Asphalt Concrete Durability

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Abstract: In road construction, asphalt concrete pavement undergoes intense mechanical and physical impacts during operation, ultimately leading to its deterioration. The most characteristic factors include impact loads and wear caused by moving vehicles, water saturation of the material, the accompanying freeze-thaw cycles, and salt corrosion. The negative impact of these factors is intensified by the accumulated residual deformations in the material, caused by operational loads and uneven foundation settlement. Ultraviolet radiation from the sun and the action of atmospheric oxygen lead to the aging of the binder, manifested in an increase in its hardness.

Keywords: Asphalt concrete, hardness, plasticity, water saturation, water resistance, frost resistance, wear resistance, fire resistance, temperature factor, freeze-thaw cycle, aging.

Introduction

Static and repeated cyclic loads cause the accumulation of irreversible deformations in asphalt concrete, eventually reaching a critical threshold. In water-saturated and frozen asphalt concrete, additional internal deformations develop, which combine with external loads, accelerating the process of irreversible deformation and ultimately leading to material degradation.

Main part

The deterioration of asphalt concrete is visually manifested by the appearance of cracks on the surface, primarily around large aggregates, with the disintegration of particles and the loosening of the material.

Asphalt concrete is a porous material. Properly selected and carefully compacted asphalt concrete primarily contains closed (or conditionally closed) pores, the quantity of which increases as the size of the aggregate particles decreases. Without external load, these pores do not fill with water. However, if the wet surface experiences brief compression (from moving traffic), some of the water is expelled from the pores, and during the release of pressure, due to the material's elastic recovery, a vacuum is created in the pores, causing water to be drawn into them from the surface. As this process repeats multiple times, water significantly fills or completely fills the pores in the surface layer of the pavement. Since water is practically an incompressible liquid, under the influence of external loads, it is forced into the micro-pores formed in the contact zone between the aggregate and the bitumen, leading to the detachment of the bitumen layer from the aggregate particles.

The water absorbed in the micro-pores of the asphalt concrete structure causes adsorptive desorption, leading to the opening of micro-defects and a reduction in structural bonds. With repeated wetting and drying, these defects accumulate. The deterioration of water-saturated asphalt concrete deepens with the presence of clay impurities on the surface of the mineral aggregates. When the clay particles absorb moisture, they accelerate the process of bitumen detachment from the surface of the mineral grains.

When water freezes in the pores of asphalt concrete, which always occurs on the surface layer, the ice crystals formed from the frozen water exert pressure on the remaining liquid water in the closed pores, causing it to fill the pores. When the water saturation of the pores reaches a critical level (theoretically no less than 91%), subsequent freezing leads to dangerous tensile stresses, resulting in plastic (irreversible) deformations, with the volume of the pores increasing irreversibly. During thawing, the volume of ice decreases (by approximately 9%), and the pressure in the pores becomes lower than atmospheric pressure, causing a certain amount of water to be absorbed into the pores. With repeated freezing and thawing, the accumulated irreversible deformations reach a critical point, leading to the formation of initial micro-defects, which then accumulate and enlarge, eventually transforming into macro-defects. From the moment macro-defects caused by freezing appear, the deterioration of asphalt concrete increases progressively, as these defects also fill with water, becoming a source of internal stress.

The weakest point in asphalt concrete is the contact between the asphalt binder and the coarse aggregates. This is primarily due to the difference in the coefficients of thermal expansion between the stone materials and bitumen: the volumetric thermal expansion coefficient of stone materials averages around 1×10^{-5} °C, while for bitumen it is approximately 8×10^{-5} °C, meaning it is nearly one order of magnitude higher. As a result, during temperature changes, bitumen experiences much more deformation than the mineral aggregate. At positive temperatures, the generated thermal stresses relax quickly, and the "aggregate-bitumen" contact remains intact. However, at negative temperatures, when bitumen becomes elastic and brittle, the thermal stresses increase significantly due to reduced relaxation, leading to the detachment of bitumen from the aggregate particles. Water enters the formed cracks, which, upon freezing, expands, causing the bond between the large aggregate particles and the surrounding bitumen to break.

A key factor in the durability of asphalt concrete is the aging of bitumen, which manifests as an increase in viscosity, a loss of plasticity, and the appearance of brittleness, even at positive temperatures. The properties of bitumen change due to the effects of heat, solar radiation, and oxygen in the air. This results in the evaporation of lighter fractions, oxidation of hydrocarbons, the formation of free valence bonds, and their subsequent polymerization, leading to the creation of more viscous and rigid substances.

