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ADHESION OF BITUMINOUS BINDERS WITH AGGREGATES IN THE CONTEXT OF SURFACE DRESSING TECHNOLOGY FOR ROAD PAVEMENTS TREATMENT

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In this article the study is done for the adhesion of aggregates coming from various granite quarries of Ukraine with bituminous binder, namely with bitumen emulsion – for application in surface dressing technology for road pavements treatment. In the article there are used the Ukrainian and European testing methods for determination of adhesion in the "bitumen – aggregate" system. According to the Ukrainian method, there was determined the adhesion of residual binder with the chips surface after boiling in the distilled water and in the solution of glycerin and distilled water. As the European method, for the studies there was used Vialit Plate Shock Test. There were developed three bitumen emulsion formulations.

Key words: thin-layer road pavement, surface dressing, bitumen emulsion, hydrochloric acid, orthophosphoric acid, adhesion of bituminous binder with chips, Vialit Plate Shock Test.

Introduction

Thin-layer pavements done by surface dressing technology is wide-spread version for saving and sealing-in the top courses of road structures (DSTU-N B V.2.3-38:2016). One of the main characteristics for these pavements is adhesion between bituminous and mineral materials, which are the components of the road pavements. Nowadays this adhesion is determined by not always correct methods based on correctly selected bituminous binders (inclusive with bitumen emulsions). Therefore, it looks useful to pay attention to the efficient approach in development of bitumen emulsion formulation for surface dressing technology, as well as to propose the effective methods for evaluation of adhesion in the "emulsion – aggregate" system.

The analysis of scientific literature data has shown that the modern scientists pay the major attention to the study of bitumen emulsion component (with regard to surface dressing technology) (Zhdaniuk, 2008; Solodkyy, 2018; Sidun, 2020), as well as to the methods for evaluation of adhesion between the components of surface dressing and non-skid qualities on the surface dressing done (Ilchenko, 2011; Pavlyuk, 2010; Pavlyuk, 2013).

The main weak point of this technology is not always excellent adhesion of aggregate with bituminous binder (this binder being represented either by bitumen or by bitumen emulsion). It is known that adhesion of the residual binder (extracted from bitumen emulsion) with aggregate is better than adhesion of the initial bitumen with that very aggregate. It is due to the fact that residual binder contains not just bitumen, but also emulsifier (surfactant), which improves adhesion between binder and mineral

surface. Correspondingly, the wide-spread in the world today is the trend for surface dressings with bitumen emulsion (but not bitumen) applied. Besides of that, there exist another number of technological reasons, causing to use just bitumen emulsion (clogging nozzles of motor tar sprayer when hot bitumen is applied etc.).

Adhesion of binder with aggregate is subject to regulation in Ukraine by state standard (DSTU 8787: 2018). The essence of the method is in determination of ability of bituminous binder, applied upon the chips surface, to counteract the stripping effect of the water. The adhesion quality is evaluated by the saving degree for the bituminous binder film on the chips after boiling in water. This method is versatile from the point of view of all the road technologies, but it does not take into account the specific features of each of them (in particular, also the technology of surface dressing). Between the modern domestic methods for evaluation of surface dressing stability there is the development of National Transport University, which is realized in the construction of centrifugal machine for determination of adhesion strength CP-NTU. The essence of the method is in determination of ability of binder material to retain chips on metallic plates upon the effect of centrifugal force applied to the testing samples of surface dressing (Pavlyuk, 2011; Pavlyuk, 2010). As to the drawbacks which can be attributed to this method, it can be mentioned that its principle of action does not reflect the real process of aggregate stripping in the surface dressing course.

The most wide-spread in the world method for determination of adhesion properties of the binder and filling aggregates for the pavements made by the surface dressing technology is Vialit Plate Shock Test (EN 12272-3:2004; Louw, 2004). Although there also exist other laboratory and field methods: Frosted Marble Cohesion Test (Howard Isaac L., 2013; Ozdemir, Ugurcan, 2016.), Sweep Test of Bituminous Emulsion Surface Treatment Samples (Ozdemir, Ugurcan,2016; ASTM D7000 – 19a), Pennsylvania Aggregate Retention Test (Kandhal, 1991), Australian Aggregate Pull-out Test (Queensland Department of Transport and Main Roads, 2012), British Pendulum Test (ASTM E303 – 93; EN 13036-4:2011), Pneumatic Adhesion Tension Test (Zhou,2014). In general, the majority of scientists give special attention to technological aspects of performing the surface dressings (Vasiliev, 1999; Rvacheva, 2004; Kochetkov, 2007; Ilchenko, 2011).

