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Recycling of Materials for Pavement Dressing: Analytical Review

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Abstract. The paper presents an analytical review of materials recycling for pavement dressing. Recycling or repeated usage of pavement dressing materials while making reconstruction and repair of road pavements is not considered as a new conception and it has been realized in various countries of the world since 20th century. Recycling (hot, cold) is based on methods of its execution, properties of pavement dressing materials which are subjected to processing and which influence on the quality of final material, technical and operational indices, specific economic efficiency. Investigations on the processes of structure formation, thermo-physical properties in components based on granulates of transformed pavement dressings during recycling demonstrate that regeneration makes it possible to attain 100 % recovery of material properties for road pavement base. The paper describes other factors which represent a complex of challenges concerning exterior and internal problems. These problems have arisen due to actual processes of heat and mass transfer in one layer, multi-layer systems of pavement dressings. At known coefficients of heat conductivity, steam- and mass permeability, diffusion, filtration, temperature conductivity, density of material layers etc. initial and boundary conditions it is possible to carry out optimization of heat- and mass transfer problems from bottom surface of road layer to its base (sand, bulk materials, ground). In addition to it, while taking into account development of scientific prospective direction that concerns nano-technology and creation of nano-materials for higher reliability of road dressings it is necessary to consider nanomaterial science in road-construction industry as the most actual one because when we study problems pertaining to fractional composition of all road dressing components including transfer to nanomaterials, for example, application of modified water-reducing agent based on nanostructured carbon it is possible significantly to increase physical and technological properties of asphalt concrete and concrete road dressings. The paper reveals that it is necessary to continue and expand study of physical and technical and thermophysical properties of new materials on the basis of nano-technologies with application of modified, nanostructured carbon-based plasticizer for construction-road industry because especially these additives significantly increase cement activity that leads to improvement of strength, reliability and longevity for the obtained materials.

Keywords: recycling (hot, cold), pavement dressing, regeneration, foam bitumen, elastic and visco-plastic bindings, organo-hydraulic binding mixture, asphalt granulate, fraction composition

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Ресайклинг материалов дорожных одежд: аналитический обзор

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Реферат. Рассмотрен анализ ресайклинга материалов дорожных одежд. Переработка или многократное использование материалов одежд при реконструкции и ремонте дорожных покрытий не является новой концепцией и реализуется в разных странах мира с начала ХХ в. Ресайклинг (горячий, холодный) основан на способах его реализации, свойствах материалов дорожных одежд, подлежащих переработке, от которых зависят качество конечного материала, технико-эксплуатационные показатели, удельная экономическая эффективность. Исследования процессов структуро-

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образования, теплофизических свойств компонентов на основе гранулятов трансформируемых дорожных покрытий в процессе ресайклинга показывают, что при регенерации добиваются полного восстановления свойств материалов для устройства оснований дорожных покрытий. В статье описываются другие факторы, которые представляют комплексы вопросов, относящиеся к «внешней» и «внутренней» задачам. Эти задачи обусловлены реальными процессами тепло- и массопереноса в одно- и многослойных системах дорожных одеждах. При известных коэффициентах теплопроводности, паро- и массопроницаемости, диффузии, фильтрации, температуропроводности, плотности материалов слоев и т.д., начальных и граничных условиях возможна оптимизация проблем тепло- и массопереноса от «нижней» поверхности слоя дороги к ее основанию (песок, сыпучие материалы, грунты). Кроме того, с учетом развития научно-перспективного направления, связанного с разработкой нанотехнологий и созданием наноматериалов для повышения надежности дорожных одежд, необходимо рассматривать наноматериаловедение в строительно-дорожной отрасли как наиболее актуальное, так как, изучая вопросы фракционного состава всех компонентов, составляющих дорожную одежду, включая переход к наноматериалам, например применение модифицированной пластифицирующей добавки на основе наноструктурированного углерода, можно значительно повысить физико-технологические и теплофизические свойства асфальтобетонных и бетонных цементных дорожных одежд. В статье показано, что необходимо продолжить и расширить изучение физико-технических и теплофизических свойств новых материалов на основе нанотехнологий с применением модифицируемой, пластифицирующей добавки на основе наноструктурированного углерода для строительно-дорожной отрасли, так как именно эти добавки значительно увеличивают активность цемента, что приводит к повышению прочности, надежности и долговечности полученных материалов.

