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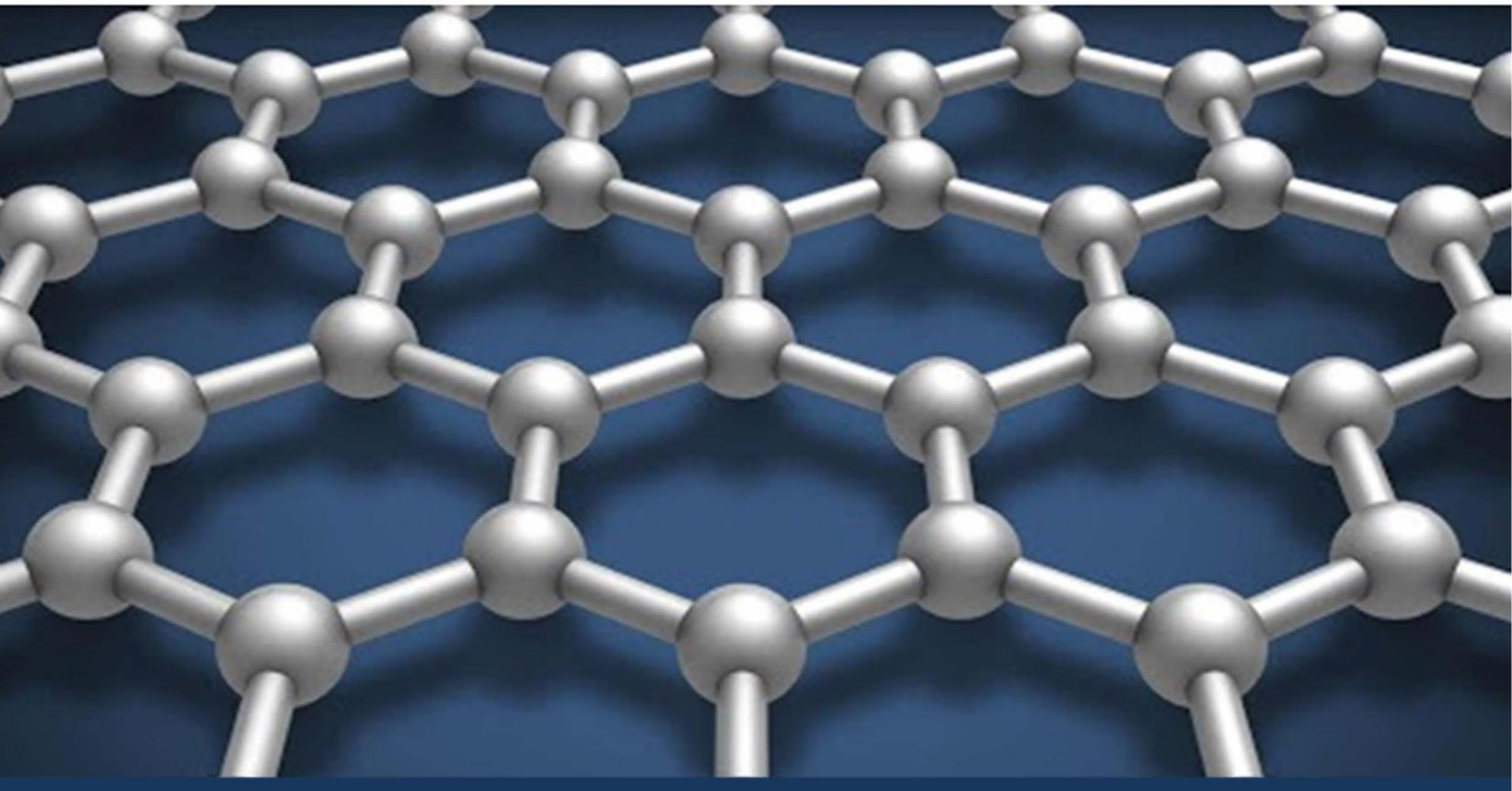

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MODERN SOLUTIONS FOR INCREASING THE STRENGTH PROPERTIES OF ASPHALT CONCRETE PAVEMENT

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Abstract: Asphalt concrete, a key material in pavement construction, demonstrates intricate rheological properties affected by variables like temperature, loading conditions, and aging. Precisely modeling asphalt's rheology is crucial for creating long-lasting and sustainable pavements. This detailed review assesses the current landscape of rheological models for asphalt concrete, covering both empirical and mechanistic methods. Furthermore, it examines widely used rheological frameworks for simulating asphalt behavior and emphasizes recent progress in experimental methods for characterizing asphalt rheology.

