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Effect of Modifying Polymer Additives on Bitumen Properties

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Abstract: The article examines road-grade viscous bitumen intended for road construction and the existing problems in its production, methods for improving bitumen quality, as well as the effect of modifying polymer additives on the main physical and mechanical properties of bitumen. The studies were carried out on the basis of BND 60/90 grade bitumen produced at the Fergana Oil Refinery, and the effects of polymer additives recommended by various manufacturers on viscosity, ductility, softening point, and brittleness temperature were evaluated. The obtained results showed that polymer additives increase the temperature stability and operational reliability of road bitumen.

Keywords: Road-grade viscous bitumen, polymer and adhesion additives.

INTRODUCTION:

Modern operating conditions of highways impose high requirements on asphalt concrete pavements in terms of durability. Achieving this requires innovative technologies for developing new asphalt concretes with high resistance to shear, aging, cracking, and climatic effects. At the same time, the selection of the most effective asphalt concrete mixtures should be based on changes in physical and mechanical properties, taking into account the specific function of each component and their overall influence on strength characteristics. [1]

In increasing the service life of asphalt concrete pavements, the quality of the materials used—first of all, the quality of the bitumen binder—plays an important role.

The most important properties characterizing bitumen quality are viscosity, plasticity, softening point, and brittleness temperature, as well as the ability of bitumen to adhere well to mineral fillers. [1]

Bitumen quality is directly dependent on air temperature, and during temperature increases or decreases these properties become critically important. For example, in the winter season, a sharp drop in temperature causes bitumen to harden rapidly, increasing its brittleness and leading to crack formation in the pavement. Conversely, during hot summer days, if bitumen with a softening point located at the lower limit of the standard-required values is used, the pavement's resistance to deformation decreases, resulting in defects such as rutting (wheel tracks).

In addition, low adhesion properties of bitumen also constitute a serious problem, since poor bonding between bitumen and mineral fillers leads to stripping of the asphalt concrete pavement surface.

To improve bitumen quality, bitumen-producing enterprises should manufacture bitumen not as a residual product of oil refining, but as a separate, fully fledhed product. For this purpose, it is advisable to use various modifiers, adhesion additives, and complex-acting polymer additives that enhance bitumen properties.

At present, the activities of oil refineries are mainly focused on oil processing with the aim of minimizing production waste, and with such an approach it is only possible to obtain low-quality auxiliary materials. [6]

In many foreign countries, road bitumen is purposefully produced from special raw materials, in particular by using adhesion and polymer additives. This significantly improves the quality indicators of the binder and makes it possible to construct roads designed for long-term service.

In fact, there are many types of modifying additives with different physical structures, chemical compositions, and purposes. However, their application in the production of asphalt concrete mixtures does not always yield positive results in terms of creating a material that fully meets consumer requirements for performance properties. [2]

Problem Statement. Conventional road-grade viscous bitumens used in current road construction practice do not exhibit sufficiently stable performance under conditions of seasonal and abrupt temperature variations. In the winter season, the effect of low temperatures intensifies bitumen brittleness, leading to the formation of cracks and fissures in asphalt concrete pavements. Conversely, at high summer temperatures, pavements produced using bitumens with a low softening point show reduced resistance to deformation, resulting in rutting (wheel tracks), slippage, and plastic deformations. [2]

In addition, in many cases the adhesion properties of bitumen with mineral materials (crushed stone, sand, and mineral filler) are insufficient, which reduces the water resistance of asphalt concrete pavements. This leads, under the influence of moisture, to the deterioration of the bond between the binder and the aggregates, surface damage of the pavement, and a reduction in service life. [6]

Therefore, the comprehensive improvement of the physical-mechanical and operational properties of bitumen, the expansion of its working temperature range, and the enhancement of its stability at both high and low temperatures constitute an urgent scientific and technical problem. In addressing this problem, the use of modifying polymer additives represents one of the most promising approaches, as it allows improvement of bitumen viscosity, elasticity, adhesion properties, and resistance to deformation.