Ключевые слова: ресайклинг (горячий, холодный), дорожная одежда, регенерация, вспененный битум, упругие и вязко-пластические связи, органогидравлические вяжущие смеси, асфальтогранулят, фракционный состав

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Introduction

Pavement dressing recycling is a technology to strengthen soil, rock materials and asphalt granulate while using crushing of asphalt concrete wastes; strengthening is ensured with the help of various binders and soil, rock materials and asphalt granulate are preliminary milled and mixed on the road.

A peculiar feature of this technology is usage of materials from recycled pavement dressings which is related with economy of material resources, energy, higher efficiency of ecological projects while having the same geometric characteristics of pavement design. These technologies have been applied while carrying out reconstruction, repair, rehabilitation of automotive highways with intensive freight traffic flows and regional (local) traffic roads of low categories in a great number of countries in the world.

Hot and cold recycling is considered as the most efficient, popular technology for highway reconstruction, repair, maintenance while using recycled materials of pavement dressings.

Hot recycling

Production of hot, warm bitumen-concrete mixtures while using components of fractionated and non-fractionated materials from recycled asphalt pavement (RAP) which is carried out at specially equipped plants, mobile recyclers makes it possible to use up to 70 % materials from recycled asphalt granulates (asphalt-concrete pavement) and this process involves various anti-aging, modifying chemical and other components that ensure higher physical and mechanical characteristics in bitumen-concrete mixtures.

Hot in-place recycling (HIR) (fig. 1) presents a method when an asphalt concrete pavement is heated up to softening, loosening state for a definite depth. While carrying out these works it is possible to add hot, warm, bitumen-concrete mixtures including materials of recycled asphalt-concrete pavements and various rejuvenating (modifying) components, binding materials. The process is carried out for one or several passages with layer thickness of 2–5 cm.

There are the following three types of hot in-place recycling:

– *Surface recycling* presents hot in-place recycling when a surface is heated, loosened while adding if necessary a binding material, a stone aggregate and compacted. In this case it is possible to use an assembly of thin protective layers against wear and for strengthening;

– *Repaving recycling* presents a continuous process for synchronous implementation of surface recycling for an asphalt-concrete layer from hot, warm bitumen-concrete mixtures with subsequent compaction;

– *Recycling with remixing* presents a continuous process when treated pavement asphalt concrete is additionally mixed with bitumen-concrete aggregate in a special mixer and then it is laid and compacted in one layer.

Cold recycling

Cold central plant recycling (cold recycling while using central plant) (CCPR) (fig. 2).

Fig. 1. Hot in-place recycling, HIR

Fig. 2. Cold recycling

Cold recycling is executed while using recycled materials from asphalt concrete pavements (asphalt granulates) which are transported from construction sites to a central plant for production of cold mixes.

Asphalt granulators (fig. 3) supplied to the central plant must be additionally subjected to size degradation, fractionating. Bitumen emulsion, foamed bitumen, special chemical modifying components, aggregates ensuring pavement reliability and longevity are used as binding materials.

While having this technology and using special methods for asphalt granulate fragmentation and further sieving coarse stone aggregate (RAP aggregates) and fine aggregate (RAP slurry materials) are sorted out separately and then they can be used for surface treatment, making thin protective layers from cast emulsion-mineral mixtures.

Fig. 3. Asphalt granulators

Cold in-place recycling (CIR) presents a method when bitumen-concrete road pavement is recycled while adding binding materials and cold mixture is subsequently laid on pavement surface and then it is subjected to compaction process.

The technology can be realized in the following way: one of the machines is milling and grinding material, the second machine is crushing and sieving the material; the third one is mixing it and the fourth machine is laying the prepared material.

