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ESTIMATION AND METHODS OF PREDICTION FOR THE STRUCTURAL AND MECHANICAL PROPERTIES OF RAP-COMPOSITES

Abstract. This article presents the study results of the processes of structure formation and analysis of the methodological evaluation features of strength and deformation properties of RAP-composites. New materials necessitate studying the peculiarities of their behavior in the temperature-time field in order to develop objective technical requirements for their physical and mechanical characteristics that allow them to provide the required values of strength and reliability.

The classical method of applying the temperature-time analogy is valid in the linear domain for the analysis of relaxation curves at low levels of deformation or creep curves at low stresses.This thesis does not allow this theory to be used for the analysis of strength properties and other characteristics associated with the process of destruction of the composite material.Concretes of composite structure containing thermodynamically incompatible binders have nonlinear viscoelasticity and are thermorheologicalycomplex.For composite materials a reduction factor (the amount of displacement curves along the time or deformation speed axis) depends not only on temperature but also material properties, and stress state.This is due to the peculiarities of the structure of composite materials as a system with a complex set of elastic and viscous bonds, and therefore the reduction coefficient depends on the number of elastic bonds involved in the deformation process.

The research is based on the principles of temperature-structural analogy, allowing predicting the properties of composites on organo-hydraulic binders. This makes possible directionally to design a cold mix and to determine the way of reaching a required materials property for construction of different layers of pavement.

The proposed methodological principles of design are based on the determination of the optimal ratio of elastic and viscous bonds, considering the properties of RAP and the amount of cement. The use of this approach allows evaluating the potential maximum durability of composites, practicability of the introduction of various modifying components and the optimum content of the organic binder.

Key words: asphalt concrete regeneration, composite based on organo-hydraulic binder, cold RAP-mix, fatigue life, temperature-structural analogy, rheological properties, maximum structural strength

Introduction. Asphaltic cement composites of various composition and preparation technology are widely used in road construction practice. These asphalt cement composites are hereinafter referred to as the concretes based on organo-hydraulic binders (concretes on OHB). The concrete that is on OHB is an artificial construction material with a structure combining the properties of thermodynamically incompatible organic (bitumen, tars) and hydraulic (cement, gypsum, ash, and etc.) binders. It is particularly important when old spent materials are reused in new construction. The reuse of pavement layer materials is an urgent issue in the road-building industry of most countries around the world. Recycling or reuse (regeneration) of materials of existing pavements during their renovation and repair is not a new concept; such projects with varying degrees of success have been implemented since the beginning of the 20th century [1-3].

The regenerated materials without mineral binder (cement) exhibit viscoelastic properties within a wide temperature-time range; plastic deformations and fatigue cracks are the main possible defects in pavements based on the materials stabilized in such a way; and vice versa, when the mineral binder content is increased, the elastic properties and increased shear resistance at high temperatures are exhibited but brittle properties which stimulate low-temperature cracking and reduction of cyclic durability may appear to a greater extent [4-6]. In this regard, increasing attention is being paid to improving the quality of composite materials obtained from the processing of existing road pavements and their reuse in the repair and construction of new pavements [7-9].

In most countries of the world, the required quality indicators of cold regenerated mixtures and concretes are similar and are focused primarily on the regulation of properties via implementation of a set of tests for [10-12]:

- shear resistance;
- crack resistance and fatigue;
- water resistance and frost resistance.

When determining the design parameters required for pavements design and prediction of composite material properties, the provisions of the Williams-Landel-Ferry theory are often used with plotting the main deformation curve and its subsequent shifting depending on the predicted level of load and temperature impact [13-15]. This makes it possible to assess the composites within a wide range of external impacts, as well as to evaluate their fatigue and fatigue life more effectively.

The difficulty of assessing the properties of composite materials on OHB is that they combine the properties of coagulation, condensation and crystallization structures. In such systems, the arrangement of the various bonds is not uniform in the material volume; the strength and deformability of structural aggregates and clusters are also very heterogeneous. With regard to deformation and destruction mechanics, the structure of such materials can be represented in the form of a phenomenological model with a complex set of elastic, viscous and plastic bonds alternating in series and in parallel [16]. This is due to the fact that the processes of influence of hydraulic binder at the levels of microstructure, mesostructure and macro-structure are not sufficiently studied taking into account the properties of the polygranular filler, that is RAP.