Target of this article

To investigate the adhesion of aggregates with bituminous binder (bitumen emulsion) by both the Ukrainian and European testing methods – for application in surface dressing technology with regard to road pavements.

Testing methods

For the study of adhesion for aggregates with bitumen emulsion there was chosen the popular in Ukraine method for determination of binder-to-chips surface adhesion DSTU 8787:2018, as well as popular in Europe Vialit Plate Shock Test (EN 12272-3:2004; Louw,2004; yi, Junyan, 2013).

By testing method DSTU 8787:2018 there was determined the adhesion of binder (extracted from emulsion after its breakage) with chips surface – by two methods, which differed by the medium for chips boiling. First of all, the cleaned from dust and dirt chips grade 20–40 mm were tied round by thread and immersed (in non-heated state) for 1–2 seconds into distilled water (letting it flow off during 15±5 seconds), immersed three times into heated till 70°C bitumen emulsion and hanged on support for storing during 24 hours at (20±5) °C.

According to method No1, after storing chips they were boiled in distilled water. To provide for that, the chemical flask was filled for 2/3 of its volume by distilled water and heated till 9 5°C. The emulsion-treated chips were immersed into heated water (so that they did not touch the walls and the bottom) and cured at given temperature during 30 min (Fig. 1). The binder floating up to the surface during the boiling was removed by filter paper. After 30 min of boiling the chips were removed from the

water medium and subject to visual evaluation (by 5-point grading scale with increment size 0.5 point) by the extent of bituminous binder coating (Table 1).

Table 1

Evaluation of quality for adhesion of bituminous binder with chips

Degree of retaining the bituminous binder film on the chips surface	Evaluation of adhesion quality, points
Bituminous binder film remained on the chips surface; it is admissible to have not more than 2 places non-covered by bituminous binder, the diameter of each of which not exceeding 1.0 mm	5.0
Bituminous binder film partly separated from angles or ribs and/or remained on more than 90 % of chips surface	4.5
From 75 % to 90 % of chips surface remained coated by the bituminous binder film	4.0
From 60 % to 75 % of chips surface remained coated by the bituminous binder film	3.5
From 40 % to 60 % of chips surface remained coated by the bituminous binder film	3.0
From 20 % to 40 % of chips surface remained coated by the bituminous binder film	2.5
Bituminous binder film remained on less than 20 % of the chips surface	2.0
Note: During the adhesion quality evaluation each range of chips surface covered by binder contains the value of lower limit and does not contain the value of top limit.	

Method No2 is similar to method No1, but chips boiling occurred in water and glycerin solution in ratio 1 to 5 and at 105 °C (Fig. 2).

