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INVESTIGATION OF PHYSICAL-MECHANICAL AND RHEOLOGICAL PROPERTIES OF POLYMER-BITUMEN BINDERS MODIFIED WITH COMPLEX ADDITIVES

Jasurbek E. Babajanov [1], Ruslan R. Hayitov [2], Shohrukh B. Mavlonov [2], Temirbek Kh. Naubeyev[1], Ikramjan Ya. Sapashov[1]

[1] Karakalpak State University named after Berdakh, Nukus, Uzbekistan

[2] Bukhara State Technical University, Bukhara, Uzbekistan

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Abstract

Polymer-modified bitumen (PMB) is an advanced binder designed to improve road pavement durability and eliminate failures such as rutting and cracking. This study examines polymer-bitumen binders modified with destructed polypropylene (DPP), diatomite, and montmorillonite. The synergistic combination of these additives enhances the binder's elasticity, heat and cold resistance, and structural stability, resulting in improved performance and extended service life of asphalt pavements.

Keywords: *polymer-modified bitumen, complex additives, rheology, destructed polypropylene, diatomite, montmorillonite*

Introduction

Polymer-modified bitumens (PMBs) are advanced binder materials developed to enhance the strength and durability of road pavements, as well as to minimize the most common operational problems such as cracking, brittleness, and aging (Sengoz B., Topal A. G., Isikyakar G., 2009). In recent years, research aimed at improving the performance and service life of asphalt pavements through the use of polymer-modified bitumen has been rapidly expanding (Zhu J., Birgisson B., Kringos N., 2014). These materials are characterized by superior physical and mechanical properties and are considered an effective solution, particularly for heavily loaded road structures (Duarte G. M., Faxina A. L., 2021).

Conventional petroleum bitumens tend to lose their plasticity and become brittle under the influence of temperature fluctuations, ultraviolet radiation, and mechanical stresses. Therefore, improving the rheological and physical-mechanical characteristics of bitumen is one of the key scientific and technical directions for extending the service life of road pavements (Ayupov D. A., Murafa A. V., 2009).

Polymer-modified bitumens represent complex dispersed systems, where interfacial interactions significantly affect elasticity, viscosity, softening temperature, and brittleness limits (Al-Azawee E. T., Qasim Z. I., 2018). Polymer components form a stable structural network within the bitumen matrix, enhancing its thermal stability, deformation resistance, and crack resistance (Gohman L. M., 2008). In addition, polymer-modified binders provide asphalt mixtures with high elasticity, and resistance to moisture and chemical reagents (Kim Y., Lee S. J., Amirkhanian S. N., 2010).

Studies by Kotenko et al. (Kotenko N. P., Shcherba Yu. S., Evforitskiy A. S., 2019) demonstrated that modification of BND 70/100 grade road bitumen with styrene-butadiene-styrene (SBS), ethylene-vinyl acetate (EVA) polymers, and carbon nanotubes (CNTs) increased the heat resistance of the modified bitumen by 1,17 times and the cold resistance by 1,2 times. These effects are attributed to the branching of polymer chains and the formation of strong interfacial bonds within the bitumen matrix (Yildirim Y., 2007).

In the present study, a similar concept was applied using destructed polypropylene (DPP), diatomite, and montmorillonite as complex modifiers to investigate their effect on the physical-mechanical and rheological properties of polymer-bitumen binders. The synergistic interaction of these modifiers enhances the thermal resistance, elasticity, and deformation stability of the binder (Khairutdinov R. F., Shakhov A. V., Ibragimov R. A., 2017). This, in turn, extends the service life of road pavements, reduces maintenance costs, and improves overall economic efficiency.

Materials and methods

The modified bitumen was prepared using the following composition: destructed polypropylene (DPP) – 3–5 wt%, diatomite and montmorillonite – 2 wt % each, and the remaining part consisted of BND 50/70 grade road bitumen. This bitumen grade is intended for use in hot climatic regions and for pavements subjected to heavy traffic loads.

The mixing process was carried out in two stages:

Stage 1: high-speed dispersion at 180 °C and 3000 rpm for 90 minutes;

Stage 2: low-speed homogenization at 600–700 rpm for an additional 90 minutes.

Table 1. *Polymer-bitumen binder samples prepared using thermo-oxidatively destructed polypropylene (JM-380)*

Sample	Bitumen BND 50/70 (%)	DPP (%)	Diatomite (%)	Montmorillonite (%)
PB-DP-1	93	3	2	2
PB-DP-2	92	4	2	2
PB-DP-3	91	5	2	2

Results and discussion

The experimental results revealed that the physical-mechanical and rheological properties of polymer–bitumen binders are significantly influenced by the content of destructed polypropylene (DPP), diatomite, and montmorillonite. During the modification process, these components exhibit a synergistic interaction that leads to the formation of an elastic, thermally stable, and deformation-resistant phase structure within the bitumen matrix.

