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

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The method of sealing materials effectiveness evaluation in the repair of bituminous-concrete surface with transversal cracks is offered. Calculation schemes and mathematical models based on the application of the thermo-viscous-elasticity theory for the prediction of temperature stresses in the sealing material at the contact with the bituminous-concrete surface, taking into account the thermal-technical and thermorheological properties of the materials and the geometric parameters of the bituminous-concrete slabs and the transversal crack. The obtained analytical dependences allow to estimate the service life before the loss of sealant compound integrity or adhesive strength of their adhesion with bituminous-concrete surface taking into account annual and daily temperature fluctuations according to the main provisions of the kinetic theory of solid bodies strength.

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

Оцінювання ефективності герметизуючих матеріалів при ремонті асфальтобетонного покриття з поперечними тріщинами

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Проведено аналіз негативних наслідків від утворенням температурних поперечних тріщин у асфальтобетонному покритті для конструкції дорожнього одягу. Показано, що поперечні тріщини призводять до потрапляння води з атмосферних опадів у конструкцію дорожнього одягу та ґрунт земляного полотна, викликаючи ослаблення в зоні тріщин основи і спричиняючи прискореному руйнуванню всієї конструкції дорожнього одягу. ці обставини потребують забезпечення ефективної герметизації покриття з поперечними тріщинами. Відмічено, що найбільш поширений метод ремонту асфальтобетонного покриття з поперечними температурними тріщинами полягає у застосуванні герметизуючих матеріалів, якими заповнюють порожнини цих тріщин. Зазначено, що умови роботи герметизуючих матеріалів залежать як від геометричних параметрів асфальтобетонних плит між тріщинами, так і від розмірів тріщин, що заповнюються герметиком. Запропоновано метод оцінювання ефективності герметизуючих матеріалів при ремонті асфальтобетонного покриття конструкції дорожнього одягу з поперечними тріщинами. Розроблено розрахункові схеми роботи асфальтобетонного покриття та математичні моделі на основі застосування теорії термо-в’язко пружності для прогнозування температурних напружень в герметизуючому матеріалі на контакті з асфальтобетонним покриттям з урахуванням тепло-технічних та термо-реологічних властивостей матеріалів і геометричних параметрів асфальтобетонних плит та поперечної тріщини. Отримано аналітичні залежності дозволяють оцінювати термін служби до втрати суцільності герметиків або адгезійної міцності їх зчеплення з асфальтобетонним покриттям з урахуванням річних та добових коливань температури на базі використання основних положень кінетичної теорії міцності твердих тіл. Використання запропонованого методу потребує експериментального встановлення таких характеристик матеріалів як: коефіцієнта лінійного температурного розширення, коефіцієнта температуропровідності, функції повзучості, функції релаксації, функції температурно-часової аналогії, функції довготривалої міцності.

Ключові слова: асфальтобетонне покриття, температурна поперечна тріщина, герметизуючий матеріал, термонапружений стан

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 spalls, 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.

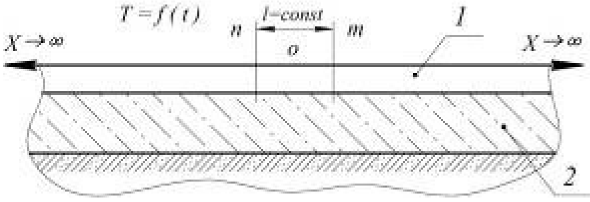

Figure 1 Design diagram of operation of bituminous-concrete surface at temperature change on the base, which does not cause additional horizontal normal stresses in the surface:
1 – surface; 2 – base.

In the first approximation in the elastic formulation of a one-dimensional problem for this design scheme, the thermal tensile stresses when it is impossible to freely reduce the longitudinal direction surface can be determined by the formula

$$\sigma_T(t) = \alpha E \Delta T, \tag{1}$$

where α is the linear temperature expansion coefficient of bituminous concrete;
E – bituminous-concrete elasticity modulus;
ΔT – 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.

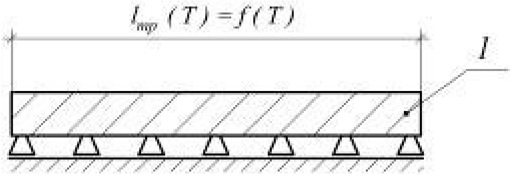

Figure 2 – Design diagram of bituminous-concrete surface operation after the formation of temperature transversal cracks

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).