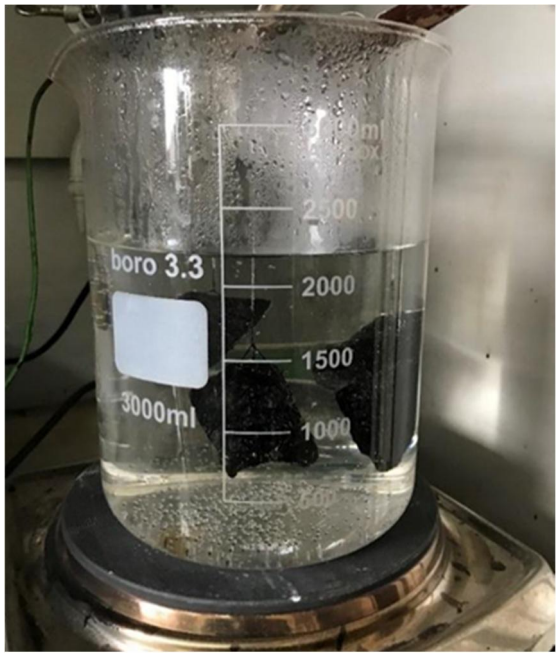

Fig. 1. Chips boiling in distilled water

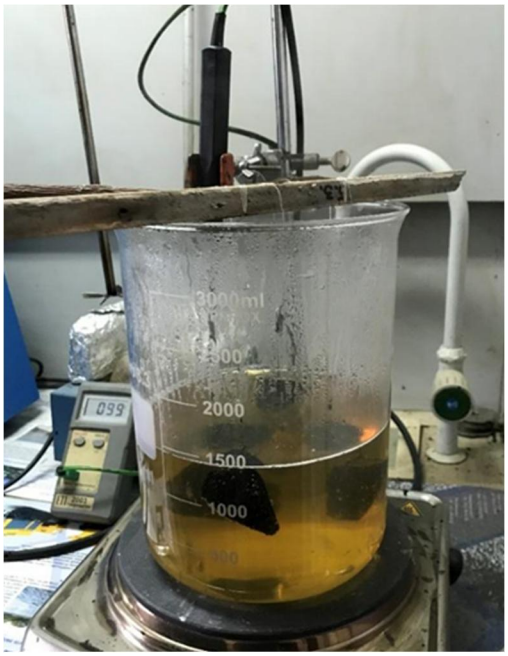

Fig. 2. Chips boiling in distilled water with glycerin

The essence of Vialit Plate Shock Test (EN 12272-3:2004) is in determination of binder's capability to retain the aggregate on a metal plate at shock effect. When running the testing by Vialit method there was taken into account both the domestic and the world experience and performance conditions for surface dressing technology. Therefore, for testing there was used chips grade 5–10 mm, and placed upon Vialit plate there were 100 pieces chips of the said grade. Besides, there were made calculations on the amount of binder, required for placing upon Vialit Plate. According to DSTU-N B

V.2.3-38:2016, the average norm of bitumen consumption per 1 m² constitutes 0.7–0.8 L – when one-layer surface dressing is done with one-stage chips application. The Vialit Plate area constitutes 0.04 m². It was proposed to test adhesion of binder with filling aggregates with different bitumen emulsion quantity (different bitumen content in emulsion), spread upon the plate (versions 1–3).

Version 1. The required bitumen quantity is determined (at its consumption of 0.8 L/m^2 and bitumen in emulsion quantity 65 % w/w), this bitumen to be distributed upon the plate area 0.04 m^2: 0.8·0.04=0.032 L= 32 ml. The 65 % bitumen emulsion quantity is determined, required to be distributed upon the plate: 32/0.65 =49.23 ml. So as to check: 49.23·0.65 =31.9995 ml ≈ 32 ml. Thus, in the final version 1 the accepted distribution upon the plate is 49.23 ml of bitumen emulsion.

Version 2 Similar to version 1, but in this version 62 % bitumen emulsion was used. Therefore, the quantity of 62 % bitumen emulsion to be distributed upon the plate: 32/0.62 =51.61 ml. So as to check: 51.61·0.62 =31.9982 ml ≈ 32 ml. Thus, in the final version 2 the accepted distribution upon the plate is 51.61 ml of bitumen emulsion.

Version 3: We determine the quantity of required bitumen (at its reduced consumption, which constitutes 0.55 L/m^2 and bitumen in emulsion content 65 % w/w), which shall be distributed upon the plate area 0.04 m^2: 0.55·0.04=0.022 L= 22 ml. We determine the quantity of 65 % bitumen emulsion, which shall be distributed upon the plate: 22 ml/0.65=33.84 ml. So as to check: 33.84·0.65 = 21.996≈22 ml. Thus, in the final version 3 the accepted distribution upon the plate is 22 ml of bitumen emulsion.

The bitumen emulsion as per versions 1–3 were heated till 70°C and applied upon the cleaned Vialit Plates with homogeneous distribution on them. After that the chips were homogeneously immersed into the bitumen emulsions. Further on, the samples obtained were placed into desiccator at 4 5°C for water vaporization and getting the constant sample weight. Later, the samples-plates were taken from the desiccator, cooled till 25 °C and turned upside down for 10 min. On completion of 10 min the samples were tenderly shaken during 10 seconds. After that, the plate was put back into the initial position and the separated chips were tenderly cleaned by brush. After this so-called “tentative testing” there was performed “the main testing” – the plate was put so as to position chips downwards, and a metal ball weighing 500 g was thrown upon the plate three times during 10 seconds. Later, the sample-on-plate was examined and the chips were counted the following way: a – quantity of accepted chips, whose surface is not covered by binder; b – quantity of non-accepted chips, whose surface is partly covered by binder; c – quantity of accepted chips.