Thesis statement. Many years of experimental studies of composites on OHB and strength analysis of their unbroken and broken structures have confirmed the possibility of phase contacts when the thickness of organic binder films is within 1-5 μm. However, taking into account the low strength of phase contacts in the presence of such films, they cannot be defined as the main structure-forming factors. In this case, the main structure-forming element is phase-to-phase transition layers of cluster type, the formation of which is influenced both by physical (crystal intergrowth, adsorption, destruction of bitumen associates, ion transfer, formation of double electronic layers) and chemical (formation of bonds of Me^{+}–OOCR type, hydrogen –H–O, and etc.) processes. The Me^{+}–OOCR bonds are formed by metal ions, their oxides and hydroxides arising from hydration of the mineral binder due to interaction with oxygen, hydroxyl and carboxyl groups of the organic binder. The hydroxyl groups of hydration products and hydroxyl, nitrogen and sulphur compounds of bitumen are involved in formation of hydrogen bonds [17,18].

Thus, at the interface between the phases of the mineral and organic binder, a certain transition layer with special properties is formed; it is formed by clusters of different sizes, including nanodomains with a different charge transfer between the system components. In these cluster domains, the interaction of atoms differs from the interaction of atoms in isolated domains of cement, bitumen, and water that significantly affects the entire complex of system properties. Therefore, the structure of composites based on cement and bituminous binders is presented by the cement aggregates hydrated to varying degrees and a number of phase-to-phase transition layers.

According to the presented structure formation scheme, the hydraulic binder's impact on the composite structure and properties manifests itself by the mechanism of an active, colmatage and reinforcing filler. Moreover, it refers to the macro- and microstructure. First of all, the cement is a reinforcing filler forming secondary structures in a bituminous or asphalt concrete matrix. The secondary structures of the mineral binder can interact with each other via phase contact or transition layers having higher strength than the bituminous matrix. As a result, the space reinforcing network with a "hinged" connection in the nodes of varying degrees of mobility is formed. The mineral binder has a colmatage effect because its aggregates, unlike inert fillers, are a rather monolithic system after hydration processes.

The structure formation processes are even more difficult when concretes on OHB are prepared with the use of RAP as fillers. The main feature of intercontact interaction of such filler and organo-hydraulic binder is the fact that RAP is a polygranular material in which the most part of grains is covered with an aged organic binder (as a rule, with a bituminous binder). Consequently, the majority of strong phase contacts with the formation of continuous condensation-crystallization backbone is developed via the filler particles not coated with bitumen, as well as due to partial penetration of crystal whiskers into the bitumen films and during interaction of hydration products with active bitumen components on the surface of RAP-particles. As a result, the formed space condensation and crystallization structure determines the elastic properties of the composite.

As described above, the strength of the condensation and crystallization backbone in the composites on OHB is determined by a ratio of concentrations by volume of bituminous and cement phases. As the volume of the bitumen phase is increased, the strength of the condensation and crystallization structure is decreased. However, the bitumen in the composite material at the macro- and mesostructure level can be located on the RAP surface in the form of structured films and fill the space between the aggregate particles and the products of cement hydration that contributes to reducing the porosity and increasing the hydrophobic properties of the composite.

Based on the full complexity of processes occurring when the structure of composites is formed on the RAP and organo-hydraulic binder, there is an important issue to ensure and predict their mechanical-and-physical properties. This issue should be addressed at the composition design stage. Currently, the majority of methodologies to assess the properties of such composite materials, including the methodology of Standard JTG F41-2008 "Technical Specifications for Highway Asphalt Pavement Recycling" [19], do not allow to predict the efficiency of one or another technical solution of cold regeneration of road asphalt concrete pavements while taking into account the features of interaction during the formation of condensation-and crystallization and coagulation structures of RAP with a complex organo-hydraulic binder within a wide range of their initial properties.

Novelty. The main method of predicting the strength and deformation characteristics within a wide range of temperatures and load action time is the principle of temperature-time analogy (TTA), according to which the experimental curves obtained at different temperatures can be combined by parallel shifting along the axis of time t (or deformation rate) [20,21].