Bitumen emulsion, foamed bitumen in specific proportions are used rather often as regenerating binding materials. Portland cement, fly ash, unhydrated lime are added with the purpose to increase stability of cold mixtures, to obtain more optimum structural characteristics of concrete which is prepared on their basis for road pavement [1–4].

Recycling with full depth reclamation of pavement dressing (FDR) presupposes recycling of a pavement dressing to a predetermined depth by means of crushing, mixing with addition of binding materials, other components that makes it possible to obtain pavement base with an optimum structure. Bitumen emulsion, chemical agents (calcium chloride and others, Portland cement, fly ash, lime etc.) are added in the composition of cold mixtures with the purpose to improve strength and longevity of pavement bases.

If availability of on-specification materials is insufficient in constructive layers of the pavement dressing then it is necessary to add materials at the recycling stage in order to ensure the required thickness of a regenerated layer. While using this method thickness of recycled layers is usually equal to 15–30 cm.

Strengthening layers from hot, warm bitumen-concrete mixtures, protective layers (cast emulsion and mineral mixtures, surface treatment, impregnation etc.) are prepared in order to improve reliability of a road pavement.

While analyzing efficiency pertaining to reliability restoration of pavement dressings, preventive and rehabilitation technologies, reconstruction and repair it is necessary to take into account the following protective technologies: surface treatment (Chip Seal), thin layers from cast emulsion and mineral mixtures (Slurry Seal, Microsurfacing), combined thin layers (Cape Seal), regenerating surface technologies (Fog Seal, Rejuvenator Seal, Scrub Seal) and others. Their service life period is equal to: hot recycling – 6–12 years; cold recycling – 8–15 years; milling and placing of new asphalt-concrete layers – 10–16 years; recycling with full depth reclamation of pavement dressing – 20 years and more.

All the mentioned technology solutions for restoration of operational pavement dressing capability have their advantages and disadvantages while implementing them. Cold technologies for regeneration of the pavement dressings applied at bitumen concrete plant or directly on the roads have gained recently rather high popularity and this fact is substantiated by the following advantages of these technologies: saving of energy, natural resources; high environmental compatibility; possibility to prepare cold regenerating mixtures with high physical and mechanical characteristics; reduction, removal and retardation of crack formation process; correction of cross slopes; restoration of road kerbs, piped drainage system along pavement dressings with economic efficiency; reduction in time expenditure for restoration of operational characteristics; reality in work execution with operational regimes of transportation flows.

Quality of road construction works while using cold regenerated mixtures is determined by a set of technological and structural and thermo-physical factors. Therefore main investigations on improvement of reliability in road objects from cold regenerated materials are directed on modernization of machines, equipment for production of cold regenerated mixtures (plants, automobile roads), their placing, compaction, longevity, heat and mass transfer stability.

Presently Wirtgen company (Germany) is considered as a leader in manufacturing equipment for cold in-place recycling of pavement while using Wirtgen WR 4200 recycler with two milling drums, highly-efficient chamber for mixing asphalt granulate and water-cement suspension and foamed bitumen and this work can be realized without placing additional layers and on the highways with high traffic intensity.

Cold regenerated mixtures are divided in two groups in European Union (project DIRECT-MAT (1)): materials stabilized by bitumen emulsion without mineral binder or with its minimum content (up to 1 %) and residual content of bitumen binder (after disintegration of bitumen emulsion) 1–3 % (Portugal, Spain, Sweden) and materials stabilized by bitumen emulsion or foamed bitumen (with residual content of bitumen binder 2.5–3.5 %, cement 1.5–4.0 %) (France, Germany, Poland, Portugal, Slovenia, Czechia).

Regenerated materials without mineral binder (cement) demonstrate their viscoelastic properties within wide temperature and time range. Main defects on the pavements laid with the help of stabilized materials are plastic deformations, fatigue cracks. Elastic properties, increased shear resistance at high temperature, brittleness contributing to low temperature crack formation, reduction in cyclic longevity are revealed to a greater extent while increasing mineral binder.

