Improvement of the Quality of Paving

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Abstract

Colloid chemical properties of surface-active substances of different classes and bitumen are investigated, their interaction with the mineral material is studied. New materials and emulsion technologies for road coatings are proposed, which allow one to improve the quality and performance characteristics of roadway.

INTRODUCTION

The Republic of Belarus, having insufficient natural resources and devoid of outlets to the sea, nevertheless has some advantages over other countries. The main one is the geographic position in the centre of Europe, at the intersection of transport ways. The most important transport passages from West Europe to Russia and the countries of Asia, from the countries of Scandinavia to the Black Sea go through the territory of Belarus.

This is the reason of the presence of a branched network of public motor roads total length of which is 63.4 thousand km, including 15.5 thousand km of republican roads and 47.9 thousand km of local ones.

Motor transport carries 74 % of all the cargos and 93 % of passengers. Transit traffic increases. The most busy roads are those of republican importance along which about 70 % of cargos and the same fraction of passengers are carried.

According to the diagnostics carried out during the recent years, it was determined that only 32 % of the length of republican roads correspond to the standard requirements in such characteristics as evenness, adhesion of paving, strength, various defects. The network of local roads is not in the best state, too.

The indicated state of automobile roads has a direct negative effect on social and economical aspects of the development of the Republic's economy and first of all on the performance of motor transport, profitability of enterprises, especially in rural territories, and on life conditions of rural population.

In this situation, the most important condition that helps one to extend the time of normal operation is timely repair of the existing roads. However, this condition is chronically non-fulfilled.

Under the existing conditions, the successful performance of the sector and finally improvement of the state of road network are to a large extent dependent on the scientific and technical policy of Belavtodor Department. The policy is based on the principles of the utmost of saving of the material and energy resources, aiming at the most up-to-date resource-saving technologies and materials.

NEW MATERIALS FOR ROAD PAVING

Under modern conditions, an important role in solving the problems connected with the elevation of technological level and lifetime of motor roads is assigned to new organic binders – bitumen emulsions and modified bitumen – and to cold technologies with their use.

The introduction of cold technologies is carried out according to several main directions: arrangement of rough topping, production of gravel-emulsion mixtures for constructive layers of road paving with the use of local lean quarry material, repeated usage of old asphalt concrete together with emulsion and compositional binders, the use of emulsion for damp-proof coatings, production and application of cold-storage mixtures for patching. A special item is the membrane technology for repair of cement concrete paving. A large-scale introduction of new technologies started in 1997.

Bitumen emulsions

The main problem to be solved with bitumen emulsifying is to obtain the first-kind emulsion with definite colloid-chemical characteristics. The stability of road emulsions as colloid systems should meet complicated requirements. The emulsions should be stable during transportation and storage, after being deposited on the surface of mineral materials they should coagulate at a definite rate which would be optimal for the accepted technology of road construction. A critical value exists for this parameter after which sharp worsening of the properties of paving starts.

During the interaction of cationic bitumen emulsions with mineral fillers, emulsifier molecules get adsorbed on negatively charged centres of the solid surface. At the initial moment of time, adsorption of emulsifier molecules from the free dispersion medium starts, which does not cause any substantial changes in adsorption-hydrate shells of bitumen particles. If the adsorption activity of the mineral material is comparatively low, while the amount of adsorbate turns out to be sufficient to compensate all the active centres on grain surface, the emulsion would not coagulate. Otherwise adsorption will continue to develop due to dehydration and desorption of the emulsifier from the adsorption-protective layer on the surface of bitumen particles, which would inevitably lead to weakening of the structural mechanical barrier around them and to coagulation of the emulsion [1].

The rate of decomposition of the emulsion depends, first, on the composition of the emulsion, second, on the size of particles of emulsified bitumen, third, on the nature and granulometric composition of the mineral material.

Surface-active substances

There is a definite regularity connecting adsorption of surfactants on the surface of a mineral, the rate of decomposition of the bitumen emulsion, and the degree of covering the crushed stone with a binder. The higher adsorption of surfactants on a given mineral, the more rapid is decomposition of the emulsion on its fine fractions, which results in incomplete coating of large grains of crushed stone with bitumen. So, the formation of coatings from emulsion-mineral mixtures is determined by adsorption equilibrium processes at the interfaces bitumen–emulsifier–mineral material. The main parameter limiting the time of destruction of bitumen emulsion during its interaction with the mineral material is desorption of surfactant molecules adsorbed on bitumen surface. Investigation of colloid-chemical properties of surfactants based on amines of different chemical structure is the basis on which it is possible to develop new receipts of bitumen emulsions and the technologies of their application.