Figure 1 shows the general curve of the relaxation modulus of concrete on OHB prepared using RAP (30% in the filler composition) with addition of 3% of cement and 5% of bitumen emulsion. This curve is plotted by horizontally shifting (with the factor a_t) the outgoing relaxation constraints $E(t)$ along the axis. $\lg t$

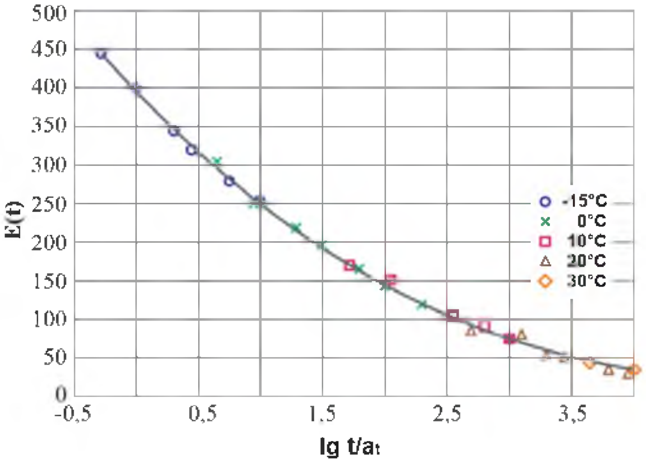

Figure 1 – A general curve of the relaxation modulus

In all cases, the temperature dependence of the shift factor $\lg a_t$ from $(T - T_0)$ is well represented by the power function:

$$\lg a_t = A \cdot (T - T_0)^m , \tag{1}$$

where T – test temperature, °C; T_0 – reduction temperature, °C; A and m – constant parameters.

The examples of parameter values of dependence of this type on the material composition are given in table 1.

Table 1 – The value of constant parameters to determine the shift factor a_t

Composition*	A, 10^2	m	$\lg a_t$**
BE – 3%; P – 0%	3.5	1.30	1.72
BE – 5%; P – 0%	3.7	1.34	2.05
BE – 3%; P – 2%	4.1	1.21	1.54
BE – 3%; P – 4%	4.9	1.09	1.28
BE – 5%; P – 6%	5.2	1.02	1.10

* The RAP content in the filler composition is 30%.
** reduction to temperature 10°C (test temperature – 30°C).
BE – Bitumen emulsion.
P – Portland cement.

As can be seen from table 1, the shift factor is decreased as the weight fraction of the hydraulic binder is increased, indicating that the temperature and time sensitivity of the concretes on the organo-hydraulic binders are decreased if the condensation- crystal lattice is formed in their structure.

At the same time, the classical method of applying the temperature-time analogy is valid in the linear range for analyzing the relaxation curves at low strain levels or the creep curves at low stresses. This provision does not allow us to use it for the analysis of strength properties and other characteristics related to the process of composite material destruction.

The concretes with a composite structure containing the thermodynamically incompatible binders have nonlinear viscoelasticity and are complex in their thermo-rheological properties. A simple visual analysis shows that parallel transfer does not allow the strength-versus-strain rate curves to be aligned (figure 2). Therefore, the reduction factor (the value of shifting the curves along the axis of time or strain rate) depends not only on the temperature but also on the material properties and the degree of strain condition. The situation is even more complicated when RAP obtained from reprocessing of asphalt concrete pavements is used as a filler (part of the filler).

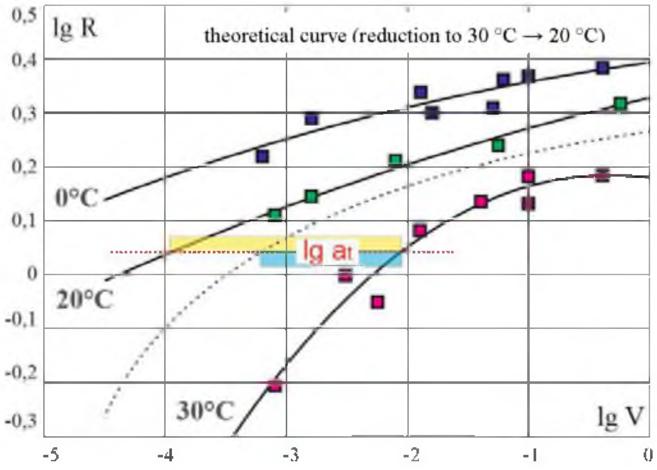

Figure 2 – Bending strength from deformation rate for the concrete based on organo-hydraulic binder

This is due to the features of the composite material structure as a system with a complex set of elastic n_r and viscous bonds n_v [16]; that's why the reduction factor $\lg a_t$ depends mainly on the number of elastic bonds involved in the deformation process. It is valid since the temperature, tension, time changes cause a change in the course of relaxation processes on which the value n_r directly depends.

