Sealing materials effectiveness evaluation in the repair of bituminous-concrete surface with transversal cracks

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The method of密封材料有效性评估在修复沥青混凝土表面与横向裂缝的关系。计算方案和数学模型基于应用的热粘弹性理论的预测温度应力在密封材料与沥青混凝土表面的接触处的沥青混凝土表面，考虑到材料的热-技术特性和热-流变学性质以及材料的热-技术参数和沥青混凝土表面的横向裂缝。所获得的分析性依赖性允许估算服务寿命之前密封化合物的完整性或其与沥青混凝土表面的粘附强度的粘附，考虑到年度和每日温度波动根据主要提供的惯性理论固体身体耐久性。

Keywords: bituminous-concrete surface, temperature transversal cracks, sealing materials, thermo-stressed state
**Introduction**

Bituminous concrete is the most common surface material on both public and communal streets and roads with non-rigid pavement. This has several advantages: component availability, manufacturing and application adaptability, a wide variety of modifications, directional properties control, high weather resistance, strength and durability, etc. However, despite the large number of studies and practical measures developed to prevent and avoid transversal temperature cracks, these types of destruction still remain one of the most common defects in bituminous-concrete surface. These transversal cracks of thermal-shrinkage origin are formed with a certain step over the length as a result of both seasonal and daily temperature fluctuations. During operation, new transversal temperature cracks are formed and the distance between them decreases from tens to several meters. Their appearance has many negative consequences. In the zone of cracks, as a result of a significant decrease in the bearing capacity of the surface layers, there is an overstress of the base layers and soil of the earth bed. Water enters them through cracks and significantly reduces their strength (including through salinity at the ingress of ice-melting substances). This leads to the acceleration of the appearance of destruction various types under the influence of traffic loads and climatic factors as the bituminous-concrete surface itself and road pavement as a whole. Therefore, in the zone of cracks spills, chipping, dimples, potholes, subsidence, cracking, wheel tracking are often formed. In this regard, the appearance of transverse temperature cracks leads to early failure of road pavement and reduces its working life.

**Definition of unsolved aspects of the problem**

In the current practice, to ensure the water impermeability of the bituminous-concrete surface and to reduce its negative effects on the strength and durability of the entire structure of road pavement, they realize sealing of temperature transversal cracks with the help of various sealants. Therefore, in this case, it is necessary to be able to evaluate the effectiveness of sealing materials in the repair of bituminous-concrete with transversal cracks. Their work effectiveness will depend on the adhesive strength at the contact "sealant – bituminous – concrete surface" and ensuring the sealing material integrity during the operation. The most influential factor in this situation is the sealing material deformation when the temperature decreases as it changes during seasonal and daily fluctuations.

**Basic material and results**

As it was previously shown in many studies [1], transversal temperature cracks on bituminous-concrete surface of non-rigid road pavement appear as a result of the influence of the following factors: tensile thermal stresses at temperature decreases as a result of casual pavement reduction in the longitudinal direction due to the friction force between the surface and the base. In this case, the design diagram (Fig. 1) presents a single-layer slab resting on the base which does not transmit its sensible deformations.

\[
E \Delta T, \quad (1)
\]

where \(\alpha\) is the linear temperature expansion coefficient of bituminous concrete; \(E\) – bituminous-concrete elasticity modulus; \(\Delta T\) – temperature gradient.

It is known that after a certain period of operation (1-5 years), transversal temperature cracks are formed on the bituminous – concrete surface due to the repeated influence of thermal stresses caused by the above-mentioned factors, as a result of temperature reductions during its fluctuations. After the formation of transversal temperature cracks, the operating conditions of the bituminous- concrete surface change. Depending on the distance of the transversal crack, the formed slabs of the pavement may be partially reduced, overcoming the friction resistance of the coating on the base, and the width of the cracks may increase with decreasing temperature. Therefore, the design diagram after the formation of transversal temperature cracks can be presented in the form shown in Figure 2.

\[f(T)\]

**Figure 1 Design diagram of operation of bituminous-concrete surface at temperature change on the base, which does not cause additional horizontal normal stresses in the surface:**

1 – surface; 2 – base.

In order to seal the transversal temperature cracks in the bituminous- concrete surface, it is necessary to make a choice of material and technology, depending on the geometrical parameters of the surface and the crack and the properties of the bituminous concrete and sealing materials. To evaluate their effectiveness,
it is necessary to consider the design diagram of the work of these materials in the surface with transversal cracks (Figure 3).

![Design diagram of bituminous concrete operation after sealing the transversal temperature crack](image)

**Figure 3 – Design diagram of bituminous concrete operation after sealing the transversal temperature crack:**
1 – bituminous-concrete surface; 2 – base; 3 – material for repair of cracks; 4 – communication scheme with surface adjacent areas; 5 – the same with the underlying layers of the pavement structure, which ensures horizontal movement through friction.

At the time of the transversal cracks sealing, their width is \( \delta \) in bituminous concrete surface 1 between blocks of initial length \( l_{bl} \). Then lowering the temperature will reduce the pavement units to the size \( l'_{bl} \). With full adhesion of the material 3 with surface 1, it will stretch to width \( \delta' \). In this case, the thermal tensile stresses \( \sigma_T \) in the sealing material, as well as on the contact with the bituminous – concrete surface, will consist of two components: the intrinsic temperature stresses due to the impossibility to reduce the dimensions \( \sigma_{T1} \) and the stresses due to the reduction of adjacent surface units \( \sigma_{T2} \):

\[
\sigma_{T1} = \alpha_1 E_1 A_T ;
\]

\[
\sigma_{T2} = E_1 \Delta \delta T (t) \left( \frac{\Delta \delta (T(t))}{\delta (T_0)} \right).
\]

Then after the corresponding transformations we get

\[
\sigma_T = E_1 \alpha_1 A_T \left( 1 + \frac{\alpha_2}{\alpha_1} \frac{l_{bl}}{\delta} \right),
\]

where \( \alpha_1, \alpha_2 \) are the coefficients of linear expansion, respectively, of materials 3 and 2.