After the “tentative testing” the initial adhesion was determined by formula (1):

$$R1=((D-A-C)/B)\cdot 100, \quad (1)$$

where: R1 – the initial percentage of chips right after the 10-second shaking and cleaning.

A – stainless steel plate weight (g),

B – chips weight (g),

C – emulsion weight (g),

D – weight of plate, chips and emulsion after the 10-second shaking and cleaning (g).

After the “main testing” the final adhesion is determined by formula (2):

$$R2=((E-A-C)/B)\cdot 100, \quad (2)$$

where: E – weight of plate, chips and emulsion after the tentative testing and the ball falling (g).

Techniques used

For the studies there were used the selected formulations of cationic bitumen emulsion (Table 2) and granite chips grade 20–40 mm from Vyrivskii, Novograd-Volynskii and Mokrianskii domestic quarries of Ukraine – for the method as per DSTU 8787:2018 and granite chips grade 5–10 mm from Vyrivskii quarry for the method as per (EN 12272-3:2004).

Table 2

Cationic bitumen emulsion formulations

Components	Formulation No, % w/w		
Mozyr Refinery bitumen	1. 70/100– 65 %	2. 70/100– 65 %	3. 70/100– 62 %
Redicote C -320 E emulsifier	–	–	1.3 %
Redicote EM-44 emulsifier	0.25 %	0.25 %	–
Water phase pH (acid)	pH=1.5 (H_3PO_4)	pH=2.5 (HCL)	pH=1.5 (H_3PO_4)

The study's results by method DSTU 8787:2018 and the two proposed methods are shown in Table 3.

Table 3

Emulsion adhesion with chips from various quarries – by methods No 1 and No. 2

Bitumen emulsion formulation number	Emulsion adhesion with chips from the quarry (in points)		
	Vyrivskii quarry	Novograd-Volynskii	Mokrianskii
	Method No 1		
1. Bitumen 65 %, Redicote EM-44 pH=1.5 (H_3PO_4)	5	4.0	3.0
2. Bitumen 65 %, Redicote EM-44 pH=2.5 (HCL)	5	4.5	3.5
3. Bitumen 62 %, Redicote C -320 E pH=1.5 (H_3PO_4)	5	4.0	3.0
	Method No 2		
1. Bitumen 65 %, Redicote EM-44 pH=1.5 (H_3PO_4)	3,5	4.0	2.5
2. Bitumen:65 % Redicote EM-44 pH=2.5 (HCL)	4,0	4.5	3.0
3. Bitumen 62 %, Redicote C -320 E pH=1.5 (H_3PO_4)	3,0	4.0	2.0

When making analysis for the data in Table 3, one can see that from among the chips tested the best adhesion with the binders studied is assigned to the aggregate from Vyrivskii quarry, while the worst one – to Mokrianskii quarry. As to the bitumen emulsions, the usage of hydrochloric acid in bitumen emulsion formulations (formulation No 2) is technically more expedient.

In studies for binder adhesion by method (EN 12272-3:2004) there were tested three emulsions (Table 2) with different quantity of bitumen emulsion, which was distributed upon the plate by three versions. As a final result, there were obtained the five studies – depending upon the bitumen emulsion content and its quantity distributed upon the Vialit Plate (Table 4). The analysis of Table 4 confirms the conclusions made after determination of adhesion for the binder, extracted from the emulsion, with the chips surface. Those ones were regarding the higher efficiency of using the hydrochloric acid in emulsion formulations – comparative to using the ortho-phosphoric one. This can be clearly demonstrated when comparing the emulsion formulations No. 1, No. 2 and No 3 (with residual binder content on the plate 32 ml), as far as the total chips loss when using bitumen emulsion by formulation No 2 constitutes 5 chips, while for the formulations N.o 1 and No. 3 – correspondingly 7 chips for each. Besides of that, the adhesion indices R1 and R2 for the bitumen emulsion by formulation 2 are higher. The decrease of weight for the residual binder distributed upon the plate from 32 ml to 22 ml (bitumen emulsion formulation No 2 with hydrochloric acid and with distribution versions V1 and V3) does not lead to the substantial worsening of

the adhesion. On contradistinction to that, the adhesion substantially worsens when going the same way with emulsion on orthophosphoric acid (bitumen emulsion by formulation No 1 with ortho-phosphoric acid by distribution versions: V1 and V3). The optimum formulation for the bitumen emulsions tested (from the point of view of adhesion for the binder, extracted from emulsion, with the chips surface, as well as of adhesion for the binder with filling aggregate by Vialit Plate Shock Test) is formulation No 2.