The stability of petroleum bitumen under the influence of air and solar radiation depends on the content of methane, naphthenic, and aromatic hydrocarbons. As the amount of oxygen-containing, nitrogenous, and sulfur compounds increases, the stability of bitumen decreases. Oxidation processes are intensified by an increase in the porosity of asphalt concrete, which allows better penetration of water and air.

Bitumen undergoes maximum oxidation and polymerization in the surface layer of asphalt concrete, which is also exposed to other detrimental influences such as mechanical stress, water saturation, freezing and thawing, and more. The impact of these processes decreases with depth, and at certain depths, it may not manifest at all. Depending on the quality of the asphalt concrete, bitumen aging can extend to a depth of 2 to 6 cm.

The aging process of bitumen is influenced by the mineral composition of the asphalt concrete. Adsorptive processes also change the group composition of bitumen and contribute to its structuring. The molecules of bitumen hydrocarbons become less mobile in the adsorptive layers compared to free bitumen, which reduces its reactivity. Regarding the loss of bitumen's plasticity, the increase in viscosity and brittleness worsens the properties of asphalt concrete. It becomes stiffer and less plastic.

Water saturation is characterized by the amount of water absorbed by a water-saturated asphalt concrete sample under a specified regime. Water saturation is determined on samples prepared in the laboratory or cut from the surface (core samples). For this purpose, cylindrical-shaped samples are used.

The determination of water saturation is carried out as follows: Asphalt concrete samples are initially weighed in air. Then, they are placed for 30 minutes in a water bath at a temperature of 20±2°C, where the sample should be covered by at least 20 mm of water. Afterward, the samples are weighed in water and placed again in a water bath at a temperature of 20±2°C. The water level above the samples should be no less than 3 cm.

The container with the samples is placed in a vacuum apparatus, where the pressure is no more than 2000 Pa (equivalent to 15 mm of water). This process lasts for 1 hour. Then, the pressure is gradually released to atmospheric pressure, and the samples are left in the chamber for an additional 30 minutes. Afterward, the samples should be removed, weighed in water, gently dried with a soft cloth, and weighed in air.

The water saturation W of the sample, in percentage, is calculated using the following formula:

$$W = \frac{m_3 - m}{m_2 - m_1} \cdot 100 \quad (1)$$

- m is the weight of the sample in air, gr.
- m_1 is the weight of the sample after being immersed in water for 30 minutes and weighed in water, gr.
- m_2 is the same sample weighed in air, gr.
- m_3 is the weight of the water-saturated sample weighed in air gr.

This formula calculates the percentage of water saturation in the asphalt concrete sample.The water saturation value is taken as the arithmetic mean of the three samples rounded to the nearest tenth. Water saturation is standardized only for dense and high-density hot asphalt concrete mixtures (Table 1).

The normative requirements for water saturation. Table 1

Type and grade of asphalt concrete.	Volume water saturation, %.	
	For samples formed from the mixture.	For cores extracted from the finished pavement, not exceeding.
High density.	1...2,5	3,0
Dense type.		
A	2,0...5,0	5,0
B, C, D	1,5...4,0	4,5
E	1,0...4,0	4,0

For cold asphalt concrete mixtures, water saturation should be between 5% and 9% (by volume).

The magnitude of water saturation depends on the structure of the asphalt concrete. As the content of mineral aggregates increases, the volume of pores also increases, resulting in a higher number of open pores. This is confirmed by numerous data (Fig. 1).

In the figure:

Curve 1 represents the water saturation of the asphalt binder,

Curve 2 represents the water saturation of the asphalt mortar,

Curve 3 shows the water permeability of asphalt concrete after prolonged exposure to water.

The swelling of asphalt concrete is characterized by its hydrophilic properties and the degree of bitumen adhesion to the surface of mineral aggregates. Swelling is defined as the increase in the sample's volume after being saturated with water under vacuum. The determination of swelling is based on the data obtained during water saturation testing.

The swelling of asphalt concrete is determined in volumetric percentage:

Swelling

$$V = \frac{(m_3 - m_4) - (m_1 - m_2)}{m_1 - m_2} \cdot 100 \quad (2)$$

- m1 – the mass of the sample after being immersed in water for 30 minutes and weighed in air, grams;
- m2m_2m2 – the same sample weighed in water, grams;
- m3m_3m3 – the mass of the vacuum-saturated sample weighed in air, grams;
- m4m_4m4 – the same sample weighed in water, grams.The swelling value is taken as the arithmetic mean of three samples, rounded to the first decimal place.