The obtained dependence (3) allows to determine the level of thermal stress state of the mastic and adhesive contact, depending on the characteristics of mastic and bituminous concrete, as well as the initial size of the surface units and the width of the transversal cracks at the time of their filling with mastic.

Existing sealing materials and asphalt concrete bituminous – concrete surface are characterized by apparent thermo-viscous-elastic properties, which depend on both temperature and time, and the of stress change behavior, and such materials show kinetic fracture [1, 2].

Based on the fundamental provisions of the thermal elasticity theory, the temperature stresses that occur in the sealing material 3 (Figure 3) can be determined by the dependencies:

\[
\sigma_T(t, T) = \frac{1}{0} R(\xi(t) - \xi(t)) d\varepsilon_T(t) ,
\]

where

\[
\xi(t) = \frac{1}{0} \frac{dt}{a_T(T(t), Q)}
\]

\[
\xi(t) = \frac{1}{0} \frac{d\tau}{a_T(T(t), Q)}
\]

where \( R(t) \) is the relaxation function of the sealing material;

\( \varepsilon_T \) – relative thermal strain;

\( t \): the time at which the stress is determined;

\( \tau \): the instant of time preceding \( t \);

\( \xi \) is the time given on the basis of the principle of temperature-time analogy (PTA) to the temperature \( Q \) at which the parameters of the relaxation function \( R(t) \) are experimentally determined;

\( a_T \) – the PTA function.

The relaxation function of a sealing material can be written in the form of a modified power law [1, 3]:

\[
R(t) = H + (B - H)(1 + t / r)^{-m} ,
\]

where \( m \) and \( r \) are constants determined from the experiment on relaxation;

\( H \) and \( B \) are long-term and instantaneous elasticity modules, respectively. The PTA function can be described by an expression

\[
a_T(T, Q) = e^{-m(T - Q)} ,
\]

where \( m \) is a constant, determined experimentally.

Based on the design diagram (Figure 3), the values for \( \varepsilon_T(t) \) can be written as

\[
\varepsilon_T = \alpha_1 \cdot (T_0 - T(t)) \left( 1 + \frac{\alpha_2}{\alpha_1} \frac{l_{bl}}{\delta} \right),
\]

where \( T_0 - T(t) = \Delta T \).

Taking into account the harmonic change of temperature \( T(t) \) according to [1], the annual and daily fluctuations of the average surface thickness, temperature can be written in the following form

\[
T(t) = T_{cp} + \mathcal{A}_r \cos \frac{2\pi}{t_c} + \mathcal{A}_r \cos \frac{2\pi}{t_r} ,
\]

where \( T_{cp} \) is the surface average annual thickness; \( \mathcal{A}_r, \mathcal{A}_r \) and \( t_c, t_r \) are respectively the amplitude and the fluctuation period of the surface temperature averaged thickness in the daily and annual cycles.

The amplitude of the fluctuations averaged over the thickness of the surface temperature (\( \mathcal{A}_r \) or \( \mathcal{A}_r \)) can be considered approximately equal to the average thickness of the amplitude of the temperature fluctuations at different depths.

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where $\alpha$ is the coefficient of thermal conductivity of the surface material; $t_a$ is the period of temperature fluctuation.

On the basis of the above-mentioned expressions, it is possible to predict temperature stresses at any time $t$. However, since the strength characteristics also depend on the temperature and the time of the load, showing the kinetic nature of the cracks, it is necessary to determine the durability of the sealing materials and the condition of the limit state. Having the solution to determine the temperature stresses in the surface, the strength conditions and the expression for the durability function, it is possible to calculate the thermal crack strength index $M_{\text{mp}}$ by the end of the service life $t_a$:

$$M_{\text{mp}} = \frac{t_a}{t_a} \int_0^{t_a} \frac{\sigma(t,T)}{B(t,T)} dt.$$  \hspace{1cm} (10)

Taking into account the expression (10), it is possible to check the fulfillment of the condition in which it is required that the crack strength $M_{\text{mp}}$ does not exceed its admissible value, that is, to evaluate the condition for providing thermal crack strength $C_{\text{mp}}$:

$$M_{\text{mp}} \leq C_{\text{mp}}.$$  \hspace{1cm} (11)

In this case, based on the known results of the studies $C_{\text{mp}}$ equals the limit value of the damage degree to the $C_H$, i.e. $C_{\text{mp}} = C_H = 1$ [4-6].

Conclusions

The results of the research allow us to draw the following conclusions.

1. Design diagrams and mathematical models based on the application of the thermo-viscous-elasticity theory for the prediction of thermal stresses in the sealing material at the contact with the bituminous – concrete surface, taking into account the properties of the materials and geometrical parameters of the bituminous – concrete surface slabs and transversal cracks are worked out.

2. The obtained analytical dependences allow to estimate the service life before the loss of sealant integrity or the adhesive strength of their adhesion with the bituminous – concrete surface, taking into account the annual and daily temperature fluctuations on the basis of the kinetic theory main provisions of the strength of solids.

3. The method of efficiency of sealing materials evaluation in repair of bituminous – concrete surface with transversal cracks taking into account thickness and sizes of bituminous – concrete slabs between transversal temperature cracks, sizes of these cracks, thermostechnical and thermorheological properties of sealing materials and bituminous – concrete is offerred.

References

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