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Article

Improvement of road infrastructure on the example of the Center-South transport corridor of the Akchatau-Akzhal section

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Abstract. The study investigates the enhancement of road infrastructure in the Center-South transport corridor of the Akchatau-Akzhal section, addressing the challenges posed by rapid road pavement deterioration due to increased traffic flow. By analyzing the natural and climatic conditions of the area, optimal concentrations of additives were determined to improve the properties of bitumen and asphalt concrete, with a focus on increasing strength and durability. Specifically, the addition of monoethanolamine to bitumen at a concentration of 0.08% led to notable improvements in key properties. The needle penetration depth at 25°C decreased from 80 to 71, indicating enhanced consistency. Moreover, the ring and ball softening point increased from 52 to 56, demonstrating increased resistance to temperature variations. Stretchability at 40 improved from 65 to 70, highlighting enhanced flexibility and durability. The study emphasizes the critical importance of quality construction and regular maintenance to ensure the durability and resilience of road networks to various factors. By utilizing innovative technologies and materials, such as modified binders with additives, the study showcases the potential to significantly enhance the performance, safety, and efficiency of road networks while reducing costs and environmental impact. The findings underscore the need for continued research and implementation of optimized solutions to improve road infrastructure sustainability and longevity.

Keywords: road infrastructure, transportation corridor, improvement, innovative technologies, bitumen, asphalt concrete, additives.

1. Introduction

Together with the growth of the transport industry and the increase in traffic flow, the problem of rapid deterioration of pavements arises. Operational stresses, including heavy vehicle traffic, exposure to weather conditions, and inadequate road construction and maintenance, lead to rapid deterioration and damage to the road surface. This not only increases infrastructure repair and maintenance costs, but also creates inconvenience for road users and jeopardizes road safety. Therefore, it is necessary to pay special attention to improving the quality of construction and regular maintenance of the road network to ensure its durability and resistance to various factors.

The introduction of innovative technologies and materials into the construction and maintenance of road infrastructure is essential to improve its durability, safety and efficiency. Research shows that modifying bitumen using various additives such as recycled high-pressure polyethylene, polypropylene, polymers and carbon nanotubes helps to significantly improve its performance and durability of asphalt mixtures [1-2].

The additives effectively affect the rheological properties of bitumen, reducing its stiffness, increasing resistance to low-temperature cracking, increasing fatigue strength and overall resistance to rutting [2-3]. The optimum concentration of these additives plays a key role in achieving the desired results, and exceeding the optimum dosage can negatively affect the improvement of bitumen properties [4-5].

The use of modified bitumen binders with additives of polymer industry wastes, such as recycled high-pressure polyethylene and polypropylene, also makes it possible to significantly improve the performance characteristics of bitumen and increase the strength properties of road pavements [6].

Special attention is given to the geotechnical studies necessary to understand the characteristics and behavior of expansive soils during road construction. This is important to prevent structural problems and premature failure of road infrastructure [7].

Using effective modifications, additives and rejuvenators, the performance, safety and durability of road networks can be significantly improved, while reducing costs and negative environmental impact.

Thus, the main objective of research in this area is to determine the optimum concentrations of additives that can maximize the properties of bitumen and asphalt concrete and provide improved strength and durability of road surfaces.

1. Methods

The road section within the reconstruction of the Center-South corridor on the Akchatau-Akzhal section was selected for the study.

The analysis of natural and climatic conditions of the area of reconstruction of the Center-South corridor section showed the following.

Road and climate zone – IV.

Normative frost depth of soils:

- loams and clays - 158 см;
- sandy loam and fine, dusty sands - 193 см;
- medium coarse, gravelly sands - 207 см;
- coarse clastic - 234 см.