Table 4

Adhesion indices by Vialit method with Vyrivskii quarry chips

Version No, quantity of emulsion (residual binder), which was distributed upon the Vialit Plate, ml		Adhesion indices by Vialit method						
		a	b	c	R1, %	$R\ 1^{I}+ R\ 1^{II}/2$	R2, %	$R\ 2^{I}+ R\ 2^{II}/2$
V1= 49.23 (32) ml 1. Bitumen 65 % Redicote EM-44 pH=1.5 (H_3PO_4)	I	0	2	98	100	100	92	91
	II	0	5	95	100		90	
V1= 49.23 (32) ml 2. Bitumen 65 % Redicote EM-44 pH=2.5 (HCL)	I	0	3	97	100	100	94	94
	II	0	2	98	100		94	
V2=51.61 (32) ml 3. Bitumen 62 % Redicote C -320 E pH=1.5 (H_3PO_4)	I	0	4	96	100	100	92	92
	II	0	3	97	100		92	
V3=33.84 (22) ml 1. Bitumen 65 % Redicote EM-44 pH=1.5 (H_3PO_4)	I	0	5	95	100	100	90	88
	II	0	10	90	100		85	
V3=33.84 (22) ml 2. Bitumen 65 % Redicote EM-44 pH=2.5 (HCL) B3=33.0 *ml*	I	0	2	100	100	100	95	94
	II	0	4	98	100		93	

Conclusions

1. The bitumen emulsions formulations were developed for the thin-layer road pavements by the technology of surface dressing, depending upon the bitumen-in-emulsion content, type of the acid used (hydrochloric or ortho-phosphoric) and emulsifiers.

2. There was studied the adhesion of aggregate from various quarries with the residual binder formed after the emulsion breakage – in accordance with both the Ukrainian and European standards.

3. There was determined that the emulsions based on hydrochloric acid have better adhesion with granite aggregate, if to compare with those ones based on ortho-phosphoric acid, from the point of view of the methods proposed for application.

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ЗЧЕПЛЮВАНІСТЬ БІТУМНИХ В’ЯЖУЧИХ ІЗ КАМ’ЯНИМИ МАТЕРІАЛАМИ В КОНТЕКСТІ ТЕХНОЛОГІЇ ПОВЕРХНЕВОЇ ОБРОБКИ ДОРОЖНІХ ПОКРИТТІВ

Розглянуто тонкошарові покриття за технологією поверхневої обробки, які є поширеним варіантом збереження та герметизації верхніх шарів дорожніх конструкцій. Однією з основних характеристик якості цих покриттів є зчеплюваність (адгезія) між бітумним та мінеральним матеріалом. В статті досліджено зчеплюваність кам’яних матеріалів різних гранітних кар’єрів України з бітумним в’яжучим, а саме бітумною емульсією, для застосування в технології поверхневої обробки дорожніх покриттів. В роботі використано українські та європейські методи досліджень визначення зчеплюваності в системі бітум–кам’яний матеріал. За українським методом визначено зчеплюваність залишкового в'яжучого, виділеного з емульсії після її розпаду, з поверхнею щебню після кип’ятіння в дистильованій воді та в розчині гліцерину та дистильованої води. Як європейський метод для досліджень використано ударний метод із застосуванням плити Віаліт. Розроблено три склади бітумних емульсій для тонкошарових покриттів автомобільних доріг за технологією поверхневої обробки залежно від вмісту бітуму в емульсії, типу використаної кислоти (соляна чи ортофосфорна), ph водної фрази бітумної емульсії та двох варіантів емульгаторів. Результати випробувань за вибраними методами показали схожі результати, що дало змогу встановити оптимальний кам’яний матеріал серед досліджених і відповідно оптимальний склад бітумної емульсії. Також досліджено необхідну кількість бітумної емульсії, яка має бути розподілена по плиті Віаліта за критерієм зчеплюваності для цього методу досліджень.

Ключові слова: тонкошарове дорожнє покриття, поверхнева обробка, бітумна емульсія, соляна кислота, ортофосфорна кислота, зчеплюваність бітумного в’яжучого із щебенем, ударний метод із застосуванням плити Віаліт.