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Influence of DAD-TA temperature-reducing additive on physical and mechanical properties of bitumen and compaction of asphalt concrete.

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Abstract. The paper is devoted to the use of DAD-TA temperature-reducing additive for the preparation and pouring of asphalt concrete mixes at reduced temperatures. It also shows positive influence of the modified bitumen on the efficiency of organo-mineral composite compaction at reduced temperatures. Physical and mechanical properties of asphalt concrete with the use of bitumen modified by DAD-TA additive including indicators characterizing road surfacing life are presented. Arguments to use this material from the point of view of its production technology and environmental impact are given.

1. Introduction

At present, the road-building materials industry is experiencing continuous optimization of products, their characteristics and production technology considering the recent global trends [1, 2]. Taking into account all advantages of hot-mixed asphalt constituting the majority of road surfacing, they are still sensitive to temperature conditions at the stage of preparation, laying and compaction. The asphalt concrete layer at insufficient mixing temperature will inevitably decrease in compaction factor, increase in water saturation of materials and lead to fast damage of pavement. Hence, the possibility of applying hot-mixed asphalt in a wider range of temperatures without decreasing their consistency remains a relevant task. Workers, especially those operating in countries and areas with severe climatic conditions, face essential constraints in the construction of asphalt pavements. During construction at reduced temperatures, the asphalt mix is often cooled down to the maximum density of compaction, which leads to the above-mentioned defects. Thus, the issue of paving temperature decrease will not only exclude risks related to time-consuming delivery of mix from a plant to a facility, but will also increase the timescale of asphalt pavement in spring and fall.

Another important problem that all industries are facing is the use of resource-saving technologies and reduction of carbon dioxide emissions into the atmosphere. The heating of supplied materials at bitumen concrete plants is ensured through the combustion of gaseous (natural gas) or liquid (diesel fuel, fuel oil) fuels. The reduction of asphalt production temperature is a critical task, which, if solved, will allow reducing the heating temperature of stone materials by 15-20°C that will lead to a further reduction of fuel consumption and, consequently, to the reduction of carbon dioxide and other combustion products emissions. Besides, it is also necessary to highlight direct economic benefit caused by the reduction of fuel consumption.

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It is noteworthy that the reduction of temperature of asphalt concrete preparation, when possible, will have a positive impact on material durability. First, more gentle heating of stone material will allow reducing the negative effect from thermal shock, which crushed stone is exposed to when placed into a heated dryer drum. Secondly, smaller temperature of a mix contributes to less intensive processes of bitumen aging in the course of preparation and delivery of asphalt concrete, which makes the pavement, built from this mix, more resistant to aging under the influence of UV radiation, temperature and oxygen throughout its long use.

There are several technological solutions to reduce the preparation temperature of organo-mineral composites. Bitumen foaming allows reducing the temperature of mix preparation, however it does not solve the problem of compaction. Besides, the bitumen foaming technology requires corresponding additional equipment to be installed at asphalt concrete plants.

The most widely spread are temperature-reducing additives, which allow reducing viscosity of bitumen in the range of process temperatures (from 90°C to 160°C) without changing its main characteristics at operating temperatures.

This study is devoted to the influence of DAD-TA additive produced by the Russian company Selena on physical and mechanical properties of bitumen, as well as on compaction of asphalt concrete.

2. Objectives and methods

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 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 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 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 GOST 11507-78.

Bitumen marked as BND 60/90 produced at Moscow Oil Refinery was used as a binding agent.

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 [3] 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.

Compaction was studied via Cooper CRT-GYR gyratory compactor. The composition of the dense fine-grained asphalt concrete mix (B type) was chosen for the study. Table 1 shows particle size distribution of the mix. Upon selection, the amount of bitumen in the mix was accepted as 5.5%.

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

		Grains with smaller size (mm), wt. %										
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
GOST requirements	min	90	76	68	60	50	38	28	20	14	10	6
	max	100	100	80	72	60	48	37	28	22	16	12

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.

The asphalt concrete mix was prepared at 135°C with bitumen modified by DAD-TA and at 150°C 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.

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 deviation angle of the gyrator form reached 0.81 degrees.

3. Results and discussion

Table 2 shows measurements of physical and mechanical properties of bitumen modified by the DAD-TA additive and the test bitumen sample without the additive.

Table 2. Physical and mechanical properties of bitumen modified by DAD-TA additive compared to test bitumen sample