If $n_r = 1$, then the material properties are practically independent of temperature, stress, time, i.e. the material is "absolutely elastic" and the reduction factor is equal to 1 ($\lg a_t = 0$). If n_r is decreased and tends to zero, then the material properties become close to viscous ones; the value $\lg a_t$ can be determined by the Williams-Landel-Ferry equation (WLF) [20, 21]:

$$\lg a_t^{WLF} = -\frac{17,44 \cdot (T - T_q)}{51,6 + (T - T_q)}, \tag{2}$$

where T – current temperature, K; T_q – glass transition temperature, K.

Using the additivity concept, we obtain:

$$\lg a_t = (1 - n_r) \cdot \lg a_t^{WLF}. \tag{3}$$

The value n_r can be determined by the condition [16]:

$$n_r = \frac{E_t}{E_c} = \left(\frac{R_t}{R_c}\right)^{\frac{1}{m}}, \tag{4}$$

where E_t and R_t – relaxation modulus and material strength under specific conditions of loading; E_c and R_c – maximum values of modulus and strength within the entire range of temperatures and load action time; m – parameter that depends on the material type. For example, for asphalt cement compositions it ranges from 0.8 to 0.95.

Thus, the value a_t can be characterized not only by the viscous properties but also by the elastic properties of the composite material. Taking into account that the changes in the composition and structure of concretes on OHB, in the stress degree at the same temperature and time of its action leads primarily to change of the value n_r, it is possible to predict its rheological properties in case of a change in temperature or time of load action. From the point of view of rheological behavior, the change of n_r due to the structure variation is similar to its change due to variation of temperature or time of load action, taking into account the initial properties of composite material. This provision allows the concept of temperature-structural analogy (TSA) to be applied in a similar way to the concept of temperature-time analogy (TTA).

Study methods and results. Dependence (3) according to the WLF is valid if the glass transition temperature is taken as the reduction temperature. In the case of a random selection of the reduction temperature, it is necessary to adjust the value of WLF factors according to the procedure [21]. The experimental studies and calculations (Fig. 2) have shown that the theoretical curve obtained by the TTA method (dashed line) differs from the experimental curves.

The WLF equation (2) is valid if the glass transition temperature is taken as the reduction temperature. In case of random selection of the reduction temperature, it is necessary to adjust the value of WLF factors according to the procedure [20]. It is possible to use a simplified dependence obtained by shifting the WLF curve along the axes of temperature and reduction factor $\lg a_t$. In this case, the factor T_{pr} of reduction to random temperature is determined from the expression:

$$\lg a_t = \lg a_t^{WLF} - \lg a_t^{T_{pr}}, \tag{5}$$

The value $\lg a_t^{T_{pr}}$ is calculated by (2) replacing the current temperature (T) with the reduction temperature (T_{pr}).

Table 2 shows the values of the factor of creep modulus reduction to the temperature of 0°C which is obtained experimentally (by combining the curves) and theoretically. The studies were carried out using the samples from RAP with addition of 3 % of cement and 5 % of bitumen emulsion at a temperature of 0°C and 20°C at two levels of strain. In case of theoretical determination, the value n_r was obtained by $\lg a_t$ (2), then the value $\lg a_t$ was obtained using (2) and (5). The temperature of structural glass transition (T_q) was 12°C.

Table 2 – Values of the reduction coefficient for different methods of determination

Time of load action at 20°C,	Number of elastic bonds according to (4) under strains, MPa		Logarithm of the factor of reduction $\lg a_t$ to temperature of 0°C under strains, MPa	
s	0.2	0.4	0.2	0.4
3.0	0.70	0.60	$\frac{-0.7(-0.99)}{-3.3}$	$\frac{-1.1(-1.3)}{-3.3}$
15.0	0.22	0.14	$\frac{-2.6(-2.57)}{-3.3}$	$\frac{-3.0(-2.9)}{-3.3}$
30.0	0.15	0.08	$\frac{-2.95(-2.86)}{-3.3}$	$\frac{-3.2(-3.09)}{-3.3}$

Note. The numerator contains experimental data; theoretical data obtained using (2) and taking into account (T_{pr}) and (3) are given in brackets; the denominator contains data obtained using (2).

