The application of sulfur-asphalt concrete with modifiers in the climatic conditions of Vietnam

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Abstract. The paper considers the influence of ambient temperature and other weather factors on the properties of traditional asphalt concrete in Vietnam. The advantages of sulfur-extended asphalt concrete with modifiers containing neutralizers for the emission of toxic gases are presented to increase the quality and life of roads and solve the environmental problem of using sulfur-extended asphalt concrete. For calculating the surface temperature of asphalt concrete from the ambient temperature, the method of Yu. N. Kovalev is used (Russia). The weather data for January and July 2015, taken from the hydrometeorological stations of the cities of the respective zones in Vietnam, are used for calculations. The paper presents an experimental setup for determining the intensity of toxic gases evolution and the effect of neutralizers. The widespread introduction in the practice of building progressive environmentally friendly sulfur-containing materials: sulfur-extended asphalt concrete with modifiers, containing toxic gases emission neutralizers, which have higher physical and mechanical properties (wear resistance, etc.) compared to traditional ones at less or equal cost, can open up opportunities to increase quality and lifetime of roads in Vietnam.

Keywords: sulfur-extended asphalt concrete, toxic gases, neutralizers, environmental problem.

1 Introduction

Recently, all over the world and, in particular, in Vietnam, the rapid development of the economy requires improving the quality and quantity of transport services, which are closely related to the condition of roads. The total length of the road network in Vietnam is about 223,000 km, including 30,000 km of federal roads with asphalt concrete pavement [1].

Asphalt concrete work in difficult operating conditions under the influence of constantly increasing axial loads, speed and intensity of movement and weather conditions. Operation of asphalt concrete under such conditions leads to the formation of defects on the road surface. The most common defects are bumps, waves, ruts, peeling and chipping, etc [2, 3]. Road wear is formed due to external and internal impacts on asphalt concrete pavements. Internal factors arise due to improper design for roads, their construction and repair. The actual service life of asphalt concrete pavements in many cases is no more than 4-5 years, and often 1-3 years [4-6]. Defects on the road surface are most often formed as a result of weather conditions, one of the main factors is the temperature: the hot rays of the sun spoil the top layer of the track - asphalt concrete strength deteriorates, which leads to the formation of potholes. In the period of sub-zero temperatures, the collected moisture in the layers of asphalt concrete can increase in volume and thereby destroy the structure and compaction of asphalt [7-9]. At present, in Vietnam, the way to increase the durability and transport operating index of automotive road surfaces is applying sulfur as a component of the asphalt mix. The sulfur addition increases the strength of the material and significantly improves the adhesion of the binder to the surface of the mineral aggregate [10-12]. Sulfur-extended asphalt concrete, provides quality improvement of road surfaces with good operational and
physico-mechanical properties (such as high compressive strength, high values of heat and water resistance coefficients, resistant to long-term water saturation, frost resistance, resistance to rutting), maintainability (like increasing turnaround times and reducing the total cost of construction and repair of road surfaces) and safety to increase the durability of asphalt concrete pavements. The physico-mechanical properties of sulfur-extended asphalt concrete crucially depend on the relative content of various sizes particles in aggregates and their chemical nature [13-17].

However, a considerable limitation associated with sanitary and hygienic problems is the emission of toxic gases, such as hydrogen sulfide and sulfur dioxide in the production of sulfur-asphalt mixes. One of solutions for the problem above is adding neutralizing agents into the composition of the sulfur modifying. These agents can chemically interact with hydrogen sulfide and sulfur dioxide to form sparingly soluble or insoluble compounds, such as MnO₂, ZnO, CuO, Zn, CaCO₃,MgCO₃, SiO₂… [18-20].

The study of the effect of temperature on traditional asphalt concrete and the advantages of using sulfur-extended asphalt concrete in the climatic conditions of Vietnam may open up opportunities to increase the quality and life of roads in Vietnam.