In this connection selection, design, optimization of binding component composition (organic and mineral) acquire a crucial significance for preparation of cold regenerated mixtures.

Every cold recycling project includes detailed prefeasibility diagnostics of repair object, an analysis of materials in constructive layers of pavement dressings, design of regenerated material composition, calculation of design for pavement dressing that presupposes the following: determination of type and scope of defects in the road pavement; core samples collection from the pavement; laboratory test of road pavement material; selection of binding component type and determination of their amount; if it is necessary, determination of amount for additives, fillers, aggregates; structural analysis of the placed pavement dressing with a layer and layers from regenerated materials.

Pavements can not be repaired with help of cold recycling method without additional works or without adding new materials if there are destructive processes in the pavement dressing which are caused by excessive moistening of basement, road bed; heaving properties in road bed; insignificant shear resistance of road pavement due to high content of bitumen, small-grained components (it is necessary to include a new coarse stone aggregate up 20 % by weight); insignificant adhesion between bitumen and stone aggregate which is revealed in high porosity.

The following test methods are used to assess physical and mechanical characteristics of asphalt concrete in constructive layers of a pavement dressing: extraction of binding material; binder analysis with the help of burning-out method; binder restoration; penetration of the restored binder; binder viscosity; grain composition.

Design of cold regenerated mixture composition is carried out with due account of test results for asphalt concrete pavements: selection of binding components; determination of optimum water content; preparation of cold regenerated mixtures, manufacturing of laboratory samples; storage of laboratory samples.

While testing laboratory samples the following physical and mechanical indices of regenerated concrete are determined: residual porosity; breaking strength for fracture (in dry, wet state); water resistance (according to climatic conditions – frost resistance); elasticity modulus and thermal and physical characteristics.

If it is necessary tests for shear resistance or cyclic longevity are carried out and they are connected with investigations on properties of design composition for a cold regenerated mixture.

Values of the required qualitative indices for regenerated mixtures, concrete are analogous and oriented toward correction in the following aspects: shear resistance; crack resistance, fatigue, water resistance, frost resistance.

Fig. 4 presents a model diagram for structure of pavement dressings; and tab. 1 shows physical characteristics of some road materials.

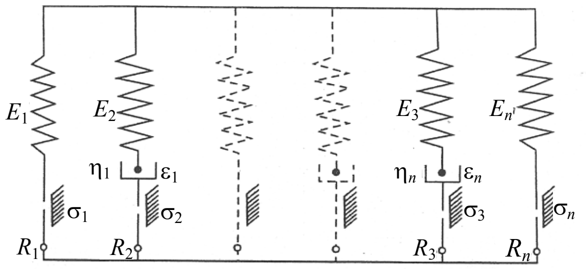

Fig. 4. Scheme of pavement dressing structure model

The required value of breaking strength for fracture within temperature range 5–15 °C is equal to 0.3–1.0 MPa, Marshall Stability – 5–7 kN, water resistance – 60–70 %.

Peculiar features pertaining to analysis of properties for cold concrete on the basis of asphalt granulates while milling road pavements are in that they combine properties of coagulative, condensed, crystallized structures. Arrangement of various bonds in them is non-uniform by volume (strength, deformability of structural aggregates, clusters). On the basis of deformation, destruction principles a structure of similar materials can be presented in the form of a phenomenological model with a complex set of elastic, viscous and plastic bonds which are interchanging according to sequential and parallel schemes.

A great number of components (additives): polymer and other additives (Nicoflok (Russia), NanoSTAB (Germany), RoadCem (Netherlands), NovoCrete (Germany), Perma-Zyme (USA), Dorzin (Ukraine), ANT (Russia), Polybond (Switzerland), ITERLENE A.C.E.R. 1000 (Italy)) and others; special emulsion with high characteristics (GSB-Repave (USA), PASS R (USA), Cyclogen (USA), Reflex (USA)) and rejuvenating substances (predominantly components (including emulsion), containing various oil of biological origin, mineral, synthetic and waste solvent in their composition are used in order to improve physical and technical characteristics of cold regenerated mixtures on the basis of organic (bitumen emulsion, foamed bitumen) and mineral binders (cement).