Keywords: Automobile roads, asphalt concrete, bitumen, surface-active additives, empirical and mechanistic approaches, dynamic mechanical analysis, shear strength.

Introduction. The In our country, most public roads are surfaced with asphalt-concrete pavements Asphalt concrete is widely used in road construction due to its versatility and durability. Rheological properties, including viscosity, elasticity, and stiffness, govern the behavior of asphalt concrete under different conditions. This section introduces the importance of rheological modeling in pavement engineering [1].

This covers concepts such as viscosity, elasticity, and viscoelasticity, emphasizing their role in determining the performance of asphalt pavements. The influence of temperature, loading rate, aging, and aggregate characteristics on asphalt rheology is discussed.

Empirical Rheological Models: Empirical rheological models, such as the Multiple Stress Creep and Recovery (MSCR) test and the Superpave Performance Grade (PG) system, are widely used in asphalt engineering. This section reviews these empirical models, discussing their principles, advantages, and limitations [2].

Examples of their application in pavement design and quality control are provided. Mechanistic Rheological Models: Mechanistic rheological models aim to describe asphalt behavior based on fundamental material properties and mechanics principles. This section evaluates various mechanistic models used in asphalt rheology, such as the asphalt mixture viscoelastic continuum damage (AVECD) model and finite element method (FEM) simulations. The applicability, accuracy, and computational challenges associated with these models are discussed [3].

Rheological Schemes and Formulas: Rheological schemes refer to mathematical formulations and constitutive equations used to describe the viscoelastic behavior of asphalt concrete. Commonly employed rheological schemes include [4-5].

Burgers model:

$$\sigma(t) = \eta_0 \epsilon^{\cdot}(t) + \eta_1 \int_0^t \epsilon^{\cdot}(\tau) d\tau + E\epsilon(t) \quad (1)$$

Maxwell model:

$$\sigma(t) = \eta_0 \epsilon^{\cdot}(t) + E\epsilon(t) \quad (2)$$

Generalized Kelvin-Voigt Mode:

$$\sigma(t) = \eta_0 \epsilon^{\cdot}(t) + E_1\epsilon(t) + E_2 \int_0^t \epsilon^{\cdot}(\tau) d\tau \quad (3)$$

Here:

(t) is the stress at time t

(t) is the strain at time t

$\epsilon^{\cdot}(t)$ is the strain rate at time t

E is the elastic modulus (spring constant)

η is the viscosity coefficient (dashpot coefficient)

This model represents the response of asphalt to loading over time. When a load is applied, the elastic element (spring) deforms instantaneously, while the viscous element (dashpot) resists the deformation, causing a time-dependent stress relaxation [6].

To apply this model to asphalt pavement, you need to consider the properties of both the asphalt binder and the aggregate mixture. The elastic modulus (E) and viscosity coefficient (η) can be determined experimentally through tests such as dynamic mechanical analysis (DMA) or bending beam rheometer (BBR) tests [7].

Experimental Techniques for Asphalt Rheology:

Advancements in experimental techniques have enabled detailed characterization of asphalt rheology. This section discusses various experimental techniques used in asphalt rheology characterization, such as dynamic mechanical analysis (DMA), rotational rheometry, and molecular dynamics simulations. The principles, applications, and recent developments in these techniques are highlighted. Despite advancements, challenges remain in asphalt rheological modeling, including model validation and computational efficiency. This section discusses these challenges and proposes future research directions to address them. Areas such as multiscale modeling and the integration of machine learning algorithms are identified as promising avenues for advancing asphalt rheological modeling [8-9].

One effective strategy for extending the lifespan of asphalt concrete involves enhancing the physical and mechanical properties of bitumen within the asphalt mixture through the application of surfactants [10].

Currently, there exists a variety of methods and additives that road engineers utilize to enhance the quality and durability of asphalt and bitumen against external factors. For instance, the modification of asphalt with polymers is a common practice in road construction and maintenance. Polymer-modified asphalt offers improved performance characteristics, including enhanced elasticity, durability, resistance to rutting and cracking, and improved adhesion [11-13].

In essence, this approach reinforces the asphalt concrete, thereby extending its service life and reducing the need for frequent repairs and maintenance [14].

