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PREDICTING THE DURABILITY OF EXTRUDED FOAM POLYSTYRENE IN ROAD STRUCTURES

Statement of the problem. It is possible to improve working conditions of road pavement and to use it more efficiently by regulating water-thermal conditions of the subgrade thereby reducing humidity in the design period and mitigating its seasonal changes.

Results and conclusions. It is suggested to use extruded foam polystyrene as a heating layer. The thermal fluctuation approach was applied to failure and deformation processes. Physical constants for the analytical description of these processes at varying temperatures and stresses are calculated. The technique for determining acting stresses and temperatures was described. The prediction of the durability of extruded foam polystyrene in road structure is presented.

Keywords: water and thermal conditions, extruded foam polystyrene, thermal fluctuation theory of solid strength, durability prediction.

Introduction

Increasing the service life and promoting basic operational features of constructed and reconstructed roads are the problems faced by the road construction industry. It is known that road pavement is a multi-layer structure consisting of layers with varying physical and mechanical characteristics. The durability of the overall structure is therefore determined by the strength of the weakest layer.

The road pavement strength is largely due to the subgrade strength which undergoes seasonal changes with minimums at the high humidity periods (spring and autumn). Humidity and strength of the subgrade experience not only seasonal but also long-term changes. At some point they reach their critical point which is used to calculate the road pavement thickness. The road pavement thickness is calculated according to the most deteriorated condition of the subgrade which is evaluated using the design humidity and design values of the deformation modulus or the subgrade elasticity that are dependent on them.

The operation of road pavement and a more rational use of its strength can be attained by regulating the water and heat mode of the subgrade and thereby reducing humidity in the design period and mitigating seasonal changes.

There is an intrinsic link between the subgrade strength and humidity. By reducing the subgrade humidity through a range of technology and construction activities one can enhance the subgrade strength, decrease the thickness of the road pavement and dramatically cut down its cost.

As an example [1] we have the data on the dependence between the relative humidity and hard loamy soil, the deformation modulus of the subgrade and pavement thickness of a Category II road ($E_{mp} = 600$ kg/cm^2). Therefore, the deformation modulus is 350 kg/cm^2 at the relative humidity of 0.5 %, the thickness is 10 cm and 50 kg/cm^2 and 100 cm at 0.95 % respectively.

The use of foam polystyrene panels as heat insulating layers provides a better water and heat mode of the subgrade and by reducing the design value is helpful in increasing the subgrade modulus and decreasing the road pavement thickness.

1. Behavior of extruded foam polystyrene in bending and compression

Fig. 1 illustrates an efficient use of extruded foam polystyrene in the road pavement structure for a Category III road designed to operate under most deteriorating conditions of Tambov region (Type 3 of the area according to humidity conditions, at the base is the third heaving subgrade (light loamy soil). The road pavement structure is designed in compliance with the requirements [2, 3].

The optimal laying depth of the heating layer should be determined by the acting pressure values, temperature and durability (service life) respectively of the material.

However, the problem of studying the durability of extruded foam polystyrene has not been researched into extensively. The papers [4, 5] point out the likelihood of the foam polystyrene durability being studied from the standpoint of the thermal fluctuation theory of strength.

1. Viscous bituminous БНД compressed hot type A asphalt concrete, 60/90	9 cm
2. Hot porous fine aggregate bituminous concrete БНД, 60/90	16 cm
3. Crushed stone-gravel-sand mixture treated with a non-organix binder graded 40	20 cm
4. Fine sand containing a loamy fraction 5 %	30 cm
5. Sand trasnport panels ТЕХНОПЛЕКС 45	4 cm
6. Light loamy soil	

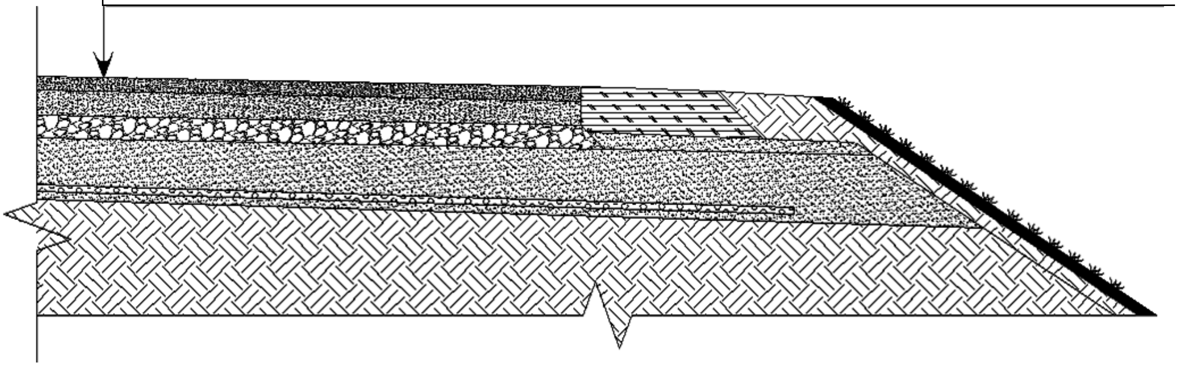

Fig. 1. Road pavement structure with the use of extruded foam polystyrene ТЕХНОПЛЕКС® 45 for a Category III road