The analysis of the results was carried out through three main groups of parameters:

- Penetration and ductility – characterizing the mechanical flexibility and hardness of the binder;
- Softening and brittleness temperatures – determining the thermal stability and the brittleness threshold at low temperatures;
- Elasticity (elastic recovery) – assessing the ability of the modified binder to recover its shape after deformation.

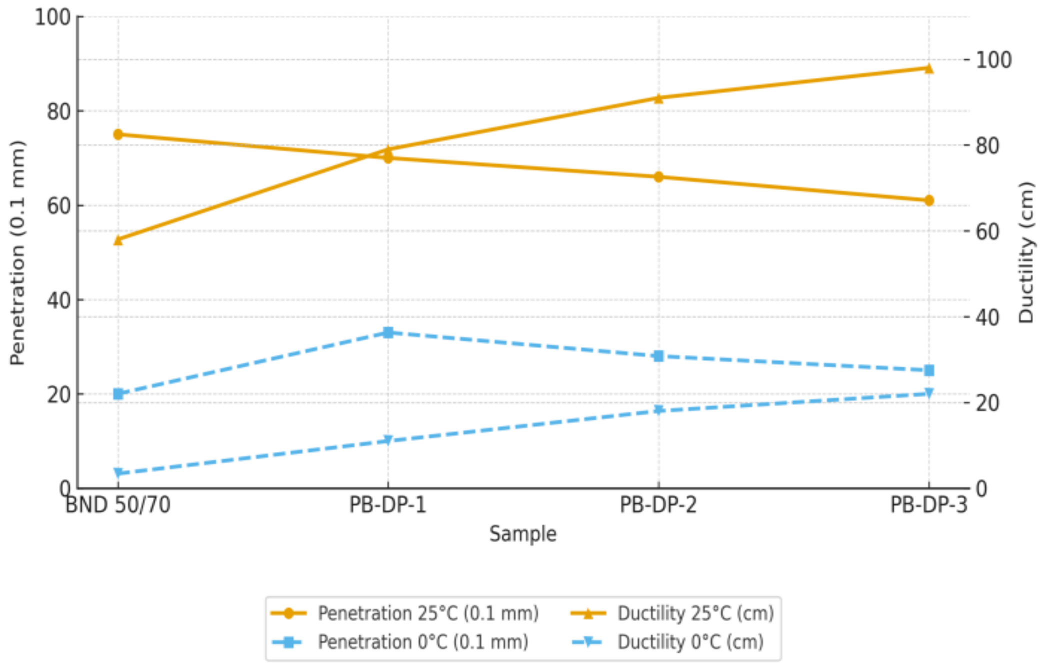
As shown in Figure 1, the penetration and ductility values of polymer-bitumen binders vary significantly with DPP content.

The base bitumen (BND 50/70) exhibited a penetration of 75 × 0,1 mm and ductility of 58 cm at 25 °C, and 20 × 0,1 mm and 3,4 cm at 0 °C. With increasing DPP concentration, penetration decreased while ductility sharply increased.

This indicates that the modified binder becomes stiffer and denser, yet more elastic and flexible under deformation.

The synergistic action of DPP, diatomite, and montmorillonite leads to the formation of an interpenetrating viscoelastic network that enhances both the flexibility and crack resistance of the bitumen matrix.

Figure 1. *Effect of DPP content on penetration and ductility of polymer-bitumen binders*

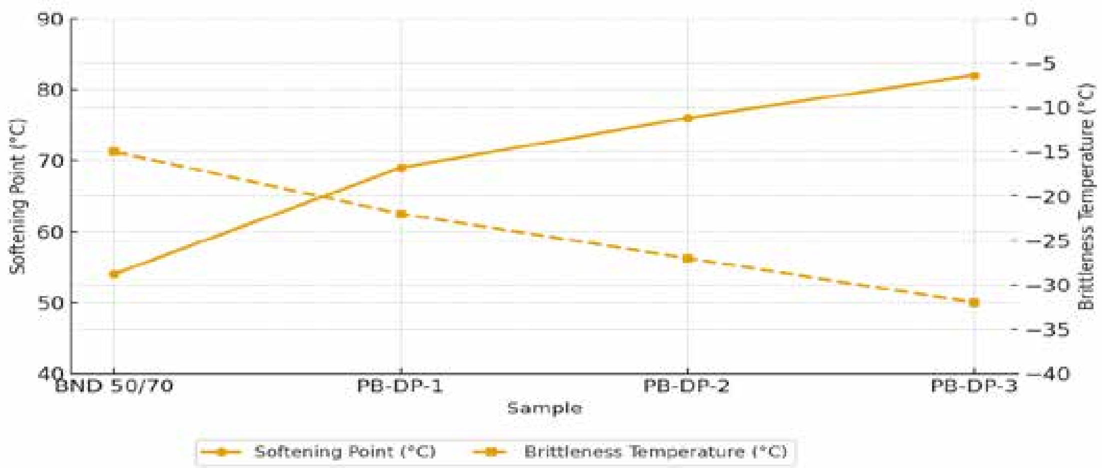


As DPP content increases, the softening temperature rises while the brittleness temperature decreases, indicating a broader operational temperature range and improved thermal stability.