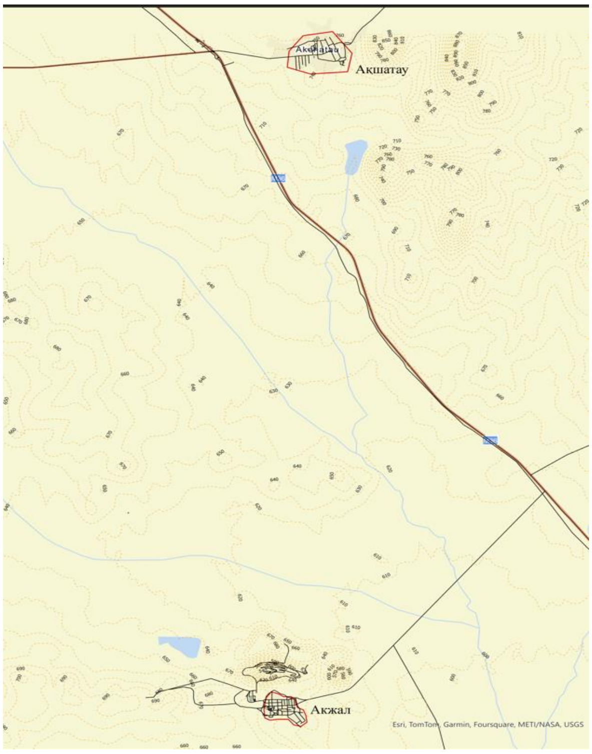

Figure 1 – Situation diagram of the highway

The road section selected for reconstruction and the corridor within the "Center-South" transport corridor is characterized by special natural and climatic conditions that need to be taken into account in the design and construction of the road.

The road corridor is located in a weakly hilly flat terrain within the Central Kazakhstan fine-grained sedimentary basin. The geological structure includes coal-bearing deposits, coarse-grained granites, alluvial deposits, dealluvial-proluvial deposits and eluvial Quaternary deposits.

Adverse physical and geologic processes observed in the area include salinization, weathering, waterlogging, lateral and bottom erosion. As a result, the existing road surface is damaged, with potholes, cracks and eroded edges.

Existing small man-made structures such as culverts are mostly in poor condition and require complete replacement. In addition, three bridges over the Zhamshi River are in an emergency condition and need to be replaced with new structures.

The road rehabilitation project aims to meet the technical characteristics of a Category I-b road, taking into account factors such as road category, speed limits, number of lanes, road width, shoulder width, alignment radius and visibility requirements.

The detailed design provides for the reconstruction of the road section according to I-b category standards.

Table 1 – Technical parameters of the highway

No. n/a	Name of parameters	Parameters	
		according to [8]	Adopted in the draft
1	Road category	I-b	I-b
2	Estimated speed of traffic, km/hour	120	120
3	Number of traffic lanes, pcs.	4	4
4	Lane width, m	3.75	3.75
5	Carriageway width, m	2x(3.75x2)	2x(3.75x2)
6	Shoulder width, m	3.75	3.75
7	Smallest width of the shoulder reinforcement strip, m	0.75	0.75
8	Width of separating strip between different directions of traffic Bss, m	2 м + fence width	3.0
9	Smallest width of the reinforcement strip on the dividing strip, m	2x1.0	2x1.0
10	Width of subgrade, m	2x(3.75x2)+7.5+ Bss	25.5
11	Transverse slope of roadway, ‰	20	20
12	Transverse slope of shoulder, ‰	40	40
13	Highest longitudinal gradient, ‰	40	21
14	The shortest visibility distance for stopping an oncoming vehicle, m	250 450	250 450
15	Smallest radii of curves in the plan, m in longitudinal profile: convex, m concave, m	 800 15000 5000	 1020 15000 5000

The use of bitumen as a road binder requires careful consideration of its properties, including penetration depth, softening point, adhesion, stability and temperature sensitivity.

Various tests and measurements of bitumen have been carried out to evaluate its suitability for road construction.

The introduction of additives and modifiers such as polymers, carbon nanotubes and rejuvenators can improve the properties and performance of bitumen and asphalt mixtures. These modifications can improve viscosity, elasticity, rutting resistance, fatigue resistance, and low-temperature performance.

The study identified specific optimum dosages and concentrations of the additives and rejuvenators used to achieve the desired improvements without degrading the overall performance of the asphalt concrete mixtures.