An extruded foam polystyrene ТЕХНОПЛЕКС®45 was selected for the research. Since the subbase material is subjected to bending and compression, a method of bending and compression testing over a range of temperatures detailed in [5] was used to evaluate the durability of extruded foam polystyrene ТЕХНОПЛЕКС®45. Using the resulting data dependencies were plotted as shown in Fig. 2, 3.

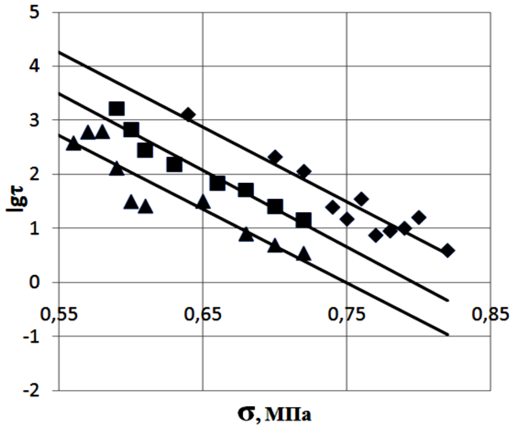

Fig. 2. Dependence of the durability logarithm τ on the stress σ and temperature *T* in bending of foam polystyrene ТЕХНОПЛЕКС®45: ◆ — 21 ^{0}C; ■ — 35 ^{0}C; ▲ — 50 ^{0}C

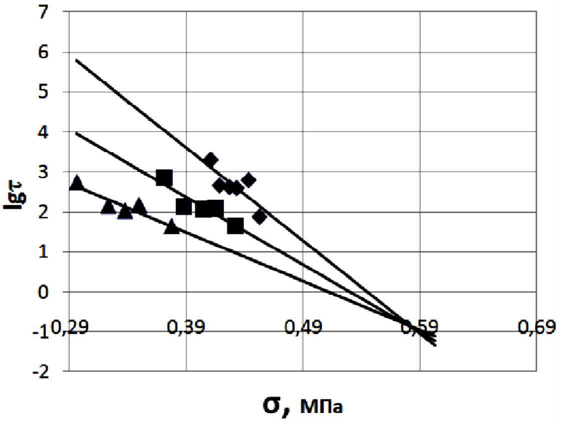

Fig. 3. Dependence of the durability logarithm τ on the stress *σ* and temperature *T* in compression of up to 10 % of the relative deformation of foam polystyrene ТЕХНОПЛЕКС®45: ◆ — 16 ^{0}C; ■ — 35 ^{0}C; ▲— 50 ^{0}C

The obtained dependencies in Fig. 2, 3 are described by the equations (1)—(2) according to [7]. The constants incorporated into these equations are defined by means of the method detailed in [5] and are identified in Table 1:

$$\tau = \tau_* \exp\frac{U}{RT}\exp(-\beta\sigma), \tag{1}$$

$$\tau = \tau_m \exp\left[\frac{U_0 - \gamma\sigma}{R}\left(\frac{1}{T} - \frac{1}{T_m}\right)\right], \tag{2}$$

where τ_m, U_0, U, γ, β, T_m are physical constants of the material: τ_m is a period of oscillation of kinetic units, U_0 is the activation energy, U is the effective activation energy, γ is the structure and mechanical factor, β is the analogy of the structure and mechanical constant, T_m is the specific temperature for the existence of the material; σ is the stress; T is the temperature; R is the universal gas constant; τ is the time prior to the failure (durability).

Table 1

Values of physical constants of extruded foam polystyrene ТЕХНОПЛЕКС®45 in bending and compression

Loading type	Constants			
	τ^*, τ_m, sec	T_m, K	U, U_0, kJ/mol	β, 1/MPa, γ, kJ/(mol·MPa)
Bending	2.9×10^{-10}	-	90.16	16
Compression of up to 10 %	$10^{-0.85}$	371.74	325	6500

It should be noted that in Fig. 4 there is a dependency between the durability and stress at 10 % of relative deformation of the material as “beyond critical zone” of deformation starts at over 10 % and according to [5] irreversible deformations therefore start building up.

Inserting the values of the constants identified in Table 1 into the Equations (1)—(2) and specifying the stress σ and temperature T, acting on the material, one can predict the service life (durability) of the material in different road pavement structures.