In this study, the main objective was defined as the experimental investigation of the effect of modifying polymer additives proposed by various manufacturers on the properties of road-grade viscous bitumen, the comparison of their effectiveness, and the development of practical recommendations.

Solution Method. One of the effective ways to solve this problem is the use of modifying polymer additives for bitumen. Polymer additives form a two-phase heterogeneous system within the bitumen, improving its elasticity, viscosity, and adhesion properties. As a result, the working temperature range of bitumen is expanded, and the operational stability of asphalt concrete pavements is increased.

METHODS

To study the effect of modifying polymer additives on bitumen properties, road-grade viscous bitumen of grade BND 60/90 produced at the Fergana Oil Refinery was used. The studies employed polymer additives BUTONAL manufactured by the German company “BASF Trading Company,” AZOL 1011 produced by the Russian enterprise “Kotlassky Chemical Plant,” and VISKODOR PV-2 from the company “SELENA.” Polymer additives were introduced into the bitumen at various concentrations, and needle penetration, ductility, softening point determined by the ring-and-ball method, and brittleness temperature determined by the Fraass method were measured.

BUTONAL is a liquid polymer modifier based on styrene–butadiene dispersion used to improve the properties of bitumen, bitumen emulsions, and asphalt concrete. It belongs to the class of SBR-type thermoplastic elastomers, whose content, depending on the polymer type and application method, составляет 63–71% of the total polymer mass. The Butonal polymer can be dosed both into bitumen and directly in the asphalt concrete plant mixer. [10]

Recommended optimal dosage: 2.5–3.5% by weight of bitumen, depending on the climatic conditions of the application region.

AZOL 1011 is a viscous liquid intended for the production of polymer-modified bituminous binders. This additive does not contain mineral oils or paraffin. AZOL 1011 becomes fluid at temperatures of 50–60 °C, which facilitates dosing, handling, and storage when added to bitumen. [11]

Recommended optimal dosage: 2.5–3.5% by weight of bitumen.

VISKODOR PV-2 is a multicomponent additive based on modified synthetic waxes. This additive increases the operating temperature interval of bitumen, significantly raises the softening point of the binder, and increases its viscosity. [9]

Recommended optimal dosage: 1.0–3.0% by weight of bitumen.

Application areas of polymer additives:

- in the production of polymer-modified bituminous binders;

- in all types of hot polymer asphalt concretes;

- in the construction of thin protective wearing courses based on bitumen emulsions (SHPO, SLURRY SEAL, microsurfacing, etc.);

- in the construction of thin hot wearing courses (porous-mastic asphalt concrete, Novachip);

- in the production of hot asphalt concrete mixtures;

- in the production of bitumen emulsions for cold recycling;

- in the production of bitumen emulsions for tack coats.

Main advantages:

- improve the properties of viscous road-grade bitumen;

- increase road resistance to deformation and rutting, as well as the stiffness and water resistance of asphalt concrete;

- ensure prolonged workability during laying (prevent segregation);

- enable direct application at asphalt concrete plants;

- reduce CO2 emissions by saving energy and fuel during mixture production and paving, and extend the road construction season.

Table 1 presents changes in the main physical and mechanical properties of BND 60/90 grade bitumen when BUTONAL, AZOL 1011, and VISKODOR PV-2 modifying polymer additives are applied at various concentrations. The table data indicate that with increasing polymer additive content, needle penetration and ductility decrease, while the resistance of bitumen to deformation at high temperatures increases. At the same time, an increase in the softening point and a decrease in the brittleness temperature confirm an expansion of the working temperature range of bitumen (Table 1)