Method. To prepare asphalt concrete mixtures, viscous road bitumens are used, in accordance with standards. BND 60/90 high-viscosity bitumen was used for the preparation of asphalt concrete samples in the processes.

The heating temperature of bitumen for asphalt concrete mixtures, depending on the brand, must correspond to that indicated in Table 1 [15].

Table 1.

Heating temperature of bitumen and asphalt concrete mixtures

Bitumen Brand	Temperature, ºC		
	Incoming Bitumen tomixer	Mineral mixture leaving the drying drum	Mixture when released from the mixer
BND 60/90	140	175	150

We conducted experimental studies under laboratory conditions with the aim of enhancing the physical and mechanical properties of asphalt concrete, following the guidelines outlined in standard protocol (GOST 31015-2002) [16].

In this initial phase, various types of asphalt samples were prepared, each containing different additives. One sample was prepared without any additives or surfactants to serve as a baseline for comparison.

Subsequently, the next stage of the research involved molding the asphalt concrete into specific shapes. The prepared hot mixture, weighing 720±5 grams, was poured into molds with a diameter of 71.4 mm that had been heated to temperatures ranging between 90-100 ºC (See Figure 3). All tested samples conformed to the required dimensions, with a height of 71.4±1.5 mm.

The aforementioned surface-active materials were incorporated into the asphalt concrete mixtures as per their selected compositions. Samples were then prepared under laboratory conditions in accordance with the specifications outlined in GOST-9128. Following preparation, test-research procedures were conducted, and the results are presented in Table 2 [15-17].

Using the selected composition as a basis, samples are prepared for laboratory testing to evaluate their rheological properties tolerance. Specifically, their ability to withstand displacement is assessed through the following procedure: the sample is placed in a water bath at a temperature of 50 °C, and a test stamp of a universal press is applied in a transverse manner. Research is then conducted following the Marshall scheme. Prior to testing for shear resistance, both the samples and the crimping device are heated in a thermo-stated environment at 50 ºC for one hour. Subsequently, they are wiped with a soft cloth and subjected to testing on a test press at a plate speed of (50.0 ± 1.0) mm/min.

Results and discussions. The compressive strength of the samples is assessed using presses with a press plate movement speed of (3.0±0.3) mm/min. When hydraulic presses are employed, this speed should be adjusted to idle stroke before testing . The sample, taken from the vessel for temperature control, is positioned in the center of the lower plate of the press. Subsequently, the upper plate is lowered and halted at a distance of 1.5-2 mm above the surface level of the sample.

The ultimate compressive strength (R) in MPa is calculated using the formula: [7].

$$R_{sc} = \frac{P}{F} 10^{-2} \quad (4)$$

Here:

P – permitted load, MPa ,

F- the original cross-sectional area of the sample, cm^2

10^2 conversion factor, MPa

After completing the aforementioned procedures, the results are rounded to the first decimal place, representing the arithmetic mean of the tests conducted on three samples. Following this, comparisons are made in accordance with standards GOST-9128-2013 and GOST-31015 [6-7-8]. The resulting analysis leads to the following conclusion [15-18]:

Based on the selected composition, samples are prepared for laboratory testing to assess their rheological properties tolerance. Specifically, their resistance to displacement is evaluated as follows: the sample is immersed in a water bath at a temperature of 50 °C, and a test stamp of a universal press is applied in a transverse manner. Research is then conducted following the Marshall scheme [18].

a)

b)

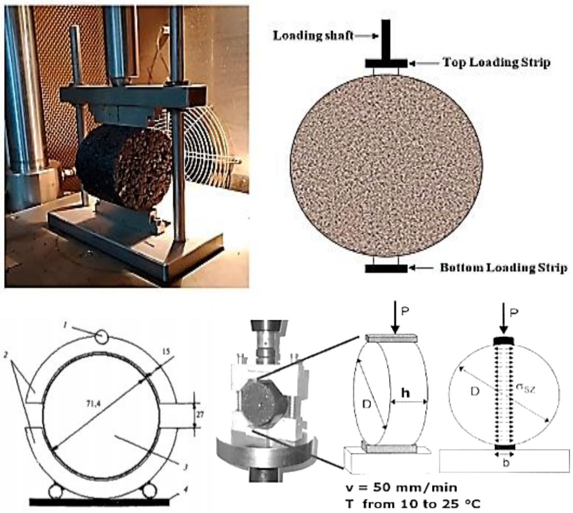

Figure 1. The process of testing the shear strength of an asphalt concrete sample in a universal press B) Scheme of the compression device according to the Marshall scheme in a universal press; 1. Hinge, 2. Cylinder surface, 3. Place for sample, 4. Bottom plate.

