Cooper CRT-GYR gyratory compactor. Influence of the asphalt concrete mix temperature on the compaction shows at figure 1.

Figure 1. Compactability of the asphalt concrete mixture based on modified bitumen (dashed line) and non-modified bitumen (solid line) at temperature a - 80°C; b - 110°C; c - 120°C; d - 130°C

According to the received data, asphalt concrete mixture based on initial bitumen at 80°C does not reach maximum density. At the same condition, asphalt concrete mixture based on modified bitumen is consolidated to the maximum density. At the temperatures of 110, 120 and 130°C, the compaction of the mix modified with a binding agent was by 17, 11 and 6%, respectively – more efficient in comparison with the test sample.

Samples of the asphalt concrete, creating at different temperature are tested for mechanical properties determination. Influence of compaction temperature on mechanical properties is sown at table 4.
Table 4. Physical and mechanical properties of asphalt concrete samples preparing and co,acting at different temperatures

| Temperature of asphalt concrete mixture production | Temperature of asphalt concrete mixture compaction | Compressive strength, MPa, measured at various temperatures, °C | Water resistance | Water resistance during longtime water saturation |
|---------------------------------------------------|-------------------------------------------------|---------------------------------------------------------------|-----------------|-----------------------------------------------|
| 150                                               | 150                                             | 4.1 1.2 10.4 0.94                                           | 0.86            |                                               |
| 130                                               | 4.0 1.2 10.5 0.92                                           | 0.83            |                                               |
| 120                                               | 4.0 1.1 11.0 0.89                                           | 0.81            |                                               |
| 110                                               | 3.8 1.2 11.1 0.88                                           | 0.78            |                                               |
| 100                                               | 3.8 1.1 11.4 0.86                                           | 0.76            |                                               |
| 140                                               | 140                                             | 4.0 1.2 10.5 0.94                                           | 0.85            |                                               |
| 130                                               | 4.0 1.1 10.6 0.80                                           | 0.83            |                                               |
| 120                                               | 3.9 1.1 11.1 0.87                                           | 0.80            |                                               |
| 110                                               | 3.8 1.2 11.3 0.87                                           | 0.78            |                                               |
| 100                                               | 3.8 1.1 11.2 0.85                                           | 0.76            |                                               |
| 130                                               | 130                                             | 4.0 1.2 10.8 0.89                                           | 0.80            |                                               |
| 120                                               | 3.9 1.1 11.0 0.88                                           | 0.78            |                                               |
| 110                                               | 3.8 1.1 11.2 0.86                                           | 0.76            |                                               |
| 100                                               | 3.8 1.2 11.4 0.85                                           | 0.75            |                                               |
| requirements of national standard Technical Specifications for Asphalt Concrete - GOST 9128-2013 | no less 2.2  no less 1.0  no more 12.0  no less 0.85  No less 0.75 |                                               |                                               |

From the results of research it can be seen that reducing the preparation temperature for asphalt mixture to 130 °C, and the compaction temperature of the hot mix to 100 °C, by using the additives, the characteristics of warm asphalt concrete meet the requirements of national standard Technical Specifications for Asphalt Concrete - GOST 9128-2013. Moreover, the reduction of strength at 20 and 50 °C and the increase in strength at 0 °C at reducing the production and compaction temperatures is negligible and does not exceed 10%. More significant is the change of water resistance of asphalt concrete samples, at all temperatures of research this index did not fall below 0.85, and at prolonged water saturation below 0.75.

It is known that asphalt concrete mixtures, characterized by easy compaction, subjected to wheel track rutting. In this case, main reason of wheel track appearance is low heat resistance of organic binder. But, as mentioned above, bitumen, after DAD-TA modification, has the same heat resistance as initial bitumen. Consequently, wheel truck resistance should not decrease in comparing with control sample, as confirmed by results, shown at figure 2.

Research results [7] describes positive influence of low-temperature mixture preparation on aging processes in the bitumen and asphalt concrete. According to the investigation, DAD -TA decreases intensity of aging processes by two ways. The first one is the influence of DAD-TA on bitumen as age resistor by virtue of the fact that mechanical properties after high temperature impact become more stable in compare with non-modified bitumen. The second way is low temperature during preparation and transportation of the unconsolidated asphalt concrete mixture, due to this fact thermo-oxidative degradation of thin bitumen films accrues with low intensity. As a result, asphalt pavement has stable properties and long service life under the influence of weathering conditions and transport load.
4. Conclusions

Testing results of bitumen after its modification with DAD-TA additive show that key physical and mechanical properties do not change considerably in comparison with the test binding sample and remain within the standard requirements. The obtained data demonstrate that when the additive is introduced, thermal stability of bitumen does not decrease and the temperature plastic range remains unchanged.

The efficiency of DAD-TA additive application is illustrated by the increase in asphalt concrete mix mobility in a wide range of temperatures. The mix compaction improved considerably at reduced temperature (80°C - 90°C), while in cased with the mix containing the test binding agent it failed to reach the specified density. Besides, there is a positive impact of the additive under normal compaction temperature (120°C -130°C).

Thus, the efficiency of DAD-TA temperature-reducing additive may be described with the following conclusions:

- possibility of producing hot-mixed asphalt at reduced temperature without deteriorating the material, which leads to a cost decrease and a reduction of carbon dioxide emissions and emissions of other fuel combustion products;
- possibility of compacting hot-mixed asphalt up to required density at reduced temperature without deteriorating its physical and mechanical properties [3], which fosters the increase in duration of a construction season of asphalt concrete construction in early spring and late fall and the increase in the shipment length of asphalt concrete mix;
- improvement of compaction of asphalt concrete mix at standard paving temperatures (120°C -130°C), which that leads to the reduction of roller passes until achieving the specified density, to the increase in compaction uniformity and the decrease in construction cost.

Finally, it should be noted that DAD-TA additive serves as an attribute of resource-saving technology thus providing for the reduction of material and technical costs and an environmental impact during the preparation of hot-mixed asphalt and construction of pavement layers without deteriorating the quality of performed works.

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