To improve the properties of bitumen, the effects of various plasticizers that enrich the dispersion medium of bitumen, lower its softening point and increase penetration were investigated. Laboratory experiments were carried out with samples of bitumen grade BND 100/130 weighing 100 grams (Table 2).

Table 2 – Results of laboratory tests on determination of bitumen parameters

Indicators	BND 100/130 grade
Needle penetration depth at:	
25°C	80
0°C, not less than	20
Softening temperature by ring and ball, °C, not lower	100
Stretchability, cm,not less:	
at 25°C	2
0°C	1
Brittleness temperature, °C, not higher	40
Flash point, °C, not lower	220

The following methodology was used to determine the physical and mechanical properties of bitumen, such as needle penetration depth, softening point, extensibility and brittleness temperature.

In determining the depth of needle penetration at 25°C and 0°C, the standard test method according to [9] was used, using a test bench with adjustable needle weight and a marker to measure the penetration of the needle into the bitumen (Figure 2). Softening temperature by ring and ball was determined using the test method according to [10], using a special device where bitumen is heated and its softening temperature is determined by the device readings at penetration of a cone-shaped indenter (ring) and ball into the heated bitumen sample (Figure 3). Tensile strength at 25°C and 0°C was measured in accordance with the test procedure [11], where the bitumen sample was heated to the required temperature, then measured its tensile strength in a special testing device (Figure 4). To determine the brittleness temperature, the test methodology was used in accordance with the requirements of [12], where a specialized test apparatus was used, in which the bitumen was heated and the temperature at which the bitumen becomes brittle was determined (Figure 5).

The amino alcohol monoethanolamine was added to these samples at concentrations of 0.02%, 0.05%, and 0.08% at 180°C. Using a laboratory dispersant, the samples were mixed. Then physical and mechanical properties of the newly obtained mixture were determined.

Figure 2 – Determination of bitumen viscosity on penetrometer

Figure 3 – Determination of bitumen softening temperature on the "ring and ball" device

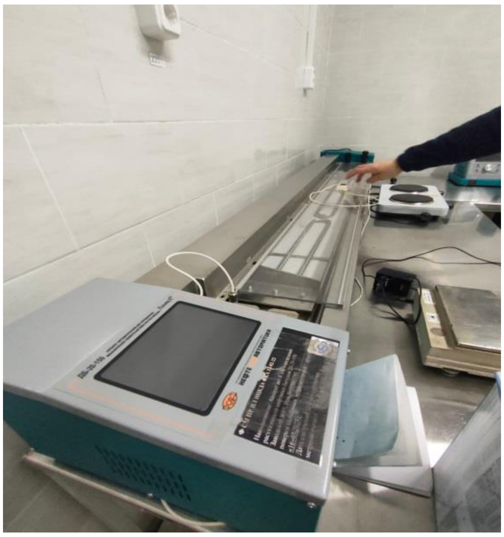

Figure 4 – Determination of bitumen extensibility on a ductilometer

Figure 5 – Bitumen heater

3. Results and Discussion

The performance of bitumen with monoethanolamine concentrations is presented in Table 3.

Table 3 – Performance comparisons

Indicators	BND 100/130	Monoethanolamine 0.02%	Monoethanolamine 0.05%	Monoethanolamine 0.08%
Needle penetration depth at 25°C	80	73	75	71
Needle penetration depth at 0°C	20	23	25	28
Ring and ball softening point	100	52	56	53
Stretchability at 25°C	40	65	95	70
Stretchability at 0°C	1	3.2	3.8	3.1
Brittleness temperature	40	18	22	19

From the table it can be seen that the concentration of monoethanolamine 0.05% provides optimal physical and mechanical properties of bitumen grade BND 100/130, such as increased needle penetration depth at 25°C, increased extensibility at 0°C and increased brittleness temperature. These results indicate that this additive concentration is effective in improving bitumen properties and can be recommended for use in road construction practice.