We investigated colloid-chemical properties of a number of emulsifiers based on di- and polyamines, quaternary ammonium bases (QAB), amidoamines, imidazolines and their mixtures, and developed the procedure of quantitative determination of the adsorption of amine derivatives on the mineral material.

Adsorption isotherms of amine-containing compounds used as emulsifiers of bitumen emulsions on granite with the fractions less than 0.071 (with the specific surface of 8 m^2/g as determined by benzene vapour adsorption) *versus* their equilibrium concentration in solution are shown in Fig. 1. The analysis of these data shows that the adsorption of QAB on granite surface is substantially lower in comparison with di- and polyamines. This is likely to be due to the steric factor: diffusion of bulky QAB cations to sorption-active centres of granite is hindered, which prevents the formation of a tightly packed adsorption layer of emulsifier on its surface. So, the reagents may be arranged

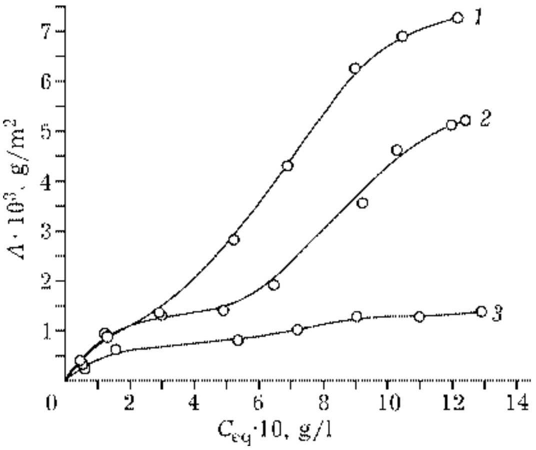

Fig. 1. Adsorption isotherms for surfactants on granite surface: *1* – diamine, *2* – polyamine, *3* – quaternary ammonium bases.

in the following row according to their surface and adsorption activity at interfaces: alkyl diamines > alkyl polyamines > salts of quaternary ammonium bases [2].

Hihg surface activity and adsorption ability of alkyl propylenediamine provides, on the one hand, its lower consumption in obtaining bitumen emulsions, on the other hand, rapid decomposition of the emulsion when in contact with a mineral material, and high adhesion strength of the bitumen film to the solid surface. These emulsifiers are used in rapidly decomposable bitumen emulsions, for example, for the surface treatment of road paving.

Emulsifiers based on polyamine derivatives are distinguished by lower tendency to get adsorbed on a mineral material, so the destruction of emulsions obtained with these compounds occurs somewhat slower, which allows one to use them in technologies connected with the production of emulsion-mineral mixtures in mixers directly at paving sites. These emulsions are not decomposed during a definite time of residence in mixers, while rapid decomposition is observed during paving. So, to obtain slowly decomposable bitumen emulsions, emulsifiers based on polyamines or their mixtures with alkyl aminoimidazolines are used [3].

Mineral materials

Adsorption of emulsifiers on the surface of a mineral material depends on the mineralogical composition of the material used to prepare emulsion-mineral mixtures.

Our X-ray diffraction investigations of the component composition of dust-like fractions of granite crushed stone from the Mikashevichi quarry allowed us to state that, along with fine granite and quartzite fractions, they incorporate clayish and carbonate minerals; their specific surface and sorption volume are shown in Table 1.

It is evident that the presence of clayish and carbonate minerals possessing high specific surface and a large number of negatively charged sorption-active centres leads to an increased adsorption of emulsifier molecules, which causes rapid decomposition of bitumen emulsions. This is one of the main and determinant factors of the negative effect of these admixtures on structure formation processes in emulsion-mineral mixtures.