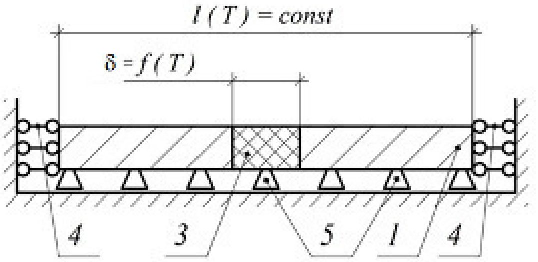

Figure 3 – Design diagram of bituminous concrete operation after sealing the transversal temperature crack:
1 – bituminous-concrete surface; 2 – base;
3 – material for repair of cracks;
4 – communication scheme with surface adjacent areas;
5 – the same with the underlying layers of the pavement structure,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

At the time of the transversal cracks sealing, their width is δ 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 δ'. In this case, the thermal tensile stresses σ_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 σ_{T1} and the stresses due to the reduction of adjacent surface units σ_{T2}:

$$\sigma_{T1} = \alpha_1 E_1 \Delta T ;$$
$$\sigma_{T2} = E_1 \cdot \frac{\Delta\delta(T(t))}{\delta(T_0)} . \qquad (2)$$

Then after the corresponding transformations we get

$$\sigma_T = E_1 \cdot \alpha_1 \cdot \Delta T \cdot \left(1 + \frac{\alpha_2}{\alpha_1} \cdot \frac{l_{bl}}{\delta}\right), \qquad (3)$$

where α_1, α_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 apparant 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:

$$\sigma_T(t,T) = \int_0^t R\big(\xi(t) - \xi(\tau)\big) d\varepsilon_T(\tau) \ , \qquad (4)$$

here

$$\xi(t) = \int_0^t \frac{dt}{a_T(T(t),Q)} \ ;$$

$$\xi(\tau) = \int_0^t \frac{d\tau}{a_T(T(t),Q)} \ ,$$

where $R\ (t)$ is the relaxation function of the sealing material;
ε_T – relative thermal strain;
t is the time at which the stress is determined;
τ is the instant of time preceding t;
ξ 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]:

$$R(t) = H + (B - H)(1 + t/r)^{-m} , \qquad (5)$$

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

$$a_T(T,Q) = e^{-p(T-Q)} , \qquad (6)$$

where p is a constant, determined experimentally.

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

$$\varepsilon_T = \alpha_1 \cdot (T_0 - T(t)) \cdot \left(1 + \frac{\alpha_2}{\alpha_2} \cdot \frac{l_{бл}}{\delta}\right), \qquad (7)$$

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

$$T(t) = T_{cp} + \overline{A}_c \cos\frac{2\pi}{t_c} + \overline{A}_r \cos\frac{2\pi}{t_r} t \ , \qquad (8)$$

where T_{cp} is the surface average annual thickness;
$\overline{A}_c$, $\overline{A}_r$ 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 ($\overline{A}_c$ or $\overline{A}_r$) can be considered approximately equal to the average thickness of the amplitude of the temperature fluctuations at different depths

$$\overline{A} \approx \frac{1}{h}\int_0^h A(z)dz = \frac{A(z=0)}{h\sqrt{\pi / t_n a}}(1-e^{-h\sqrt{\pi / t_n a}}), \qquad (9)$$

where a is the coefficient of thermal conductivity of the surface material;

t_n 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_{mp} by the end of the service life $t_{сл}$

$$M_{mp} = \int_0^{t_{сл}} \frac{\sigma_T(t)^{b_\tau(t,T)}}{B_\tau(t,T)}dt. \qquad (10)$$

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_{mp} does not exceed its admissible value, that is, to evaluate the condition for providing thermal crack strength C_{mp}

$$M_{mp} \le C_{mp}. \qquad (11)$$

In this case, based on the known results of the studies C_{mp} equals the limit value of the damage degree to the C_H, i.e. $C_{mp} = C_H = 1$ [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 crack 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, thermotechnical and thermorheological properties of sealing materials and bituminous – concrete is offered.

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