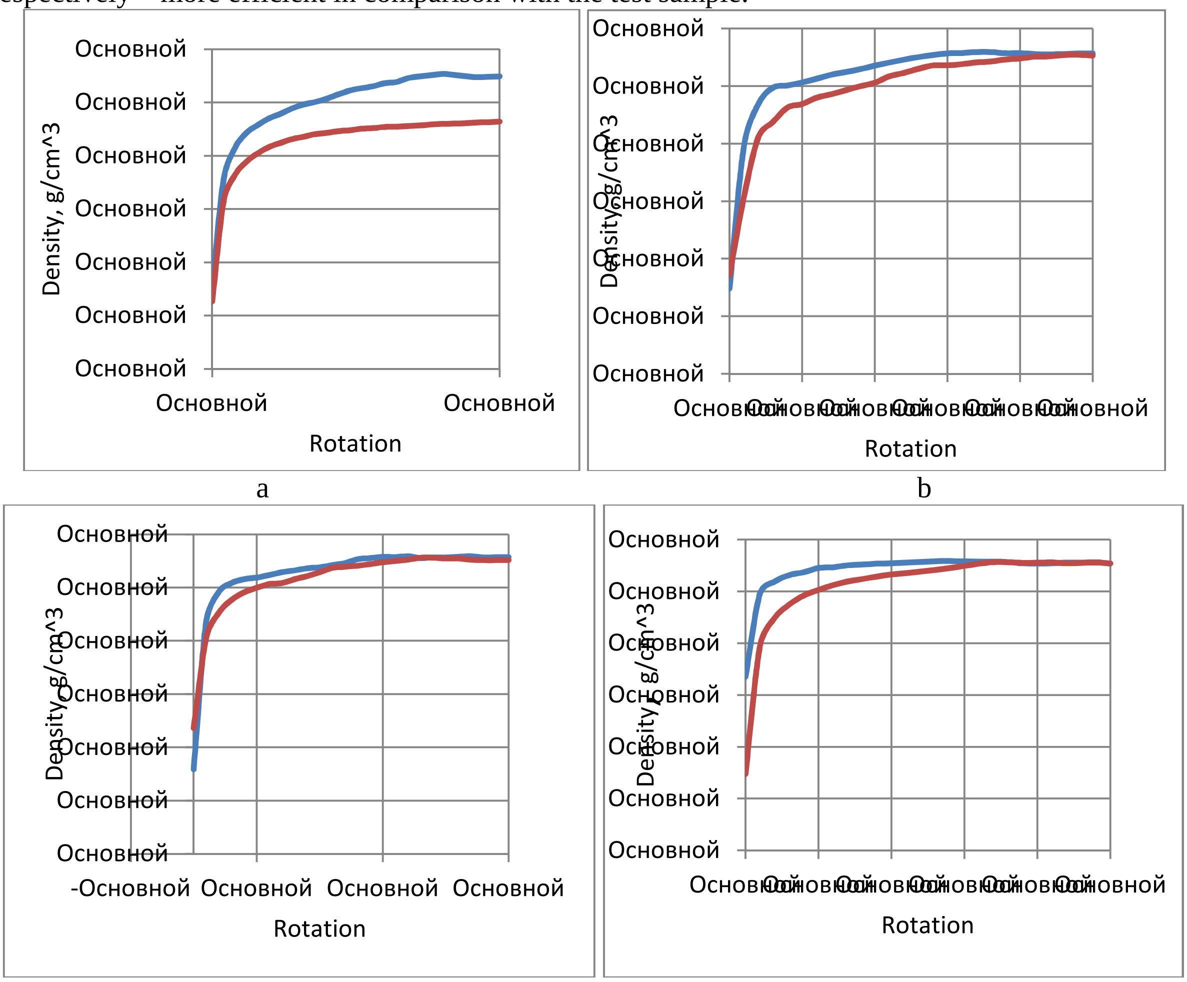
Parameter	Test sample	Bitumen + DAD-TA
Needle penetration depth, 0.1 mm, at 25°C at 0°C	 70 25	 73 25
Ductility, cm, at 25°C at 0°C	90 3.6	94 3.6
Ring-and-ball softening point, °C	47	47
Fraas brittle point, °C	-19	-18
Adhesion to mineral material		

The above-mentioned data demonstrate that after the additive was introduced, the depth of needle penetration into bitumen under loading slightly increased, which indicates minor change of viscosity in the field of low temperatures. The melting point of modified bitumen in comparison with the source sample did not change. The obtained results make it possible to conclude that the applied DAD-TA additive does not deteriorate properties of the modified organic binding agents. The increase in the depth of needle penetration at 25°C made 4%; at the same time the penetration at 0°C did not change. Thus, the ductile temperature range of bitumen modified by this additive is almost identical to the source sample, allows forecasting the production of organo-mineral composites on the basis of such bitumen with thermal and crack resistance similar to asphalt concrete produced following the traditional technology.

Proper mixing and compaction of the asphalt concrete mix at reduced temperature are primarily ensured by the decrease in absolute viscosity. Firstly, this will contribute to good wetting and distribution of bitumen along the surface of stone material, and secondly, it will maintain high workability (mobility) of the mix at reduced temperatures.

The efficiency of DAD-TA additive influence on mobility of the organo-mineral composite was estimated according to the mix compaction, i.e. according to growth intensity of asphalt concrete sample density during compaction. The compaction was defined at the following temperatures: 80, 110, 120 and 130°C. The mix was consolidated until it reached the specified density of 2,380 g/cm^3. The consolidation was measured according to the number of gyrator RMP.

The results are presented in Fig. 1. The data show a substantial mobility increase of the bitumen-based asphalt concrete mix modified with DAD-TA additive in the temperature range of 80-120°C. The analysis of obtained data shows that at 80°C, the specified density of asphalt concrete was not reached when bitumen was used without the additive, though the bitumen-based asphalt concrete mix with additive at the same temperature was consolidated to the specified value. 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.



c d

Figure 1. Dynamics of density of asphalt concrete mix with modified bitumen (blue line) in comparison with test sample (red line) during gyrator testing at: a - 80°C; b - 110°C; c - 120°C; d - 130°C

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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