It was established on the basis of the investigation of the interaction of QAB with granite and mineral materials included in dusty fractions that their adsorption on clayish minerals is much higher than on granite and varies in the row: montmorillonite > kaolinite > dolomite > granite > quartzite, which is confirmed by the calculated adsorption characteristics and the results of thermogravimetric measurements carried out by means of differential thermal analysis. This

TABLE 1

Structural sorption characteristics of mineral materials

Mineral	Sorption volume (v_s), cm^3/g	Specific surface (S_{sp}), m^2/g	Macropore radius (r_{eff}), nm
Montmorillonite	0.135	140	1.9
Kaolinite	0.035	34.6	2
Dolomite	0.013	18.2	1.4
Granite	0.009	8	24
Quartzite	0.008	15	10

allowed us to substantiate the efficiency of QAB and their salts as stabilizers of the rate of decomposition of emulsion-mineral systems which are used to prevent the unfavourable effect of dust-like fractions on the formation of a binder film on the surface of a mineral material. These surfactants are introduced into the emulsion-mineral mixture at the stage of wetting the mineral material; due to relatively low adsorption activity with respect to granite, they are easily desorbed from its surface getting fixed on fine grains of the mineral material, first of all clayish and carbonate one.

One of the main properties of bitumen emulsions providing their suitability in a specific technology of road making is their viscosity. The viscosity of emulsions should prevent the binder from flowing into lower regions and ensure easy spreading with usual distributors.

The viscosity of bitumen emulsions is determined, first of all, by the nature of the disperse phase, that is, the origin of bitumen, its penetration, and the presence of a plasticizer; second, by the nature of the disperse medium – type and amount of surfactants, the presence of inorganic electrolyte; third, by the granulometric composition, or particle size of the emulsified bitumen.

It is evident that the viscosity of bitumen emulsions depends on the amount of bitumen present in it. However, granulometric composition of the emulsion should be taken into account, too. The smaller are the particles of the disperse phase, the larger number of the droplets of emulsified bitumen is present in the emulsion for the same total content, and the higher is viscosity of emulsion. To obtain a fine bitumen emulsion, along with changes in emulsifier consumption, it is necessary to follow the optimal temperature regime when preparing the aqueous and bitumen phases, and to control the characteristics of the bitumen phase. In particular, changing the structural and rheological characteristics of bitumen by adding liquefiers or polymers one can obtain emulsions with the required physicochemical properties for different kinds of surface treatment.

Fundamental research into the colloid chemical properties of the surfactants of different classes that is carried out in IGIC, NAS of Belarus, during a number of years, close collaboration with road-making organizations, home and foreign scientific and technological centres allowed one to accumulate the experience necessary to develop new emulsifiers of petroleum hydrocarbons, paraffins and bitumen, and to introduce advanced energy- and resource-saving technologies into the road-making industry of Belarus.

NEW EMULSION TECHNOLOGIES FOR ROAD PAVING

Technology of the arrangement of surface treatment

Surface treatment is responsible for the upper layer of road coating; it consists of the bitumen binder and fractionated crushed stone. This technology needs rapidly decomposable cationic bitumen emulsions with bitumen content 60–69 % (65 % being the optimal value). Depending on the necessary hardness of paving and taking into account the traffic intensity, various designs of the rough layer are chosen. An important parameter is the quality of crushed stone, which is to have a definite shape, be maximally pure and contain no clayish impurities.

The group composition and physicochemical characteristics of oxidized bitumen from the Mozyr and Novopolotsk plants were investigated at the IGIC, NAS of Belarus. It was shown that low acid number is characteristic of the bitumen from the OPP of Belarus: 0.245 and 0.395 mg KOH/g for the nitumen from the Novopolotsk and Mozyr plants, respectively; high pyrobitumen content is also characteristic, which results in an increase in emulsifier consumption for obtaining bitumen emulsions.

In order to govern the quality of road bitumen used to make bitumen emulsions, we studied the effect of some oil fractions on their properties. The composition of oil fraction No. 1, %: aromatic hydrocarbons 2–15, alkanes 45–55, cycloalkanes 50–60; the content of aromatic components in fraction No. 2 reaches 20 % with increased content of paraffins of medium and heavy fractions.

Curves plotting changes in the physicochemical characteristics of bitumen *vs*. the concentration of the additive introduced is shown in Fig. 2.