The variation of softening and brittleness temperatures with increasing DPP content clearly demonstrates the improvement of thermal stability and low-temperature flexibility of the modified binders.

As seen in Figure 2, the softening point of the base bitumen (BND 50/70) was 54 °C, while that of the modified binders increased to 69 °C, 76 °C, and 82 °C for PB-DP-1, PB-DP-2, and PB-DP-3, respectively.

Figure 2. *Effect of DPP content on softening and brittleness temperature of polymer-bitumen binders*



Conversely, the brittleness temperature decreased from –15 °C to –22 °C, –27 °C, and –32 °C. This behavior confirms that the polymer network restricts molecular mobility and prevents crack propagation under thermal stress.

Diatomite and montmorillonite further act as thermal stabilizers, dispersing heat uniformly and delaying crystallization at low temperatures.

As DPP content increases, the softening temperature rises while the brittleness temperature decreases, indicating a broader operational temperature range and improved thermal stability.

The results of elastic recovery tests at 25 °C and 0 °C show a remarkable increase in deformation recovery ability after modification.

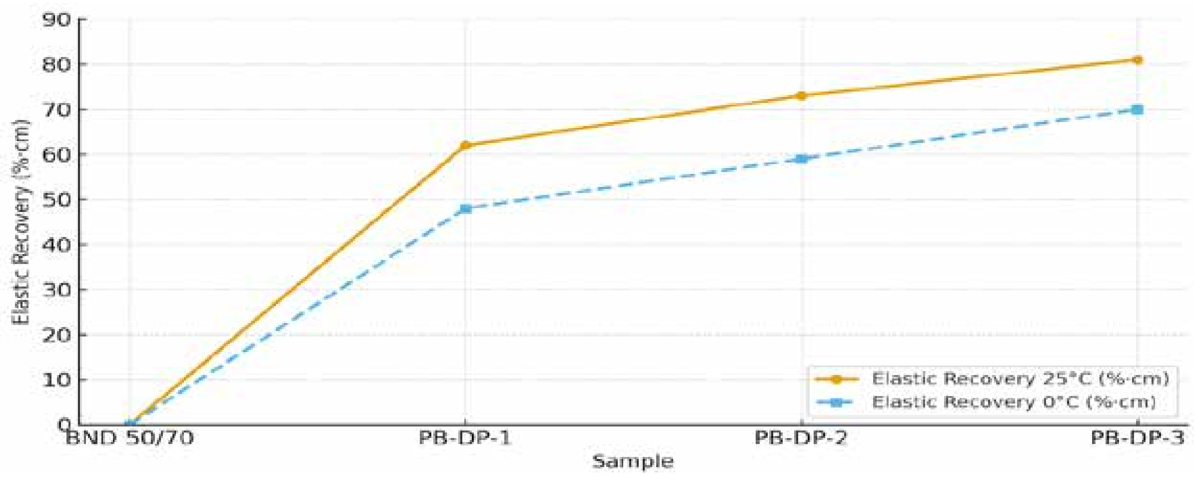
As illustrated in Figure 3, the base bitumen exhibited almost no recovery, whereas the modified samples achieved 62, 73, and 81%·cm at 25 °C, and 48, 59, and 70%·cm at 0 °C for PB-DP-1, PB-DP-2, and PB-DP-3, respectively.

This confirms that destructed polypropylene contributes to the formation of a three-dimensional elastic network within the bitumen matrix.

The oxidized polymer chains interact physically with the bitumen components, enabling the binder to recover its shape after deformation.

Moreover, the micro-porous structure of diatomite and the layered configuration of montmorillonite reinforce this network, enhancing overall flexibility and durability.

Figure 3. *Effect of DPP content on elastic recovery of polymer-bitumen binders at 25 °C and 0 °C*



Elastic recovery increases sharply with DPP addition – from 0 to 81% cm at 25 °C and from 0 to 70% cm at 0 °C confirming the formation of a stable elastic structure within the modified binder.

Conclusion

The study demonstrated that complex modification of BND 50/70 bitumen with destructed polypropylene, diatomite, and montmorillonite leads to substantial improvement in its rheological, mechanical, and thermal properties. The modified binders exhibit increased softening temperature (up to 82 °C), decreased brittleness (down to –32 °C), and improved elastic recovery (up to 81%·cm), confirming the formation of a three-dimensional viscoelastic structure. Such materials are promising for road pavements operating in extreme climatic conditions, ensuring higher durability and service life. Future work will focus on optimizing additive ratios and studying long-term aging resistance of the modified systems.

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Contact: sapashov85@mail.ru