The table shows that the values $\lg a_t$ obtained by the proposed procedure are close to experimental data while those data calculated by the WLF equation, have significant deviations and do not take into account the strain level and time. The changes in the concrete composition and structure, in the strain level at the same temperature and time of load action lead primarily to changing the value n_r. As a result, the material takes on the rheological properties that it would have when the temperature or time of load actions changes, i.e. in terms of rheological behaviour, the change of n_r due to a structure variation is similar to its change due to a variation of temperature or time of load action for the source material. This provision allows developing the concept of temperature-structural analogy (TSA).

Let's assume that the material at a temperature T_1 and time of load action t_1 has some value of properties E_1 that corresponds to the quantity of elastic bonds n_{r1}. As the temperature is varied from T_1 to T_2, the material properties are also varied. As a result, the material will have the same values of properties E_1 at some time of load action t_2.

The difference between the factors of reduction to temperature T_2 and T_1 taking into account (3) is as follows:

$$\Delta \lg a_t^{T_{pr}} = \frac{-17.44\left(T_2 - T_q\right)}{51.6 + \left(T_2 - T_q\right)}\left(1 - n_{r1}\right) + \frac{17.44\left(T_1 - T_q\right)}{51.6 + \left(T_1 - T_q\right)}\left(1 - n_{r1}\right). \tag{6}$$

The same property values E_1 at time of load action t_2 can be obtained by keeping the temperature T_1 but by changing the number of elastic bonds from n_{r1} to n_{r2} due to the material structure (e.g. by varying the amount of cement in the composite, binder modification, and etc.). This provision can be considered to be valid because the glass transition temperature is almost independent of the structure [17].

If the value of elastic bonds is varied from n_{r1} to n_{r2}, the difference between the reduction factors will be equal to:

$$\Delta \lg a_t^{T_{pr}} = \frac{-17.44\left(T_1 - T_q\right)}{51.6 + \left(T_1 - T_q\right)}\left(1 - n_{r2}\right) + \frac{17.44\left(T_1 - T_q\right)}{51.6 + \left(T_1 - T_q\right)}\left(1 - n_{r1}\right). \tag{7}$$

Considering the equality of dependencies (5) and (6) and having made some transformations, we will find:

$$T_2 = \frac{51.6A + T_q(1 - A)}{1 - A}, \tag{8}$$

where

$$A = \frac{\left(T_1 - T_q\right)\left(1 - n_{r2}\right)}{\left[51.6 + \left(T_1 - T_q\right)\right]\left(1 - n_{r1}\right)}. \tag{9}$$

Formula (8) allows calculating the temperature equivalent ($T_2 - T_1$) to the structural equivalent of the material ($n_{r2} - n_{r1}$).

According to the TSA concept, it is possible to predict the properties of materials having a different composition within a wide range of temperatures and load time. For this purpose it is enough to obtain dependence of material properties of one composition on time of load action at a fixed temperature and strain, then obtain dependence n_{r2} on the material composition for one time of load action t_1 . The value T_2 is calculated using (8); and the value $\Delta \lg a_t^{T_{pr}}$ is calculated by formula (7).

If experimentally obtained dependence $\Delta \lg a_t^{T_{pr}}$ on the temperature with a certain value n_{r1}, then for using this dependence with other values n_{r2}, the reduction factor should be multiplied by the ratio $\left(1 - n_{r2}\right) / \left(1 - n_{r1}\right)$.

The TSA concept can be used as a fundamental one in the design of concrete mixes on organo-hydraulic binders for certain conditions of their use based on the specified level of reliability (service life) of the road surface dressing (road pavement). Thus, there is a possibility to estimate the design characteristics of concretes on organo-hydraulic binders which values are difficult to find by direct experiment using a method of standard elementary tests, for example, elasticity modulus for various temperatures and time of load action $E_{T(V)}$ [16] by formula (4).

