Experimental evaluation of reclaimed asphalt with foamed bitumen strength

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Abstract. The results of laboratory studies of strength and water resistance indicators of asphalt treated with different amounts of added foamed bitumen by using cylindrical specimens for indirect tensile strength test are presented. It has been experimentally established that the fulfillment of the minimum requirements for material of class 1 is observed with the addition of foamed bitumen of at least 2.2%.

1. Introduction
When pavements repairing by the cold recycling method, the asphalt granular material is obtained as a result of an old asphalt layers processing [1-3]. Various binders are added to the processed layer of bitumen-containing material to increase its strength and rigidity [4-9]. A feature of this technology is the possibility of using of wastes production as part of a recycled mixture [10-11]. To improve the adhesion of the binder to the stone material the foamed bitumen technologies are used in the road construction practice. This makes it possible to reduce the consumption of bitumen, mixing time and construction costs [12-17]. The asphalt granule material obtained as a result of processing is used for intermediate base layers construction. In accordance with PNST 265-2018 such layers can be classified as half-rigid monolithic pavement bases. Their main performance indicators are strength, shear resistance, crack and water resistance. It is required to make indirect tensile strength test with series of samples in a dry, wet and water-saturateted state, to assess these indicators in accordance with GOST 58401.18-2019.

It should be understood that the stress-strain state of a cylindrical specimen when indirect tensile strength test is not quite adequate to the state of elasto-viscoplastic asphalt material in the pavement, but it sufficiently allows one to assess the strength characteristics of bitumen materials when bending.

2. Experimental technique
The indirect tensile strength test in accordance with GOST 58401.18-2019 is used when determining the strength and water resistance of asphalt concrete material. This practice is widespread abroad as well. For example, in the South African Academy of Asphalt Concrete TG2 «A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials» 2009 describes the procedure for testing cylindrical samples of reclaimed asphalt with foamed bitumen to determine Indirect Tensile Strength. According to this document the German Wirtgen company has developed its own manual on cold recycling technology.

Experimental studies of reclaimed asphalt with foamed bitumen were carried out in accordance with the recommendations of Wirtgen and the TG2 technical manual. Four types of asphalt-granular...
mixture compositions were prepared preliminarily with different amounts of added foamed bitumen: 1.9; 2.1; 2.3 and 2.5%. Six cylindrical samples with a diameter of 100 mm and a height of 63.5 mm were made from each composition of the mixture and compacted using the modified Marshall method. Three samples from each batch were stored for 72 hours in the open air at a temperature of 25° C for subsequent indirect tensile strength test in a dry state \( ITS_{DRY} \). The remaining three samples from each batch were soaked in water for 24 hours also at 25° C for the indirect tensile strength test in a wet state \( ITS_{WET} \). The test was carried out to determine the breaking load applied along the diametral plane of the specimen at a constant speed of 50.8 mm / min at a temperature of 25 ° C. The cylindrical sample was placed in the clamp of the test device shown in figure 1.

![Figure 1](image.png)

**Figure 1.** General form of the installation with a sample for the indirect tensile strength test

The ultimate indirect tensile strength for each sample regardless of the type of curing is calculated with an accuracy of 1 kPa using the formula

\[
ITS = \frac{2P}{\pi dh} \times 10^6
\]

where \( P \) is breaking load, kN, \( h \) is specimen height, mm, \( d \) is specimen diameter, mm.

Tensile strength retained \( TSR, \% \), is determined by the formula

\[
TSR = \frac{ITS_{WET}}{ITS_{DRY}} \times 10^2
\]

In Russian regulatory documents (GOST 58401.18-2019) it is undimensional characteristic called the water resistance ratio.

In formulas (1) and (2) the average values of the tensile strengths are used. They are calculated as the arithmetic mean of the results of three tests of samples in a batch. The residual tensile strength TSR is then determined. It is used for the initial assessment of the quality of the mixture in terms of the need to add an active aggregate. If the TSR value for the first mixture without the addition of
active aggregate exceeds 60% it is not required to add it to the mixture. This usually happens with materials containing high quality crushed stone, often containing a significant proportion of reclaimed asphalt concrete.

If the TSR value for a mixture without the addition of an active aggregate is less than 60%, then it is necessary to switch to mixtures with an active aggregate. Preference is given to cement or slaked lime depending on the TSR value which increases significantly with their use (usually the TSR increases by more than 10% compared to that of the first batch). When the TSR values for these two active aggregates are approximately the same (less than 5% difference), either of them is suitable. In this case cement is preferred as the most technologically advanced material.

For the final decision on the exact dosage of foamed bitumen it is necessary to plot the results obtained on a graph of the dependence of the ITS tests results for wet and dry samples respectively on the corresponding additives of foamed bitumen.

3. Results. Discussion
The obtained test results of cylinder specimens with a diameter of 100 mm from reclaimed asphalt treated with foamed bitumen are presented in Table 1 and Figure 2.