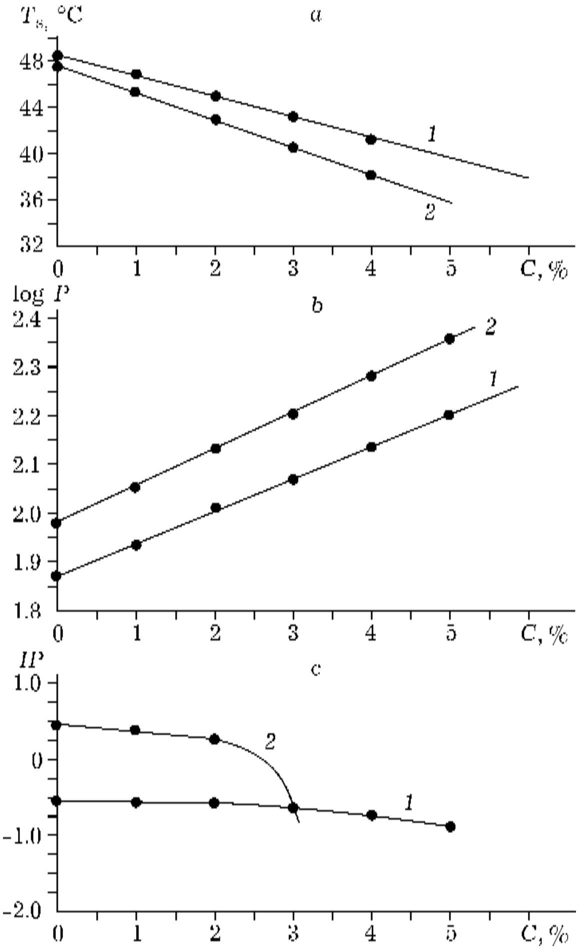

Fig. 2. Effect of the consumption of oil fractions Nos. 1 (*1*) and 2 (*2*) on colloid-chemical properties of bitumen: *a* – softening point, *b* – penetration, *c* – penetration index.

Bitumen is a complicated colloid system in the metastable state in which the equilibrium is due to the set of many factors, first of all temperature and dissolving ability of the dispersion medium. Addition of liquefiers disturbs the colloid equilibrium in the system, which is exhibited as the changes in structural-rheological and physicochemical characteristics of bitumen [4].

One can see in Fig. 2 that, within the entire region investigated, an increase in the amount of the liquefier is accompanied by almost linear decrease in softening temperature (see Fig. 2, *a*) and in penetration logarithm (see Fig. 2, *b*) for the bitumen; however, the slope ratio is larger with oil fraction No. 2 added. In addition, with this additive, even within the concentration range 2–3 % a sharp pip is observed on the curve of penetration index (see Fig. 2, *c*), which is an evidence of changes in the colloid structure of bitumen.

The group composition of basic bitumen from the Mozyr and Novopolotsk Oil Processing plants (MOPP and NOPP, respectively) and bitumen plasticized with oil fractions Nos. 1 and 2 (in the amount of 5 %) is shown in Table 1. Determination was carried out according to the requirements of the State Standard GOST 11244–76.

Analysis of these data shows that the addition of oil fraction No. 2 into the bitumen dispersion medium promotes peptization of

TABLE 2

Group composition of bitumen

Group composition, %	Bitumen			
	basic (MOPP)	with fraction No. 1 added	basic (NOPP)	with fraction No. 2 added
Oil				
Naphthene-paraffin	14.4	16.3	10.2	16.2
Aromatic:				
monocyclic	11.5	12.5	13.3	13.8
bicyclic	6.7	7.6	4.8	8.3
polycyclic	7.5	8.0	16.4	4.5
Total	40.1	44.4	44.7	42.8
Resin				
Alcohol-benzene	4.5	6.3	15.1	4.0
Benzene	31.3	23.6	15.2	33.0
Total	35.8	29.9	30.3	37.0
Pyrobitumen	24.2	25.8	25.0	20.3

TABLE 3

Characteristics of bitumen emulsions prepared on plasicized bitumen

Characteristics	Emulsion, bitumen phase		
	A, bitumen BND 60/90	B, bitumen with fraction No. 1 added	C, bitumen with fraction No. 2 added
Binder content, %	61.5	60.1	61.5
Viscosity, °E	3.2	3.0	3.5
Decomposition index	89	78	96
Particle size, μm:			
d_{50}	8.95	9.92	7.43
D (3,2)	5.3	4.95	4.6

pyrobitumen, which results in a decrease in their relative amount for deposition with light petroleum (40/70), while the colloid structure of bitumen approaches the sol type. Because of this, with a heavier oil fraction No. 2, its amount in the binder should not exceed 1–2 %.

The introduction of paraffin-naphthene hydrocarbons into the mixture results in a decrease in the solubility of pyrobitumen in the bitumen dispersion medium. This causes some increase in its concentration in the disperse phase, which results in a more smooth decrease in bitumen penetration coefficient [5]. With the light oil fraction No. 1 as liquefier, its content can be varied within the range 1–3 % without any essential changes in the colloid structure (see Fig. 2, *c*).