For example, multi-year researches confirm the validity of the empirical dependence relating the value of the maximum structural strength (R_c) to the maximum elasticity modulus (E_c) within the entire range of temperature and time of load action:

$$E_c = 3,6 \cdot (16,3 \cdot R_c)^{1,9}. \tag{10}$$

Thus, using the principles of temperature-structural analogy, it is possible to predict the properties of composites based on organo-hydraulic binders as applied to the mechanistic and empirical methods of calculation for road pavements; as well as it is possible to calculate and directly adjust the long-term indicators of properties at the stage of concrete composition design. For example, the required value of elasticity modulus E_{V_1} at the time of load action V_1 can be directionally adjusted while keeping the temperature conditions and the current load but changing the number of elastic bonds from n_{r1} to n_{r2}, i.e. due to the material structure (for example, by varying the amount of cement in the composition of bitumen cement composite binder.

Conclusion. For preparing the quality concretes during the regeneration process, RAP should be treated with complex organo-hydraulic binders. The received structure is very complex that is reflected in the behaviour of the received composite in a temperature-time field and by the estimation of its reliability and durability.

The main feature of the inter-contact interaction between the filler and the organo-hydraulic binder is poly-granularity and inhomogeneity of RAP in which the most part of grains are covered with an aged organic binder. Consequently, the majority of strong phase contacts of cement with the formation of continuous condensation-crystallization backbone is developed via the filler particles not coated with bitumen, as well as due to partial penetration of crystal whiskers into the bitumen films and during interaction of hydration products with active bitumen components on the surface of RAP-particles.

The concretes with a composite structure containing the thermodynamically incompatible binders have nonlinear viscoelasticity and are complex in their thermo-rheological properties. The reduction factor (the value of shifting the curves along the axis of time or strain rate) for such materials depends not only on the temperature but also on the material properties and the degree of strain condition.

As a result of studies performed, the concept of temperature-structural analogy is proposed. Along with the temperature and time factor, it takes into account the features of the structure described by the ratio of elastic and viscous bonds. The TSA concept allows obtaining necessary structural features for specific temperature-time factors. Using this concept, it is possible to predict the properties of composites based on OHB suitable for mechanistic and empirical methods of calculation of road pavements. As a result, it is possible to calculate the long-term indicators of properties at the stage of concrete composition design that determines the prerequisites for their directional adjustment.

It is necessary to take into account that an increase in cement content leads to an increase of strength properties and durability at an elastic stage of work; however, the resistance to dynamic impacts and cracks is decreased that reduces durability. In this regard, the proposed method to select the composition of concretes on OHB based on the optimal ratio of elastic and viscous bonds, taking into account the properties of RAP and the amount of cement, allows adjusting effectively the durability and reliability indicators.

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ӨҢДЕЛҒЕН АСФАЛЬТБЕТОНДЫ ЖОЛ ЖАМЫЛҒЫЛАРЫНАН АЛЫНҒАН ТҮЙІРШІКТЕР НЕГІЗІНДЕҒІ КОМПОЗИТТЕРДІҢ ҚҰРЫЛЫМДЫҚ-МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІН БОЛЖАУ ӘДІСТЕМЕСІ ЖӘНЕ БАҒАЛАУ

Аннотация. Бұл мақалада асфальт түйіршіктері негізіндегі композиттердің беріктілік және деформативті қасиеттерін бағалаудың әдіснамалық ерекшеліктерін талдау және құрылым құру үдерістерін зерттеу нәтижелері берілген. Жаңа материалдар беріктілік пен сенімділіктің талап етілетін мәнін қамтамасыз етуге мүмкіндік беретін олардың физикалық-механикалық сипаттамаларына объективті техникалық талаптарды әзірлеу мақсатында температура-уақыт өрісінде олардың әрекет ерекшеліктерін зерттеуді талап етеді.

Температура-уақыт аналогын қолданудың классикалық әдісі деформацияның шагын деңгейлерінде релаксациялық қисықтарды талдауга арналган сызықтық аймақта дұрыс. Мұндай жагдай оны композиттік материалды бұзу процесімен байланысты беріктік қасиеттері мен басқа да сипаттамаларын талдау үшін пайдалануга мүмкіндік бермейді. Құрамында термодинамикалық үйлеспейтін байланыстыргыш бар композициялық құрылым бетондары сызықсыз тұтқырлыққа ие және термореологиялық күрделі болып табылады. Композициялық материалдар үшін келтіру коэффициенті (қисықтардың уақыт осі бойымен жылжу шамасы немесе деформация жылдамдыгы) температураға гана емес, материалдың қасиеттеріне де, сондай-ақ кернеулі күй деңгейіне де байланысты болады. Бұл серпімді және тұтқыр байланыстардың кешенді жиынтыгы бар жүйе ретінде композиттік материалдар құрылымының ерекшеліктерімен байланысты, осыган байланысты келтіру коэффициенті деформациялау процесіне тартылган серпімді байланыстардың санына байланысты.