Technology using foamed bitumen that increases strength and stress-related characteristics with less expense of binding material is considered as an efficient method for improvement of strength and stress-related characteristics in cold regenerated concrete.

Foamed bitumen is produced by injecting small quantities of water and air into hot bitumen under high pressure. The water evaporates and makes the bitumen foam up intermittently and due to this the bitumen increases its original volume by 15–20-fold. The formed foam is then injected into a mixer through injection nozzles and optimally mixed into cold and moist construction materials. Quality of the foamed bitumen is primarily characterized by such parameters as expansion and half-life. The greater the expansion ratio and half-life, the more easily the foamed bitumen can be processed (fig. 5).

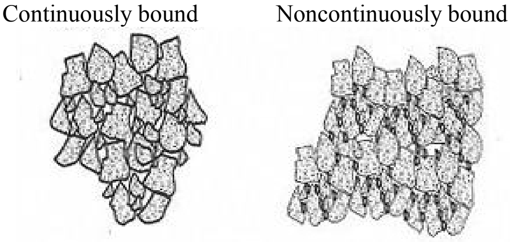

Fig. 5. Scheme of asphalt emulsion and foam asphalt

Thus it is possible to conclude that presently there is no clear option (technology) for cold regeneration of asphalt concrete pavement that ensures maximum restoration of strength and strain properties which permit to use cold regenerated concrete in top pavement layers and that is related to non-availability of efficient methods for quality evaluation of asphalt granulate-based composite materials while performing milling of asphalt concrete pavement with organic and mineral binders and consequently it is not possible to control intentionally their properties and predict them in time. There is no as well methodology for evaluation of efficiency in usage of various additives for reliability of cold regenerated concrete operating under heavy transport load conditions, climatic factors.

Table 1

Physical characteristics of some road materials (concrete based on organic and hydraulic binder) according to standard of the Republic of Belarus – РБ СТБ 1415–2003

Name of index	Mixture type, %			
1. Water saturation W, % by volume, not more	0.5–7.0	0.5–7.0*	0.5–10.0	0.5–10.0
2. Intumescence H, % by volume, not more	1.0	1.0	1.0	1.0
3. Index of resistance to plastic deformation I_{area}, not less	1.0	1.0	1.0	1.0
4. Index of temperature crack resistance I_{temp}, not less	0.5	0.5	0.4	0.4
5. Maximum structural strength R_c, MPa, not less	2.2	2.5	1.8	1.8
6. Ultimate compressive strength R_{50} at temperature 323 K (50 °C), MPa, not less, at the age:				
1 day (for mixtures of 1st group)	0.5	0.7	0.3	0.5
14 days (for mixtures of 2nd and 3rd groups)	0.9	1.1	0.6	1.0
28 days (for all mixtures)	1.0	1.4	0.8	1.2
7. Coefficient of frost resistance in aggressive environment $C_{frost\ resistance}$, not less	0.7	0.7	0.6	0.6
* In case of placing a protective layer not less than in 6 months maximum permissible level of water saturation must constitute not more than 4 %.				

Problem pertaining to development of methodology for quality evaluation of asphalt-granulate-based composite materials with due account of milling, nano-components in existing asphalt concrete, concrete pavements is considered as one of the most important in the project “Development of complex technical system for activation and full regeneration of pavement dressings” which has been implemented within an international project of Henan Excellence Bureau in the field of green technologies for regeneration and recycling of road construction materials; results of the development can be used as in the People’s Republic of China so in the Republic of Belarus as well and in other countries of the world.

While making selection of components (filler material, structuring additives, modifiers, stabilizers and others) which exert an action on properties of cold regenerated mixtures, asphalt-granulate-based concrete it is necessary to take into account fields of elastic, viscoplastic bonds in the structure.