Table 1. Dependence of the ultimate strength on the addition of foamed bitumen on samples-cylinders with a diameter of 100 mm.

| Bitumen consumption, % | ITS\(_{\text{DRY}}\), kPa | ITS\(_{\text{WET}}\), kPa | TSR, % |
|------------------------|---------------------------|-------------------------|--------|
| 1.9                    | 185                       | 85                      | 45.9   |
| 2.1                    | 205                       | 110                     | 53.7   |
| 2.3                    | 265                       | 155                     | 58.5   |
| 2.5                    | 250                       | 170                     | 68.0   |

Figure 2. Graphical dependence of strength on the addition of foamed bitumen on samples-cylinders with a diameter of 100 mm

Foamed bitumen addition intervals related to the minimum ITS value for the required material classification are selected as the primary indicator of the minimum permissible bitumen addition. An engineering assessment is then used to determine the amount of foamed bitumen required for the additive in order to increase confidence in the results. This additive is determined by taking into account the fluctuation in test results according to the regression curve or line passing through the test results points on the graph. The curves passing through the four points of the tensile strengths in dry
and wet conditions, respectively, reflect the relationship between these values and the addition of foamed bitumen. Thin solid lines indicate that an addition of 2.0 to 2.2% foamed bitumen will meet the requirements for a high shear strength material (class 1) suitable for use as a base of pavement in severe traffic conditions (more than 3 million applications of axial load of 10 tons according to GOST 58406.2-2020). The minimum value of the indirect tensile strength in the wet state must be at least 100 kPa, and in the dry state at least 225 kPa. For a medium shear strength material (class 2) suitable for use in a base of pavement with a capacity of less than 3 million design load applications, the minimum value of the indirect tensile strength in the wet state should be in the range of 50-100 kPa, and in the dry state - from 125 to 225 kPa.

It can be seen from the values of the residual tensile strength TSR that after treatment with a small amount of foamed bitumen, the water resistance of the material remains insufficient, especially with a proportion below 2.1%, since the TSR is less than 50%. It is therefore important to ensure that there is sufficient bitumen to achieve the minimum ITS\textsubscript{WET} required for class 1. Engineering decisions are then made based on the understanding that the values obtained from the ITS tests are not absolute and their variability is expected when it comes to recycled material from existing pavement. The results obtained for the mixture with 2.1% foamed bitumen additive do not meet the class 1 requirements for ITS\textsubscript{DRY} values, while the ITS\textsubscript{DRY} and ITS\textsubscript{WET} values for the mixture with 2.3% additive exceed the minimum requirements of this class. It means that the foamed bitumen addition should not be less than 2.2%.

The additional tests were carried out on samples with a diameter of 150 mm and a height of 127 mm to increase the reliability of the results. The samples were made of reclaimed asphalt mixture with the amount of added foamed bitumen: 2.0; 2.1; 2.2 and 2.3%. Proctor compaction was used for making samples. Before testing these samples were cured to achieve equilibrium moisture content. The indirect tensile strength in the equilibrium moisture state ITS\textsubscript{EQUIL} was determined as a result of the tests. Equilibrium humidity compensates for the suction forces that increase the ITS\textsubscript{DRY} values with a corresponding decrease in the TSR values. The remaining three samples from each batch were soaked in water for 24 hours also at a temperature of 25\degree C for indirect tensile strength test in a water-saturated state ITS\textsubscript{SOAK}.

The data presented in table 2 and the graphs in figure 3 show typical results achieved under the respective minimum limits for ITS\textsubscript{EQUIL} and ITS\textsubscript{SOAK} required for class 1 material stabilized with foamed bitumen (ITS\textsubscript{EQUIL} > 175 kPa and ITS\textsubscript{SOAK} > 100 kPa).

Table 2. Dependence of strength on the addition of foamed bitumen on samples-cylinders with a diameter of 150 mm.

| Bitumen addition, % | ITS\textsubscript{EQUIL}, kPa | ITS\textsubscript{SOAK}, kPa | TSR, % |
|---------------------|-------------------------|-------------------------|--------|
| 2.0                 | 200                     | 90                      | 45.0   |
| 2.1                 | 210                     | 130                     | 61.9   |
| 2.2                 | 205                     | 150                     | 73.2   |
| 2.3                 | 195                     | 145                     | 74.4   |
Figure 3. Graphical dependence of strength on the addition of foamed bitumen on specimen cylinders with a diameter of 150 mm

The test results clearly show that on samples-cylinders with a diameter of 150 mm the strength in the water-saturated state $\text{ITS}_{\text{SOAK}}$ with the introduction of 2.0% foamed bitumen does not reach the minimum required values for class 1 (not less than 100 kPa). With introduction of 2.1% foamed bitumen the both indicators are met required for material of class 1 when testing samples with a diameter of 150 mm ($\text{ITS}_{\text{EQUIL}}$ not less than 175 kPa and $\text{ITS}_{\text{SOAK}}$ not less than 100 kPa). However, on samples 100 mm in size a positive result was achieved with 2.2% foamed bitumen.

4. Conclusion
Analyzing the results of the tests carried out, it can be concluded that only the addition of at least 2.2% foamed bitumen mass gives a high level of confidence in the guaranteed fulfillment of the minimum requirements for class 1 material stabilized with foamed bitumen.

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