The mass density of oxygen molecules in the reference bitumen film after 5-min diffusion at different temperatures (25°C, 50°C and 100°C) was also investigated. The study revealed that the best ratio of oxygen molecule mass density in the bitumen film was observed at 50°C, indicating that more desirable bitumen properties were obtained at this temperature (Figure 6).

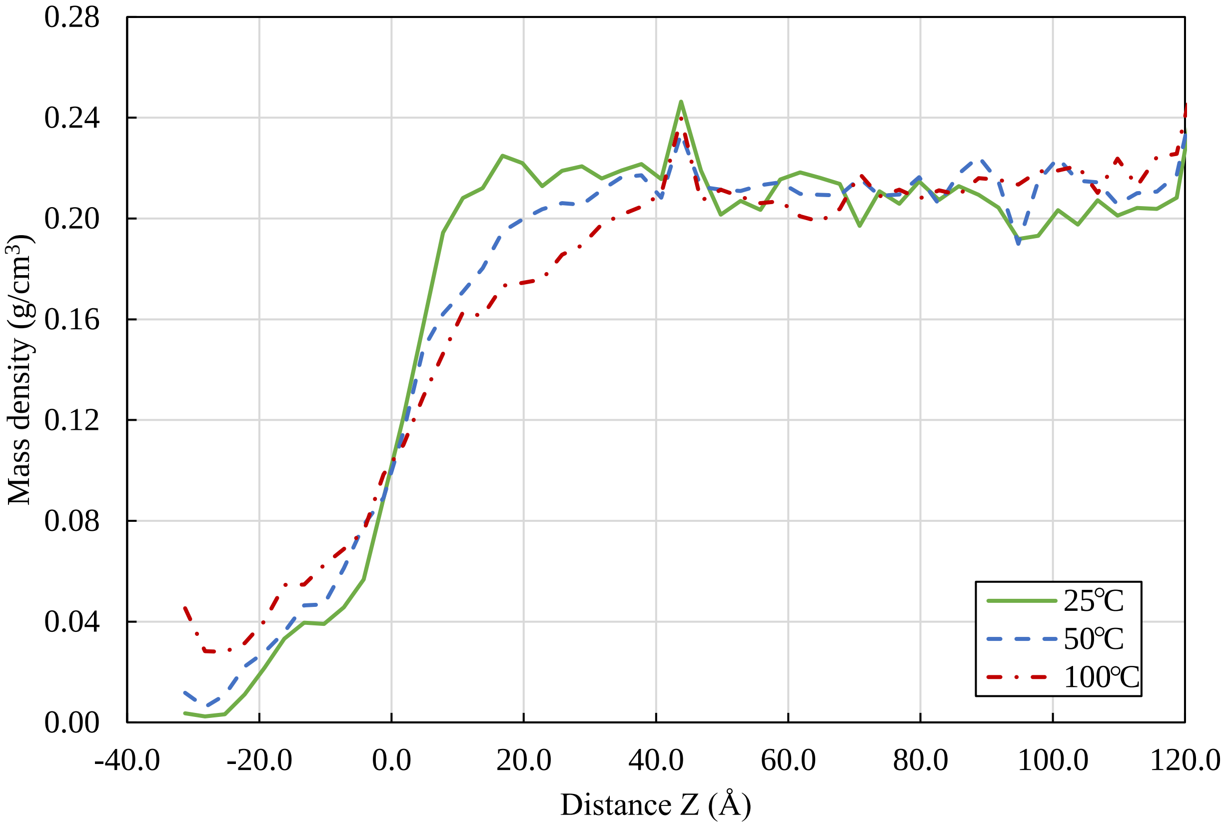

Figure 6 – Dependence of mass density of oxygen molecules in bitumen film on distance at different temperatures

Thus, the results of the study confirm the effectiveness of monoethanolamine concentration of 0.05% to improve the properties of bitumen and indicate the importance of taking into account the temperature conditions when working with bituminous materials to achieve optimal characteristics of road surfaces.