Bonds (elastic, viscous, plastic) in a composite concrete with organic and hydraulic binder have own mechanical characteristics, so such concrete possesses a spectrum of elastic and viscoplastic properties. Changes in temperature, load value and regime lead to inter-bond substitution. Various elastic and viscoplastic bonds are functioning in the process of deformation in accordance with temperature, load regime, concrete composition, so the concrete reveal to various extents properties of elastic and viscous solid (fig. 6).

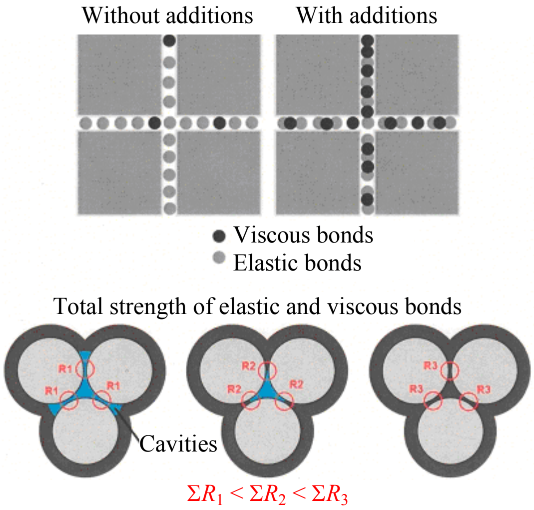

Fig. 6. Schemes of total bonds in concrete with organic and hydraulic binder

If only elastic bonds are deformed then it is possible to observe complete deformation reversibility, and destruction occurs according to mechanism of brittle solid irrespective of loading period. At the other extreme viscoplastic bonds characterize occurrence of residual deformation and they are subjected to influence of temperature and loading period.

Deformation processes in the concrete structure can arise due to the following factors: breakage in elastic bonds; attainment of ultimate deformations in viscoplastic bonds. Whatever the composition and structure concrete having equal number of elastic (viscoplastic) bonds possesses the same relaxation capability, relaxation rate, Poisson’s ratio, ratio between dissipated and stored energy.

Having denoted portion of elastic bonds characterizing concrete state by some scalar quantity n_r, viscoplastic n_v, then the following assumption must be fulfilled

$$n_r + n_v = 1. \quad (1)$$

As due to deformation of viscoplastic bonds dissipation of applied energy takes place then we can accept theoretically that n_r and n_v proportion is determined by ratio of dissipated energy to the applied one. Consequently number of n_r and n_v depends principally on relaxation concrete properties and load action time, and number of elastic bonds in the deformation process can be determined from the following dependence

$$n_r = \frac{E_t}{E_c} = \left(\frac{R_t}{R_c}\right)^{\frac{3}{m}}, \quad (2)$$

where E_t, R_t – module of relaxation and concrete strength, MPa; E_c, R_c – maximum values for module of relaxation and concrete strength within all ranges of temperature and load action rate (load action time), MPa; m – coefficient depending on concrete properties (types).

Thus it is necessary to evaluate not only quantitative characteristics of strength and deformability according to the results of elementary tests but it is necessary to evaluate as well process of changes in deformation regimes due to adding of modifying and other additives. This equates to exert intentionally an influence on ratio of elastic and viscoplastic bonds in the structure of cold regenerated asphalt-granulate-based concrete within specific range of transport load actions and climatic factors.

A large value of property parameters obtained during elementary tests (for example, strength resistance to disruption at temperature of 15 °C) does not always mean a long time performance of cold regenerated concrete.

Such approach must be taken into account while optimizing compositions of cold regenerated mixtures and it is especially important while modifying them with the help of various additives.