2. Determining a range of acting stresses and temperatures

The stress acting on the material is calculated using the method detailed in [8]. In this case, in order to calculate stress and strain of the subbase and pavement layers, a multi-layer structure with heterogeneous properties is converted into an equivalent homogeneous array. The equivalent thickness of the road pavement is given by the ratio:

$$z_э = z\sqrt[2,5]{\frac{E_{верх}}{E_{нижс}}}, \tag{3}$$

where z is the thickness of the pavement layer, $E_{верх}$, $E_{нижс}$ is the elasticity modulus of a higher and lower layers respectively.

The strain values can be calculated using the formula by M. I. Yakunin [8]:

$$\sigma_z = \frac{p_0}{1+(z_э/D)^2}, \tag{4}$$

where p_0 is the tire pressure on the pavement, $z_э$ is the equivalent thickness of the road pavement, D is the diameter of the circle as large as the contact patch.

Besides the interior load, the material is affected by its own weight and road pavement. An example of calculating the stress distribution is given in Fig. 4.

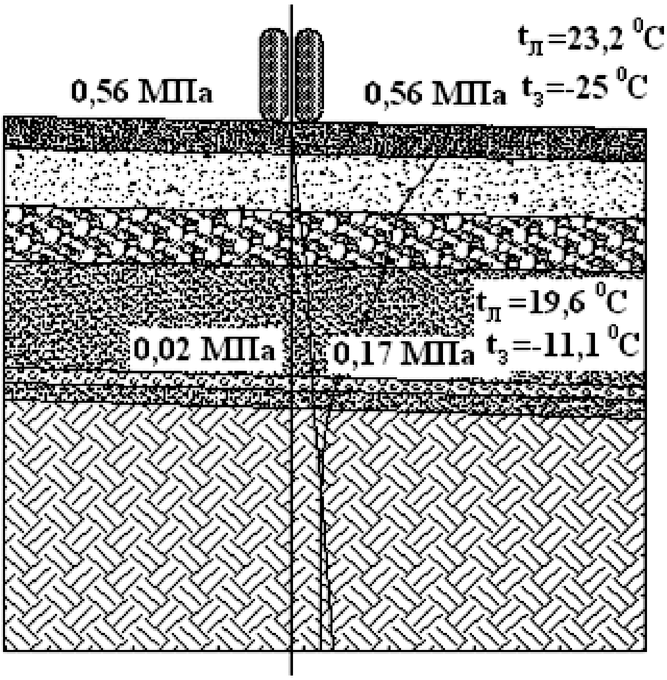

Fig. 4. Stress distribution under the weight of the subgrade and external loading. Temperature distribution on the surface of foam polystyrene panels ТЕХНОПЛЕКС®45

The method suggested in [9] allows one to determine the temperature in the subbase provided that the temperature of the subgrade is known as well. The equation for the temperature in any plane n of a road structure has the form:

$$t_{\text{п}} = t_{\text{в}} + \frac{t_{\text{г}} - t_{\text{в}}}{R}\left(R_{\text{п}} + \sum R_{\text{п}}\right), \tag{5}$$

where $\sum R_n$ is the total thermal resistance of the higher *n*-th layer; *R* is the thermal resistance of a road structure; $t_{\text{в}}$ is the air temperature; $t_{\text{г}}$ is the subgrade temperature; t_n is the temperature in the examined layer.

The subgrade temperature is determined by a certain likelihood of the climatic data on the region. The average annual temperature of the areas of the earth foundation is calculated according to the following formula [10]:

$$t_{\text{г}} = t_{\text{в}} + \frac{B - LE}{\alpha_k} + 0,07 A_M \sqrt{R_{\text{сн}}}, \tag{6}$$

where *B* is a radiation balance, kcal/m^2·month; *LE* is the heat flow rate on evaporation, kcal/m^2·months; A_M is the annual air temperature oscillation, degrees; $R_{\text{сн}}$ *is the* thermal resistance of snow, m^2·hour·degrees/kcal; α_k is the heat transfer coefficient, kcal/m^2·hour·degrees.

Using the above method we determined the temperature on the surface of foam polystyrene panels in the summer/winter operation periods (see Fig. 4). Considering the above from Table 2, we calculated the durability of an extruded foam polystyrene for a road structure identified in Fig. 1.

Table 2

Durability of the extruded foam polystyrene ТЕХНОПЛЕКС®45

Road category		Durability *τ*, sec	
		Bending	Compression
III	Summer	$10^{5.37}$	$10^{9.90}$
	Winter	$10^{7.25}$	$10^{15.47}$

Conclusions

1. The use of extruded foam polystyrene in road structures enables the enhancement of strength and durability of the subgrade structure due to the improvement in the water and heat mode of the subgrade and thus an increase in the subgrade modulus by reducing the design humidity of the soil.

2. The thermal fluctuation theory of strength was for the first time used to predict the durability of extruded foam polystyrene over a range of acting stresses and temperatures. Above all, using constants this approach allows for a more reliable prediction of long-term strength of the material from the physics standpoint.
3. The method for determining force and temperature factors acting on the material in the road pavement structure was described.

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