Зерттеудің негізіне органикалық-гидравликалық тұтқыр композиттердің қасиеттерін болжауга мүмкіндік беретін температуралық-құрылымдық ұқсастық принциптері алынган. Бұл жол жамылғысының әр түрлі қабаттарын салуга арналған материалдардың құрамын жобалауга және алу технологиясын анықтауга мүмкіндік береді.

Жобалаудың ұсынылган әдістемелік принциптері асфальттүйіршіктердің қасиеттері мен цемент мөлшерін ескере отырып, серпімді және тұтқыр байланыстардың оңтайлы арақатынасын белгілеуге негізделген. Мұндай тәсілді пайдалану композиттердің барынша ұзақ мерзімділігіне қол жеткізу перспективасын, түрлі түрлендіргіш компоненттерді енгізудің мақсаттылығын және органикалық тұтқыр-тұтқыр шыгынының оңтайлы шегін багалауга мүмкіндік береді.

Түйін сөздер: асфальтбетонды регенерациялау, органикалық-гидравликалық байланыстыргыш композит, салқын регенерацияланган асфальтбетонды қоспа, циклдық ұзақ мерзімділік, температуралық-құрылымдық ұқсастық, реологиялық қасиеттер, максималды құрылымдық беріктік.

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ОЦЕНКА И МЕТОДИКА ПРОГНОЗИРОВАНИЯ СТРУКТУРНО-МЕХАНИЧЕСКИХ СВОЙСТВ КОМПОЗИТОВ НА ОСНОВЕ ГРАНУЛЯТОВ ИЗ ПЕРЕРАБОТАННЫХ АСФАЛЬТОБЕТОННЫХ ДОРОЖНЫХ ПОКРЫТИЙ

Аннотация. В настоящей статье представлены результаты исследования процессов структурообразования и анализ методологических особенностей оценки прочностных и деформативных свойств композитов на основе асфальтогранулятов. Новые материалы требуют изучения особенностей их поведения в температурно-временном поле с целью выработки объективных технических требований к их физико-механическим характеристикам, позволяющих обеспечить требуемые значения прочности и надежности.

Классический способ применения температурно-временной аналогии справедлив в линейной области для анализа релаксационных кривых при небольших уровнях деформации или кривых ползучести при небольших напряжениях. Такое положение не позволяет использовать его для анализа прочностных свойств и других характеристик, связанных с процессом разрушения композитного материала. Бетоны композиционной структуры с содержанием термодинамически несовместимых вяжущих, обладают нелинейной вязкоупругостью и являются термореологически сложными. Для композиционных материалов коэффициент приведения (величина смещения кривых вдоль оси времени или скорости деформации) зависит не только от температуры, но и свойств материала, а также уровня напряженного состояния. Связано это с особенностями структуры композитных материалов как системы с комплексным набором упругих и вязких связей, в связи с чем коэффициент приведения зависит от числа упругих связей, вовлеченных в процесс деформирования.

В основу исследования положены принципы температурно-структурной аналогии, позволяющие прогнозировать свойства композитов на органо-гидравлических вяжущих. Это позволяет направленно проектировать состав и определять технологию получения материалов для устройства различных слоев дорожных одежд.

Предложенные методологические принципы проектирования основаны на установлении оптимального соотношения упругих и вязких связей с учетом свойств асфальтогранулятов и количества цемента. Использование такого подхода позволяет оценивать перспективность достижения максимальной долговечности композитов, целесообразность введения различных модифицирующих компонентов и оптимальные пределы расхода органического вяжущего.

Ключевые слова: регенерация асфальтобетона, композит на органо-гидравлическом вяжущем, холодная регенерированная асфальтобетонная смесь, циклическая долговечность, температурно-структурная аналогия, реологические свойства, максимальная структурная прочность.

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