Table 1 – Effect of modifying polymer additives on bitumen properties

Content in bitumen, %	Penetration depth at 25 °C, 0.1 mm	Ductility at 25 °C, cm	Bitumen softening point determined by the ring-and-ball method, °C	Bitumen brittleness temperature by the Fraass method, °C
Applied bitumen grade BND 60/90				
-	88,2	81,4	47,2	-17
BUTONAL				
2,5	80,5	69,2	48,3	-19
2,7	77,5	66,5	48,6	-19
3,0	72,6	66,5	51,5	-21
3,2	63,3	56,7	53,5	-23
3,5	58,2	42,3	55,8	-24
AZOL 1011				
2,5	79,5	65,5	49,2	-20
2,7	72,8	64,4	49,9	-20
3,0	70,7	61,5	51,9	-21
3,2	61,8	55,5	53,2	-22
3,5	55,6	46,4	54,7	-24
VISKODOR PV-2				
1,0	83,2	76,4	48,9	-19
1,2	82,8	72,2	49,1	-19
1,5	79,5	68,8	51,3	-21
1,7	74,3	65,4	52,0	-22
2,0	66,4	63,4	53,8	-23
2,2	65,2	63,0	54,6	-24
2,5	59,2	54,2	56,4	-24
2,7	55,5	48,2	58,6	-24
3,0	52,1	40,5	60,5	-26

Figure 1 shows a graphical representation of the change in needle penetration depth with an increase in the concentration of modifying polymer additives. It can be seen from the graph that for all types of polymer additives, this indicator consistently decreases as the concentration increases, which indicates an increase in the degree of bitumen hardening and its stability at high temperatures (Figure 1).

Figure 1 – Dependence of needle penetration depth on modifying additives

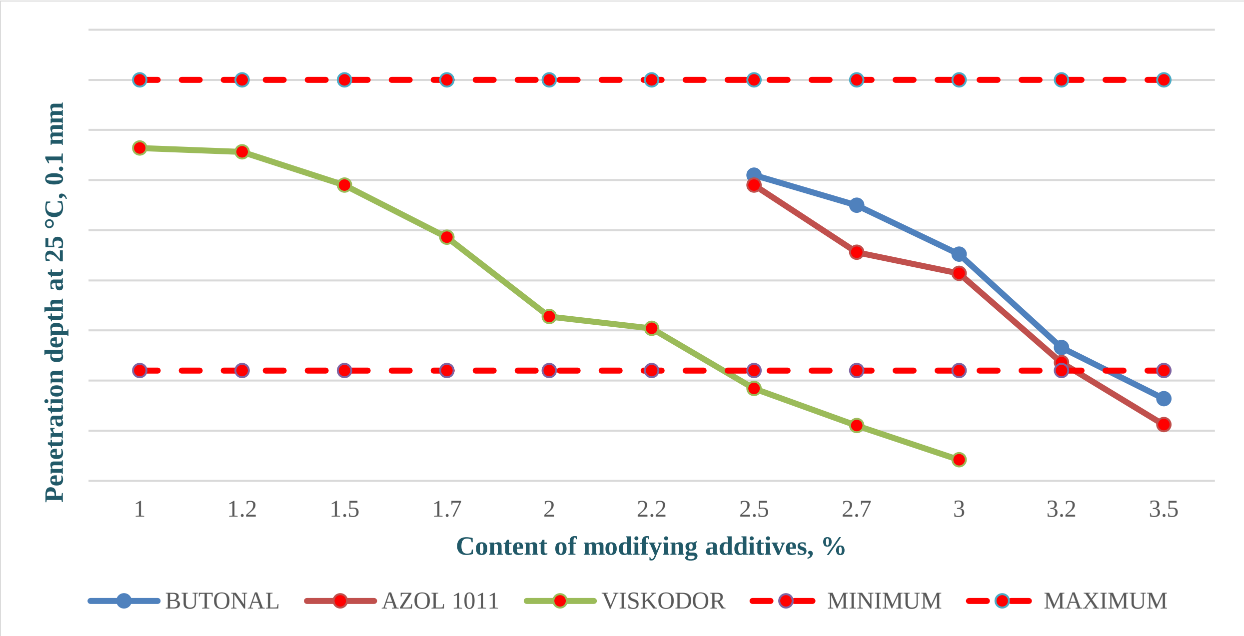
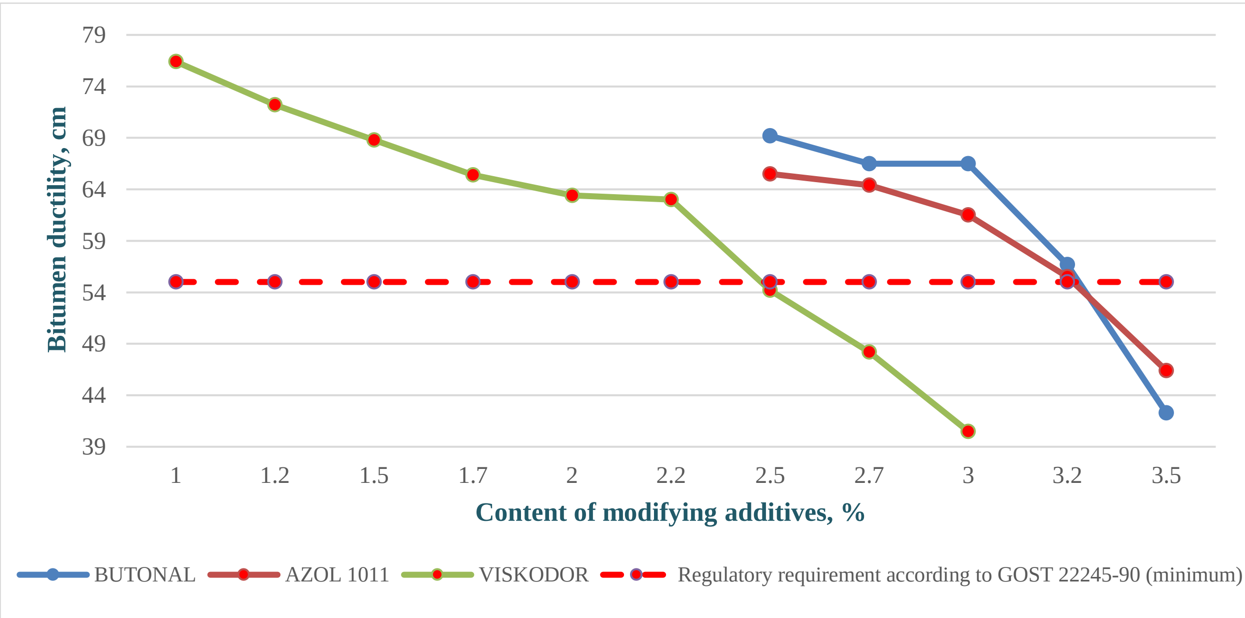