The physicochemical characteristics of bitumen emulsions prepared with the basic bitumen BND 60/90 and bitumen plasticized by 3 % of oil fractions Nos. 1 and 2 are shown in Table 3. One can see that the addition of a low-boiling component is accompanied by an increase in mean particle size of the emulsion; therefore, the index of emulsion decomposition decreases. However, depending on weather and climatic conditions and on the materials used, both emulsions are suitable for surface treatment, have low thermal sensitivity (meet the requirement $\eta_{10}-\eta_{20} < 0.3\eta_{20}$ and $\eta_{20}-\eta_{40} < 0.3\eta_{20}$) and provide good covering of the mineral material.

The performance characteristics of the surface treatment are determined by the type of binder used for the treatment. A binder should be rather soft to provide good covering of the crushed stone and primary adhesion of bitumen, but al the same time it should be sufficiently viscous to prevent crushed stone detachment and plastic deformations under traffic. Because of this, the decisive criterion of suitability of an emulsion with liquefied bitumen for surface treatment is estimation of the quality of a binder extracted from the emulsion (Table 4) [6].

One can see that the introduction of a heavier oil additive No. 2 leads to changes in the rheological properties of the binder extracted from the emulsion, up to a change in bitumen grade. This, in turn, slows down the formation of the protective layer of surface coating and worsens the strength characteristics of the binder. Because of this, it is preferable to use light oil fractions is liquefiers.

TABLE 4

Characteristics of the residual binder extracted from bitumen emulsions

Characteristics	Bitumen			
	Initial	Extracted from emulsion		
		A	B	C
Melting point according to ring and ball method , °C	55.0	54.5	53.0	50.5
Penetration, ×0.1 mm	74	71	78	96

The use of a binder modified with a polymer allows one to broaden the range of application of surface treatments with bitumen emulsions due to improvements in binder cohesion, especially at low temperature, and prevention of crushed stone detachment, including the regions with heavy lorry traffic and motorways.

It should be kept in mind that bitumen-elastomer emulsions can be, first, of the two-phase type, prepared by mixing bitumen, emulsifier and latex (latex is an emulsion of a polymer in the aqueous phase), the latter being introduced into the aqueous phase of bitumen emulsion when preparing it or into the final emulsion before using it; second, emulsions can be obtained with bitumen modified preliminarily with polymers. Till present, definite difficulties accompany emulsifying if modified bitumen. Modified bitumen emulsions with cationic butadiene-styrene latex does not cause any difficulties and can be used at every emulsion plant.

On the basis of research, the IGIC, NAS of Belarus, together with BeldorniiNII Institute developed recommendations concerning surface treatments; the recommendations were approved by the Ministry of Transport and Communications of the Republic of Belarus.

ARRANGEMENT OF PROTECTIVE LAYERS OF PAVING OF THE SLURRY SIL TYPE

High performance characteristics of the coatings made of emulsion-mineral mixtures prepared directly at the paving site are achieved by meeting all the technological requirements and maturing of these mixtures under proper weather and climatic conditions.

Desinging of the protective coatings made of Slurry Sil mixtures includes the following stages:

1. Selection of the component composition of the emulsion-mineral mixture (firs of all, the mineral material and bitumen emulsion) with the characteristics providing the best compatibility with the mineral material used.

2. Development of the receipt of Slurry Sil, including the possibility to control the properties of the mixture during laying.

3. Estimation of the physicomechanical properties of the coating fro the purpose of providing high performance characteristics of the protective layer.

Five main stages of the interaction of bitumen emulsions with the mineral materials during the formation of the binder can be distinguished in arranging the protective coatings of road paving of Slurry Sil type [7].

The first stage involves Slurry Sil mixing is a laying machine. Bitumen emulsion does not lose stability; no interaction with the mineral material is observed. This allows one to mix all the components without decomposition.

At the **second stage**, coalescence of bitumen droplets of the emulsion is observed, that is, the layers of aqueous phase between them decreases in size, and the Slurry Sil mixture thickens when passing out of the distributor. The interaction of emulsion with the mineral material has a reversible character at this stage.