Generally, in case of positive influence of low-molecular, ion active, organic, SAS (Surface Active Substance) – and enzyme-based stabilizers on properties of cold asphalt-granulate-based concreted it is possible to reach their high calculative characteristics which can be clearly predicted according to value of maximum structural strength (Rc) at the level of 2.5–4.0 MPa (while making calculations according to methodology of the People's Republic of China) or 4.0–6.5 MPa (while calculating strength according to methodology of the Republic of Belarus) and the level of maximum elasticity modulus is equal to 25000 MPa. On the assumption of reaching the indicated maximum structural strength it can be said that there is a possibility to use cold concrete in top layers of pavement dressings with appropriate indices of residual porosity even for rather busy highways.

Therefore one of the main characteristics determining the possibility to reach the required indices for cold regenerated mixtures and concrete is granulometric composition of asphalt granulators while milling old asphalt-concrete pavements. Quality of asphalt granulate, its sensible use in cold regenerated mixtures are determined by its fractional composition, bitumen content and its properties which are taken into account for further optimization of organic binder content. Tab. 2 and 3 present a granulometric composition of asphalt granulators and European standard (DIRECT-MAT project).

Table 2

Granulometric composition of asphalt granulators

Sieve size	Fine gradation	Medium gradation	Coarse gradation
	Percent passing		
1.25" (31.5 mm)	100	100	100
3/4" (19 mm)	95–100	93–97	83–87
No 4 (4.75 mm)	60–70	48–52	38–42
No 30 (600-μm)	20–30	8–12	3–7
No 200 (75-μm)	1–7	1–3	0.5–2.0

Tab. 4 presents some physical and technical characteristics of aggregates according to the standard of the Republic of Belarus.

Although there is a great variety of manufactured modern mechanisms for cold in-place regeneration of asphalt concrete pavements it is still necessary to solve a problem pertaining to synchronous obtaining of asphalt granulate of various fractions because it will permit significantly to increase reliability of cold regenerated concrete. Main attention is paid to increase of uniformity in asphalt granulate due to milling of asphalt concrete pavements that does not always allow optimally to regulate frame structure of cold concrete, its strength, deformation properties. In this connection it is expediently to develop a methodology for evaluation of regenerating ability of asphalt granulate and such approach will permit purposefully to optimize compositions of cold regenerated mixtures and improve their physical and mechanical characteristics.

Table 3

European standard (project DIRECT-MAT)

Country Czech Rep.	Emulsion cold mix		Foamed bitumen cold mix	
	Fines (<0.063 mm) ≤6 %	Fine aggregates (<2 mm)	Fines (<0.063 mm) ≤6 %	Fine aggregates (<2 mm)
Finland	4–8 %	–	4–8 %	–
Germany	2–10 %	≥20 %	3–12 %	≥25 %
Portugal, Spain[1)]	1–3 %	15–40 % (h > 10 cm) or 19–42 % (h ≈ 6–10 cm)	–	–
South Africa	4–10 %	25–40 %	2–9 %	25–40 %
[1)] Both Portugal and Spain have specifications for the grading of the reclaimed asphalt material, which must fit one of the required grading envelopes: one for applications in layer thicknesses higher than 10 cm and other for layer thicknesses between 6 cm and 10 cm.				

Table 4

Size and grade of crushed and gravel aggregates according to СТБ 1415–2003-standard of the Republic of Belarus

Constructive layer of pavement	Maximum size of crushed aggregate (gravel aggregate), mm	Content of grains with coarseness, % by weight			Grade of crushed aggregate (gravel aggregate) according to crushing (strength), not less than
		more than 5 mm, not more than	less than 0.63 mm, not less than	less than 0.71 mm, not less than	
Top layer	20	65	24	6	800
	20	50	38	6	400
	15	35	50	4	300
	10	35	50	4	200
Bottom layer	40	70	12	2	800
	40	55	20	2	400
	20	35	30	4	300
	15	35	30	4	200
Note: Volume of grains having coarseness less than 0.071 mm includes hydraulic binder.					