2 Materials and methods

2.1 The methods of calculating the road surface temperature

There are many methods for calculating the surface temperature of asphalt concrete. According to Kovalev Y. N. [21] the minimum temperature of asphalt pavement is determined by the Eq:

\[ T_{s}^{min} = 0.7 \times T_{min} \]  

Where:
- \( T_{s}^{min} \) – the calculated minimum surface temperature of asphalt pavement, °C;
- \( T_{min} \) – the minimum outdoor temperature, °C.

The maximum temperature of asphalt pavement is determined by the Eq:

\[ T_{s} = T_{air} + T_{equivalent} \]  

Where:
- \( T_{s} \) – the calculated maximum surface temperature of asphalt pavement, °C;
- \( T_{air} \) – air temperature, °C;
- \( T_{equivalent} \) – equivalent temperature, °C;

\[ T_{equivalent} = (1 - A) \times \frac{I}{\alpha_{n}} \]  

Where:
- \( A \) – the albedo of a surface coating, characterized by its reflectivity;
- \( I \) – the intensity of solar radiation, W/m²;
- \( \alpha_{n} \) – the heat transfer coefficient, W/(m²·°C);

Vietnam is located on the Indochina Peninsula, which is located in the area of the tropical climate belt [22-24]. To calculate the surface temperature of asphalt concrete in Vietnam, weather data in January and July 2015 are used [25, 26]. The data were used to determine the temperature of the roads, depending on the ambient temperature taken from the hydrometeorological stations of the cities of the respective zones in Vietnam.

2.2 The methods of measuring the concentration of toxic gases in a volume

A schematic diagram of an experimental setup is used to determine the intensity of toxic gas emissions and the effect of neutralizers (figure 1).

Conditions for conducting an experiment to study the emission of toxic gases: mass of a sample of bitumen 50 g, sulfur concentration 10%, 20% and 30% by weight of bitumen. Used additives neutralizers in the amount of 10% by weight of sulfur. The sulfur-bitumen binder is constantly mixed throughout the experiment for 1 hour with a frequency of 1 measurement per minute. The preparation of a sulfur-bitumen binder and the study of the emission of toxic gases were carried out with constant
stirring and a temperature of 140±1 °C. These agents MnO₂, ZnO, CuO, Zn, as well as CaCO₃, MgCO₃ powder and SiO₂ powder were used as toxic gas neutralizers.

3 Results

3.1 Results of calculating the road surface temperature

Asphalt concrete, being a thermoplastic material, dramatically changes its properties depending on temperature; at positive temperatures, asphalt concrete has the properties of a viscous-plastic material, and at negative-elastic one. When the temperature changes, the structural and rheological characteristics of the bitumen binder in asphalt concrete also change. The surface temperature of asphalt concrete is calculated according to Eq. (1), (2) and (3), the results of calculating are shown in figures 2 and 3.

![Figure 1. The operation scheme of the installation: 1 – air supply using a compressor; 2 – temperature control of the sample; 3 – toxic gas emission; 4 – circulation and mixing of toxic gases with the air in a vessel; 5 – sampling for analysis.](image)

![Figure 2. Comparison the minimum temperature of the pavement.](image)
Figure 3. Comparison the maximum temperature of the pavement.

From the results of calculating the surface temperature of asphalt concrete, we can make the following conclusions: In a tropical climate, the surface temperature of asphalt concrete pavement in Vietnam can reach 56 °C, which leads to weakening of the coagulation structure of bitumen and entails the accumulation of residual deformations in the event of stresses exceeding the yield strength. The temperature of the asphalt concrete roadway surfacing topping changes within a great range during the day, which has a negative impact on physical and mechanical properties of asphalt concrete and transportation and performance characteristics of the road surface. The range of temperature fluctuations of asphalt concrete roadway surfacing is approximately proportional to the range of air temperatures, which confirms their relationship. It is especially important to study the changes in the temperature regime of the road surface on winter and summer days to select the composition of asphalt concrete for the climate of Vietnam.