In this process, the specimen is tested by applying a tension of 20 (50)KN at a speed of 50 mm/min [16, 17].

Then the following calculations are performed.

$$A = \frac{Pl}{2} \quad (5)$$

A- Marshall unit of compression [Joule]

P-supplied voltage

l-specimen compressed size [mm]

After that $tg\varphi$ the coefficient of internal friction of asphalt concrete is calculated according to the formula.

$$\text{tg}\varphi = \frac{3(A_m - A_c)}{3A_m - 2A_{c)}} \quad (6)$$

A_m, A_c, - Average work of deformation of asphalt concrete samples when tested according to the Marshall scheme and uniaxial compression

After calculating these, we calculate the shear strength.

$$C_l = \frac{1}{2}(3 - 2\text{tg}\varphi)\text{R}_\text{C} \quad (7)$$

Rc- sample compression limit [15 MPa].

Based on the comparison conducted in accordance with standards GOST-9128-2013 and GOST-31015 [16-20], the results are summarized in Figure 2.

The laboratory tests yield the following outcomes:

Additionally, the strength indicators of asphalt concrete are compared with those obtained from previous studies, where different surface-active materials were utilized to enhance the strength of asphalt concrete. These materials include: Topcell, RKM 2, Ekotop, Xrizopro, Xrizotop, Viatop 66, and Aramid [18-24].

The shear strength indicators of asphalt concrete samples, prepared using various additives, are depicted.

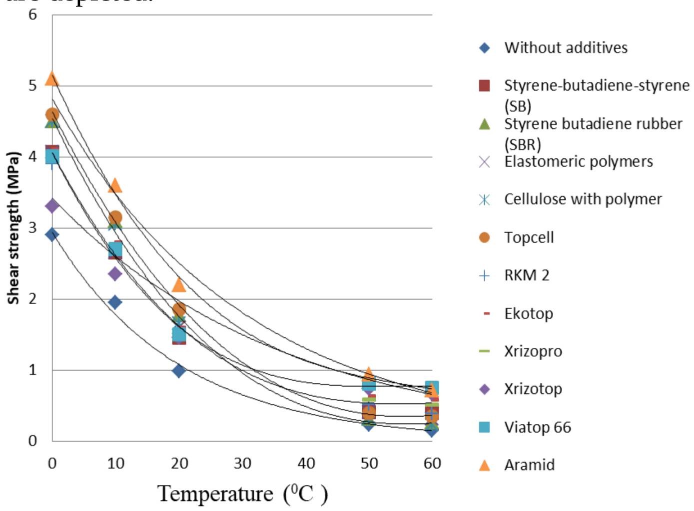

Figure 2. The shear strength indicators of asphalt concrete

Conclusion. Based on the findings of the conducted scientific research, the following conclusions can be drawn:

- Understanding asphalt rheology is crucial for the design of sustainable pavements with enhanced performance and longevity. Continuous research endeavors aimed at refining rheological models and experimental techniques will drive advancements in asphalt engineering and pavement technology.

- Various surfactant additives, including Topcell, RKM 2, Ekotop, Chrysopro, Chrysotop, Viatop 66, Aramid, styrene-butadiene-styrene (SBS), styrene-butadiene rubber (SBR), elastomeric polymers, and cellulose+polymer, have demonstrated a notable increase in both compressive and shear strength of asphalt concrete compared to the requirements stipulated in GOST 9128-2013.

- Specifically, RKM 2, Ekotop, Chrysopro, Chrysotop, Viatop 66, Styrene-butadiene-styrene (SBS), Styrene-butadiene rubber (SBR), elastomeric polymers, cellulose + polymer, and Topcell additives have led to a significant enhancement in shear strength at 50°C, with improvements ranging from 1.5 to 2 times. Furthermore, the addition of Aramid has resulted in a remarkable fourfold increase in this indicator.

- By incorporating the aforementioned surface-active additives into asphalt concrete, its durability is substantially enhanced, leading to an extension of its service life by approximately 20-25%.

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