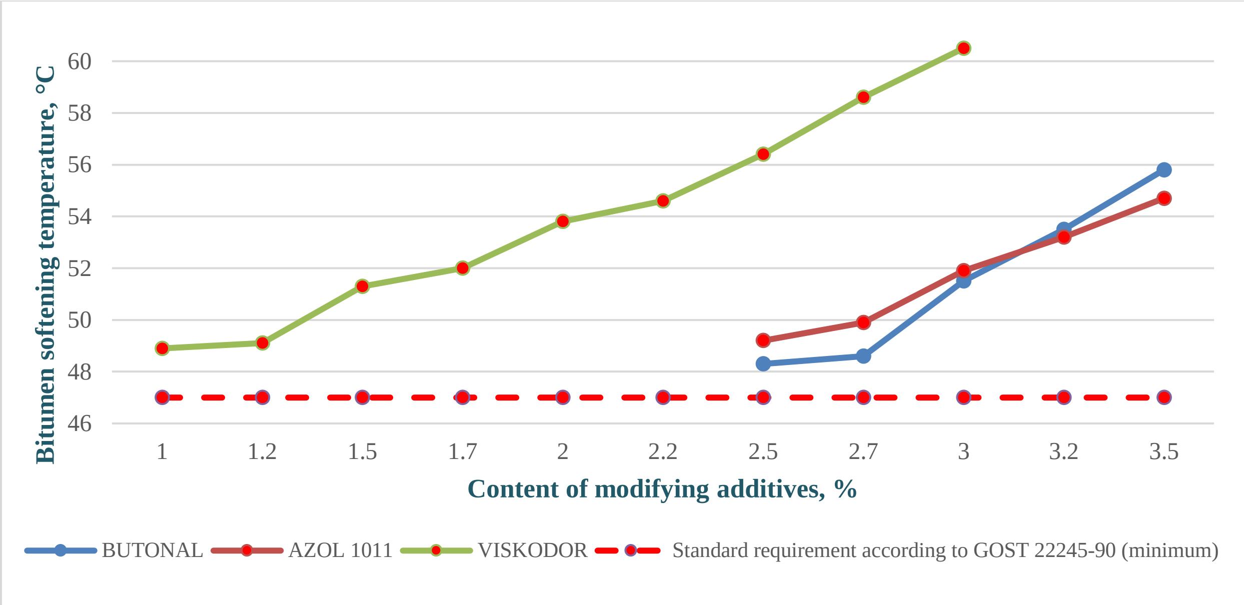
Figure 2 shows the change in the ductility of bitumen depending on the type and amount of polymer additives. Although a decrease in ductility is observed with an increase in the amount of polymer additives, it remains within the normative limits, ensuring sufficient elasticity of the bitumen (Figure 2)