At the **third stage**, a bitumen spongy film us formed, which is connected with the presence of a definite amount of emulsifier on the surface of bitumen droplets, and with the excess amount of emulsifier (in the case when its amount was not optimized but is overcharged) in the aqueous phase. This occurs even during Slurry Sil maturing on a road. However, this stage has a reversible character, too, because the presence of emulsifier can lead to re-emulsification of bitumen in the case of excess amount of water, due to wet weather, rain, *etc.*

The **fourth stage** is characterized by an increase in the cohesion strength of Slurry Sil on a road due to the interaction of emulsifier molecules with the surface of the mineral material with the formation of a continuous bitumen film. Water separation and shrinkage of the mixture occur. In the case of unfavourable weather conditions and in the presence of more active components in the mineral material on which the surfactants from the bitumen emulsion can get adsorbed, the formation of a friable bitumen film may be possible, which would not lead to an increase in cohesion strength.

Only at the **fifth stage**, in the case of absence of any unfavourable conditions described in the first four stages, a continuous bitumen film is formed, the mixture gets thickened and reaches high cohesion strength.

So, the rate of the formation of coatings from emulsion-mineral mixtures is determined by the processes of surfactant redistribution over the bitumen–mineral material interface. To develop optimal compositions of emulsion mineral mixtures, the effect of the nature of emulsifier and stabilizer of decomposition rate, ionic force of solution on the rate of coating formation was investigated at the IGIC, NAS of Belarus. This allowed us to elaborate reasonable requirements to choosing optimal surfactant systems: emulsifier–stabilizer of decomposition rate, taking into account the raw material and other materials to be used. Technological regulations were elaborated for the production of bitumen emulsions with controllable decomposition rate. Patents of the Republic of Belarus were obtained for a new cationic emulsifiers based on diamines and oxyethylated amines, as well as for a stabilizer of the decomposition rate of bitumen-latex emulsion based on alkyl amine oxides which is used to prepare an emulsion-mineral mixture for arranging protective topping of the Slurry Sil type.

The experience of the IGIC in developing the technology of arranging the protective layers of paving like Slurry Sil for Minsk and in monitoring their state allowed one to develop Recommendations on the technology of arrangement of protective layers of paving from cold emulsion-mineral mixtures which was adopted by the Ministry of Housing and Communal Services on July 22, 1997.

According to the developed technology, more than 1 million m^2 of the protective layers were laid in the streets of Minsk. Detachment of the mineral material from the protective layer during two years did not exceed 20–30 %, no destruction of the main asphaltic concrete pavement was observed after 5 years of the performance of rebuilt roads was observed. At present, arrangement of protective layers of road paving of the Slurry Sil type is being made at the arterial roads of Belarus.

Gravel-emulsion mixtures

The introduction of the technology of storable emulsion-mineral mixtures of different kinds into the road making practice required the development of special compositions of bitumen emulsions, gravel-emulsion mixtures (GEM) and mixtures for patching on the basis of local materials, and also methods to estimate their structural mechanical characteristics [8].

The gravel-emulsion mixture is a bitumen-mineral mixture of the cold type based on the crushed mineral filler with continuous grain composition, mainly sandy-gravel, a slowly decomposing bitumen emulsion and water. In some cases, various active and inactive additives are used.

Compositions of the bitumen emulsions for GEM were developed at the IGIC. On the basis of these compositions, more than 30 000 t of emulsion for gravel-emulsion mixtures were manufactured. In addition, together with IGIC and BeldorNII Institute, tests of sandy gravel mixtures from quarries used by road-building organizations of the Minsk Region were carried out, and recommendations on the technology of obtaining and applying gravel-emulsion mixtures were developed.

As a result of experimental and industrial tests, the following facts were established.

1. Gravel-emulsion coatings 50–60 mm thick arranged on the gravel base possess sufficient carrying capacity for traffic and load corresponding to the IV–V motor road categories.

2. From the economical point of view, gravel-emulsion coatings 6.0 cm thick with a layer of single surface treatment are cheaper by 8–15 % than a hot coating from a porous mixture with the surface treatment.

3. Expenses of fuel and energy per unit final product in making gravel-emulsion coatings are lower by 45–55 % in comparison with hot asphalt concrete.

4. The possibility to keep the mixture stored and perfect ecological safety are additional advantages of the gravel-emulsion technology.

5. During performance under load, after 3–4 months since the traffic has been opened, the strength characteristics of GEM increase by 60–70 % and reach the absolute values characteristic of the hot asphalt concrete. It should be specially stressed that the indicated strength characteristics are achieved with the binder content of 4.5–5.5 %, while for asphalt concrete it is 5–9 %.

The results obtained allow us to state that the mixtures of the type of gravel emulsions based on local fillers can be competitive with respect to the hot asphalt concrete mixtures and are to find application in road building, especially in rural areas.