3.2 Results of measuring the concentration of toxic gases in a volume

The results of the study of the effect of various emission neutralizers on the concentration of toxic gases are presented in table 1. Generally, the result of kinetic studying shows that with the addition of additives, there is a common decrease in the emission of hydrogen sulfide and sulfur dioxide.

| Neutralizer | Sulfur content, % | 15 | 30 | 45 | 60 | 15 | 30 | 45 | 60 |
|-------------|------------------|----|----|----|----|----|----|----|----|
|             |                  | SO₂, mg/m³ | H₂S, mg/m³ |
| Zn          | 10               | 3.4 | 5.6 | 5.2 | 3.9 | 1.1 | 2.2 | 2.9 | 3.5 |
|             | 1.2              | 1.2 | 1.1 | 1.2 | 1.3 | 1.1 | 1.1 | 1.1 | 1.0 |
|             | 20               | 5.5 | 9.1 | 8.8 | 7.5 | 1.8 | 3.8 | 5.1 | 5.9 |
|             | 1.2              | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 |
|             | 30               | 7.6 | 12.1| 11.7| 10.3| 2.7 | 5   | 6.4 | 7.2 |
|             | 1.1              | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 |
The analysis of the results of table 1 shows that the emission of toxic gases most effectively decreases with the introduction of MnO$_2$ and CuO in an amount of 10% by weight of sulfur. When using MnO$_2$ with a sulfur concentration of 10%, the concentration of sulfur dioxide and hydrogen sulfide decreases by 8.4 and 7 times, and with a sulfur concentration of 30%, the concentration of sulfur dioxide and hydrogen sulfide decreases by 12.1 and 6.4 times, respectively, after 15 minutes interactions. After 60 minutes of interaction, the efficiency of reducing the H$_2$S emission practically does not change, and SO$_2$ decreases to 2.5 and 5 times with a sulfur concentration of 10% and 30%, respectively.

Zn and ZnO are the most ineffective neutralizers. When using Zn with a sulfur concentration of 10%, the concentration of sulfur dioxide and hydrogen sulfide is reduced by 1.2 and 1.3 times, and with a sulfur concentration of 30%, the concentration of sulfur dioxide and hydrogen sulfide is reduced by 1.1 and 1.2 times, respectively, after 15 minutes interactions. After 60 minutes of interaction, the effectiveness of reducing toxic gas emissions remains virtually unchanged. The use of ZnO leads to an increase in the release of toxic gases from the sulfur-bitumen mixture.

The use of CaCO$_3$.MgCO$_3$ and SiO$_2$ significantly reduces the emission of toxic gases, is a promising material for the additional neutralization of hydrogen sulfide and sulfur dioxide, due to the cost.

4 Discussion and conclusion

According to the results of calculating the determination of the temperature of the surface of asphalt concrete from the ambient temperature (Kovalev Yu.N. method), the following conclusion can be made:
the surface temperature of the asphalt concrete coating can differ from ambient temperature in the winter period by up to 30%, and in the summer up to 50%, on the surface asphalt concrete pavement in Vietnam can reach 50-70 °C in summer, which negatively affects the physical and mechanical properties of asphalt concrete, transport and performance characteristics of the road surface. Operation of asphalt concrete at this temperature leads to the formation of defects on the road surface. A promising direction for solving this problem is the use of sulfur as a component of the asphalt mix.

The kinetics analysis of hydrogen sulfide and sulfur dioxide gas emission in the presence of neutralizers shows that with the introduction of additives, a general decrease in the emission of these gases is observed. The most effective emission of toxic gases is reduced with the introduction of CuO and MnO$_2$, the use of SiO$_2$ powder and CaCO$_3$, MgCO$_3$ powder is also effective. Zinc and zinc oxide powder has low neutralization efficiency. The application of neutralizers, which are capable of chemical interaction with hydrogen sulfide and sulfur dioxide providing the formation of sparingly soluble or insoluble compounds, allows us to solve the environmental problem in using sulfur-asphalt concrete.

Fulfillment of these requirements ensures the production of asphalt mixtures with an additive of sulfur modifier that meet sanitary and hygienic safety requirements, significantly expanding the volume of application of sulfur-extended asphalt concrete as well as increasing the quality and life of roads in Vietnam.

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