Based on the results of experiments and calculations in accordance with the requirements of standards [8] and [13] the following design of pavement for the road surface of the transport corridor "Center-South" section Akchatau-Akzhal was adopted (Figure 7):

- the top layer of the pavement is represented by crushed stone-mastic asphalt concrete ShchMA-20 in accordance with [14], with a thickness of 0.05 m, containing polymer additives;
- the bottom layer of the pavement consists of hot dense coarse-grained asphalt concrete mixture of type B of mark I according to [1]on bitumen of mark BND-100/130, with a thickness of 0.10 m and a new binder containing monoethanolamine at a concentration of 0.05%;
- the top layer of the base is made of hot porous coarse-grained asphalt concrete mixture of II grade on bitumen BND 100/130 according to [15], with a thickness of 0.12 m;
- the bottom layer of the base consists of black crushed stone, laid by the method of wedging in accordance with the standard [15], with a thickness of 0.10 m;
- the additional base layer is represented by the soil reinforced with a complex binder (composition: soil - 58%, gravel and woody soil - 38%, cement - 4%, "Roadzyme" - 0.002%), with the grade M20 and strength class F25, with a thickness of 0.20 m;
- on the dividing strip of the administrative and dividing lane the pavement is made of fine-grained dense asphalt concrete of type B - mark II on bitumen BND 100/130, with a thickness of 0.04 m.

Shoulder reinforcement is carried out in two stages: the first stage uses a mixture of crushed stone of 20-40 mm fraction and gravel and woody soil, with a thickness of 0.15 m; the second stage uses material from the dismantling of the existing pavement, with a thickness of 0.15 m.

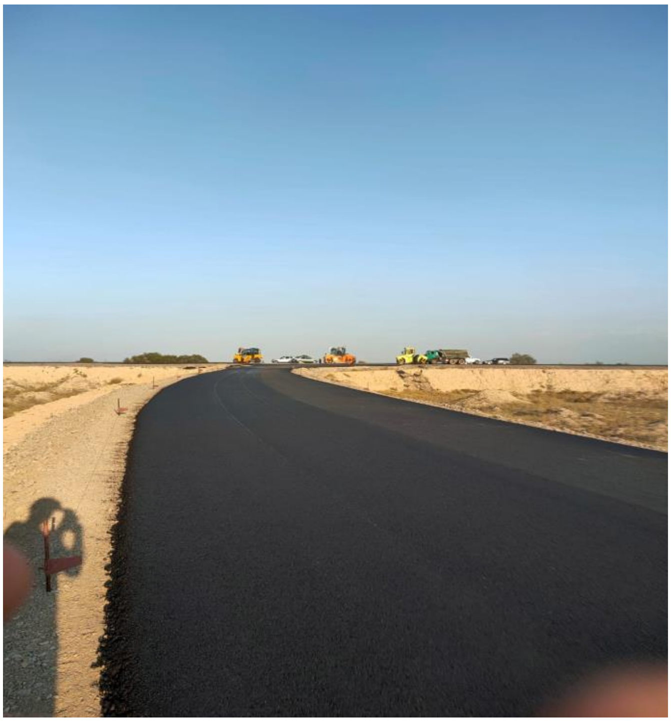

Figure 7 – General view of the highway after reconstruction

4. Conclusions

Based on the results of the experiments, the following conclusions can be drawn:

1. Addition of monoethanolamine to bitumen leads to the improvement of penetration depth, softening temperature, elongation and brittleness temperature;

2. Mass density of oxygen molecules in bitumen film shows the best ratio at 50°C, indicating desirable properties of bitumen at this temperature;

3. The use of innovative technologies and materials, such as modified binders with the addition of spent polymers and concentration optimization, can significantly improve the durability, safety and efficiency of road networks while reducing costs and environmental impact;

4. Geotechnical research is critical to understand the characteristics and behavior of expansive soils during road construction to prevent structural problems and premature deterioration of road infrastructure;

5. Adoption of innovative technologies and materials in the construction and maintenance of road infrastructure is necessary to improve its durability, safety and efficiency;

6. Attention should be paid to improving the quality of road construction and regular maintenance to ensure the durability and resilience of road networks to various factors.

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