At the same time analytical, experimental investigations in various climatic regions of countries carried out within the framework of international Henan project have shown that longevity, economy, optimum conditions for operation of pavement coatings depend not only on physical and chemical characteristics of roads and environmental systems ("road surface – horizon"; "road surface – heat flows – atmospheric air", afforestation, number (density, load capacity) of transport objects"), these indices depend also on thermodynamic, heat- and mass transfer potentials, thermodynamic parameters of air, air flow rate. Other factors have been noted as well and they represent a complex of challenges concerning exterior and internal problems which has arisen due to actual processes of heat and mass transfer in one layer, multi-layer systems of pavement dressings. At known coefficients of heat conductivity, steam- and mass permeability, diffusion, filtration, temperature conductivity, density of material layers etc. initial and boundary conditions it is possible to carry out optimization of heat- and mass transfer problems from bottom surface of road layer to its base (sand, bulk materials, ground).

For example, considering a road pavement (dressing) as a semi-closed body, whose surface is streamed by air at natural and forced convection according to Newton's law solution of differential equation of heat conductivity leads to the following equation for calculation of temperature fields of one- and multi-layer pavement dressings [5–12]

$$t(x,\tau)=\frac{2}{\sqrt{\mu}}\int_x^{\infty} f\left(\tau-\frac{x^2}{4a\vartheta^2}\right)\exp^{-\vartheta^2}d\vartheta = \\ =\frac{4}{2\sqrt{a\tau}}\int_0^{\tau}\frac{f(\tau-\eta)}{\eta^{3/2}}\cdot\exp\left(-\frac{x^2}{4\eta}\right)^{d\eta}. \quad (3)$$

If road surface temperature is constant then from (3) we can obtain

$$t(x,\tau)=t(0,\tau)\cdot\operatorname{erfc}\frac{x}{2\sqrt{a\tau}}, \quad (4)$$

where $\operatorname{erfc}\frac{x}{2\sqrt{a\tau}}$ – tabulated Gaussian error function (integral); ϑ – excess (difference) temperature of air in boundary layer and road pavement surface; η – ratio of distance from road dressing surface to its total thickness (relative distance); μ – root of modified Bessel function (table value).

In addition to it, while taking into account development of scientific prospective direction that concerns nano-technology and creation of nano-materials for higher reliability of road dressings it is necessary to consider nanomaterial science in road-construction industry as the most actual one because when we study problems pertaining to fractional composition of all road dressing components including transfer to nanomaterials, for example, application of modified water-reducing agent based on nanostructured carbon it is possible significantly to increase physical and technological properties of asphalt concrete and concrete road dressings.

CONCLUSIONS

1. Theoretical and experimental investigations on development of road-construction industry and especially improvement in reliability, strength and mainly longevity of pavement dressing are carried out within the framework of international project with the support of Henan Bureau of Outstanding Foreign Specialists, Grant No. G_TZS 2018006 (People's Republic of China, Henan).

2. Analytical, experimental investigations in various climatic regions of countries have shown that longevity, economy, optimum conditions for interaction depend not only on physical and chemical characteristics of roads and environmental systems ("surface roads – horizon"; "road surface – heat flows – atmospheric air", afforestation, number (density) of transport objects, thermodynamic, heat- and mass transfer potentials, thermodynamic parameters of air, air flow rate.

3. Multi-year in-situ investigations have shown that metastable state of pavement dressings has a limited stability and when affected by relatively small external action it is entered into more stable state (super-cooled vapor), it exists for a short period of time and it is transformed into liquid, saturated, supersaturated steam, over-heated liquid and it depends on micro-macroelements of road surface, presence of external disturbances etc.

4. Longevity, operational characteristics of asphalt-concrete, cement-concrete pavement dressings are significantly determined by stationary, quasi-stationary heat- and mass transfer processes in pavement dressings, dynamic and heat boundary layers at various boundary and initial conditions.

5. It is necessary to continue and expand study of physical and technical and thermophysical properties of new materials on the basis of nano-technologies with application of modified, nanostructured carbon-based plasticizer for construction-road industry because especially these additives significantly increase cement activity that leads to improvement of strength, reliability and longevity for the obtained materials.

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