Figure 2 – Dependence of bitumen ductility on modifying additives



In Figure 3, the change in the softening temperature of bitumen under the influence of modifying polymer additives is shown. The graphical data indicate that all additives lead to an increase in the softening temperature; in particular, the VISKODOR PV-2 additive demonstrates the greatest effect at higher concentrations. This indicates that modified bitumens exhibit increased resistance to rutting formation at high summer temperatures (Figure 3).

Figure 3 – Dependence of the bitumen softening temperature on modifying additives



Analysis Stage. According to the results of laboratory tests, all the studied polymer additives had a positive effect on the main physical and mechanical properties of bitumen.

Accordingly, when the concentration of the BUTONAL polymer additive was increased up to a maximum of 3.5% relative to the recommended amount, the needle penetration depth in bitumen decreased by 34.0%, ductility decreased by 48.0%, and the brittleness temperature decreased by 41.2%, while the softening temperature increased by 18.2%.

When the concentration of the AZOL 1011 polymer additive was also increased up to a maximum of 3.5% relative to the recommended amount, the needle penetration depth in bitumen decreased by 37.0%, ductility decreased by 43.0%, and the brittleness temperature decreased by 41.2%, whereas the softening temperature increased by 15.9%.

Similarly, when the concentration of the third polymer additive, VISKODOR PV-2, was increased up to a maximum of 3.0% relative to the recommended amount, the needle penetration depth in bitumen decreased by 40.9%, ductility decreased by 50.2%, and the brittleness temperature decreased by 52.9%, while the softening temperature of bitumen increased by 28.2%.

It can be assumed that this phenomenon is associated with the formation of a two-phase heterogeneous system due to intermolecular interactions between neighboring molecules at the component interfaces, which makes it possible to enhance the strength properties of the material. This process is also related to interactions between these phases; therefore, the brittleness temperature of bitumen decreases while the softening temperature increases.

RESULTS AND DISCUSSION

The obtained results showed that the polymer additives BUTONAL, AZOL 1011, and VISKODOR PV-2 increase the temperature stability of bitumen and improve its resistance to deformation. In particular, the VISKODOR PV-2 additive is distinguished by a significant increase in the softening temperature at higher concentrations. At the same time, all additives improve the adhesion properties of bitumen, contributing to increased water resistance of asphalt concrete mixtures.

CONCLUSION

As a result of the studies, it was established that modifying polymer additives significantly improve the physical-mechanical and operational properties of road-grade viscous bitumen. Asphalt concrete pavements produced on the basis of polymer-modified bitumen exhibit stability at both high and low temperatures, making it possible to extend the service life of road pavements. The obtained results confirm the expediency of the widespread use of polymer-modified bitumens in road construction practice.

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