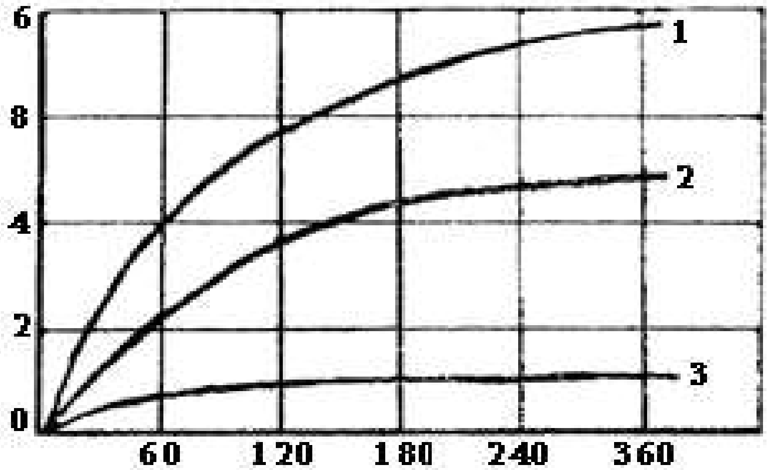

Fig. 1. Change in water saturation over time:
1 – Asphalt binder; 2 – Asphalt mortar; 3 – Asphalt concrete

The water resistance of asphalt concrete is determined by the water resistance coefficient, which indicates the extent to which its strength decreases after water saturation and characterizes the asphalt concrete's resistance to the destructive action of water.

The water resistance coefficient is determined for all types of hot and cold asphalt concrete mixtures, except for coarse-grained mixtures. There are two methods for determining water resistance.

The first method considers the reduction in sample strength due to water exposure under a vacuum. For this purpose, the same samples used for determining water saturation and swelling can be utilized.

The water resistance coefficient Kw is determined with an accuracy of one decimal place using the following formula:

$$K^{w} = \frac{R_k^{w}}{R_k^{20}} \quad (3)$$

Where: R_k^{w}The compressive strength limit of the sample saturated with water under vacuum is in MPa;

R_k^{20}The same sample's compressive strength before water saturation at 20±2°C is in MPa.

The second method differs from the first in that the samples saturated under vacuum are transferred to water at a temperature of 20±2°C and left for 15 days. After this period, the samples are tested for compressive strength.

The results of the second method for testing water resistance are lower than those of the first method. Therefore, according to the requirements of the normative documentation, the determination of the water resistance of asphalt concrete must be carried out using both methods.

The frost resistance of asphalt concrete is determined by the reduction in compressive strength due to the effects of a defined freeze-thaw cycle. The method is as follows: Samples saturated with water under vacuum at a temperature of 20±2°C are frozen in a chamber at a temperature of -18±2°C for 4 hours. After this, the samples are transferred to a water bath at a temperature of +18±2°C, where they thaw for 4 hours. For the specified freeze-thaw cycles (5, 10, 15, 25, 50 cycles), the samples should be held for 2 hours in a water bath at a temperature of 20±2°C and then tested for compressive strength.

The reduction in compressive strength ΔR,% in percentage, is calculated using the following formula:

$$\Delta R = \frac{R_k^w - R_k^f}{R_k^w} 100 \quad (4)$$

Where:

R_k^w is the average compressive strength after saturation in water at a temperature of 20±2°C, in MPa.

R_k^f is the compressive strength after the specified freeze-thaw cycles, in MPa.

The number of test cycles and the allowable reduction in compressive strength are specified in the project documentation, based on the actual climatic conditions and the intended use of the asphalt concrete.

Conclusion

During the operation of road pavements, the various factors acting on asphalt concrete, their combinations, and intensity complicate the unambiguous assessment of its durability. Therefore, indicators such as water absorption, water resistance, freeze-thaw resistance, wear resistance, and temperature factors can be used as specific criteria for assessing the durability of asphalt concrete. These factors provide valuable information on the material's ability to withstand environmental stresses and mechanical loads, contributing to a better understanding of its long-term performance and suitability for different road conditions.

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