Cold storable emulsion-mineral mixtures for patching

Storable emulsion-mineral mixtures for road repair attract the attention of road-building organizations due to the advantages connected with the possibility of long-term storage in a storehouse within a wide temperature range, complete independence of repair works unaffected by the position of manufacturing facilities, and the possibility to carry out repair works in winter.

Cold mixtures based on bitumen emulsions have the following advantages:

– the use of wet stone material is admissible;

– 10 to 30 % of bitumen is saved due to the improvement of covering of the stone material with the emulsion;

– preparation and laying can be carried out under unfavourable weather conditions;

– due to the activity of the emulsion, adhesion-cohesion properties of bitumen are enhanced;

– a uniform distribution of the binder over the whole surface of the stone material is provided due to the formation of a thin bitumen film covering each mineral grain;

– adhesive properties of bitumen are improved because viscosity of emulsified bitumen increases in comparison with the usual one when temperature decreases;

– the technology of works becomes simpler.

An efficient technology of preparation and application of storable emulsion-mineral mixtures based on bitumen emulsions with adhesive additives and fractioned crushed stone used for road repair works all year round has been developed at the IGIC [9].

At present these mixtures are widely used for patching in many road-building organizations of the Republic. In particular, Gomelobldorstroy enterprise had carried out more than 350 000 m^2 of patching.

As a total, during the five years since the start of introduction of the listed technologies, 151.7 thousand m^3 of crushed stone and 9090 t of bitumen were saved only in the Minsk Region. In addition, fuel and energy resources saved account for: boiler and furnace fuel 1246 t (of standard fuel), electric power 2198 000 kW h, heat 706 Gcal.

In the financial aspect, the savings are: in surface treatment – 28 cents (36 %), in the membrane technology – $ 2.03 US (30.8 %), in gravel mixtures – $ 0.81 US (21.5 %), in asphaltogranulated conrete paving – $ 1.8 US (47.7 %) per one square metre.

In addition, it should be stressed that the introduction of new technologies provides also an increase in traffic safety level. In fact, the existing friction coefficient of the automobile wheel with the surface of paving was 0.33–0.38 on the motor roads in the republic; after toppings with bitumen emulsions were made it became 0.6–0.71. This shows an increase in the level of traffic safety by about 50 %. The action of the environment decreases, too, because only water vapour is released into the atmosphere in the case when emulsion is used.

The noise level with asphalt concrete paving reaches 80 dB, with the crushed stone fraction of 5–20 mm it is 88 dB, with toppings based on bitumen emulsions and crushed stone of 6.3–10 mm it is 77 dB. The use of the crushed stone of 4–6.3 mm fraction allows one to decrease the noise to a level corresponding to the standards accepted for settlements in West Europe.

CONCLUSIONS

The new technologies imply also a new approach to the quality of works. It should be stressed that a successful introduction of new energy- and resource-saving technologies based on bitumen emulsions is possible only with a complex of technical, scientific, managerial measures, namely:

1. The use of high-quality initial materials (bitumen, fractionated cubiform crushed stone, emulsifiers).

2. The use of new materials and technologies requires special machines.

In order to save foreign currency which is necessary for buying foreign expensive machines, Minskobldorstroy enterprise organized the production of home machines at the Dorvektor Plant (Molodechno): auto-distributors AGDS-3600 intended for transportation and distribution of bitumen materials (bitumen, bitumen emulsions), both in the hot and in the cold state, and crushed stone distributors: hitch ShchRDS-1400 and towing ShchRD-3,5, intended for the distribution of an ordered layer of a friable inert material for arranging the surface treatment of motor roads with solid paving, milling road installation FUD 0.4, etc. Since 1998, organizations of the Minsk Region use the following mechanisms to repair road paving by impregnating with bitumen emulsion: 1) patching set-up mounted at tractor tipping trailer 2-PTS-4: 2) a kit for patching of asphalt concrete paving BTsM-24 manufactured by Bitsema JSC (Russia). At present, the production of the home set-up for patching UDV-2000 is established. Gomelobldorstroy enterprise works successfully in this direction, too. The production of machines for repair works according to the patching technology and auto-distributors for surface treatment was also established at the facilities of this organization.

3. It is necessary to develop new compositions of bitumen emulsions, to optimize them by using new emulsifiers, to carry out comparative analysis of economical and technological efficiency of the known and workable home and foreign emulsifiers in order to decrease expenses for the production of bitumen emulsions.

4. It is necessary to broaden the use of cold energy- and resource-saving technologies for road building on the basis of bitumen emulsions, in particular, for patching, ground reinforcement, dust binding, arrangement of surface coatings of Slurry Sil type, cold recycling of asphalt concrete paving, *etc.*

Taking into account the advantages of cold technologies, one should firstly provide the transition of the technologies of the surface treatment of asphalt concrete paving to emulsion technologies with two fractions of small cubiform crushed stone, which will allow one to reduce expenses for patching, decrease specific consumption of crushed stone, increase the lifetime of surface treatments; second, during thorough repairs of cement concrete paving, it is recommended to replace the direct reinforcement using two-layer asphalt concrete with the membrane technology based on modified bitumen or with the gravel-emulsion technology involving thin-layer covering or double surface treatment; third, during thorough repairs of gravel coatings it is necessary to pass completely to the arrangement of closing layers with the help of gravel emulsion technology and reinforcement with emulsion; fourth, it is necessary to manufacture the main amount of repair asphalt concrete according to the cold technology, which will allow one to exclude completely the consumption of residual fuel oil and decrease expenses for depreciation of the set-up used for production; fifth, the simplest mixing equipment of high unit power should be used in the production of gravel emulsion mixtures in order to decrease depreciation expenses.

5. The fraction of emulsion technologies in road building should account for 27–30 %, while for making adhesion layers, surface treatment and patching is should be 100 %.

6. The system of quality monitoring should be established for the works according to emulsion technologies; it is necessary to provide scientific escort of these works (this has already been done in the leading European countries), which will allow us to avoid mistakes in using bitumen emulsions. The introduction of new technologies requires higher production standards, permanent elevation of the skill of service personnel, the presence of modern laboratory equipment, examination of the foreign experience.

All the expenses for these measures are multiply compensated due to the advantages of cold technologies, as evidenced by the home and world experience.

The success and efficiency of the performance of road building branch strongly depend on the scale and thoroughness of research and development.

REFERENCES

1 O. N. Opanasenko, N. P. Krutko, O. I. Starostina, L. V. Ovseenko, *Dokl. AN Belarusi*, 40, 3 (1996) 76.

2 O. N. Opanasenko, O. I. Starostina, L. V. Ovseenko, V. T. Kudelko, Emulsifiants cationiques pour la fabrication

des emulsions de bitume, Deuxeme Congress Mondial de l'emulsion: Congress proc., Bordot, 1997, vol. 1, p. 102.
3 O. I. Starostina, O. N. Opanasenko, L. V. Ovseenko, Yu. V. Loboda, Grav-emulsionnye smesi dlya dorozhnogo stroitel′stva, in: Vibrotekhnologiya–98, Odessa, issue 8, part 2, pp. 68–70.
4 O. N. Opanasenko, L. V. Ovseenko, O. I. Starostina, Bitumnye emulsii dlya dorozhnogo stroitel′stva: Metody analiza, Belsens, Minsk, 1999, 38 p.
5 O. N. Opanasenko, N. P. Krutko, L. V. Ovseenko, O. I. Starostina, Rekomendatsii po tekhnologii proizvodstva rabot po ustroystvu zashchitnykh sloyev dorozhnykh pokrytiy iz kholodnykh emulsionno-mineralnykh smesey, Belsens, Minsk, 1999, 36 p.
6 O. N. Opanasenko, L. V. Ovseenko, O. I. Starostina *et al.*, The Influence of Petroleum Distillate on the Structural-Rheological Performances of Bitumen Binders. Eurobitume, Workshop Briefing, Luxembourg, 1999, No. 011.
7 O. N. Opanasenko, N. P. Krutko, L. V. Ovseenko, O. I. Starostina, The Influence of the Properties of Bitumen on the Physical-Chemical Characteristics of Bitumen Emulsions, Proc. of the Int. Symp. on Asphalt Emulsion Technology, Nov. 11–14, 1999, Washington, 1999, pp. 95–101.
8 N. P. Krutko, O. N. Opanasenko, O. I. Starostina, L. V. Ovseenko, The Use of Emulsion-Mineral Mixes for Road Building in Belarus, *Ibid.*, pp. 161–166.
9 N. P. Krutko, O. N. Opanasenko, O. I. Starostina *et al.*, Katioonye PAV-effektivnye emulgatory neftyanykh uglevodorodov, in: Sintez, struktura i svoystva neorganicheskikh veshchestv i kolloidnykh sistem, Minsk, 2000, pp. 50–58.