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Epoxy asphalt concrete is a perspective material for the construction of roads

Valerii Vyrozhemskyi[1], Ivan Kopynets[1], Sergii Kischynskyi[1] and Nataliia Bidnenko[1]

[1] M.P. Shulgin State Road Research Institute State Enterprise – DerzhdorNDI SE, Peremohy Ave. 57, Kyiv 03113, Ukraine

E-mail: orgviazhuchi@ukr.net

Abstract. An effective way to increase the durability of asphalt concrete pavements that are subject to high traffic loads and adverse weather and climatic factors is the use of polymer additives which drastically improve the rheological and physical-mechanical properties of bitumen. The use of thermosetting polymers including epoxy resins for asphalt and bitumen modification is seen as a perspective solution for this issue. Conducted at DerzhdorNDI SE studies have proved high riding qualities of asphalt pavements that contain epoxy resins. When replacing 20-35% of bitumen with epoxy component, a significant improvement in strength characteristics of asphalt pavement is noted, especially at elevated temperatures. Specific feature of epoxy asphalt concrete is its ability to gain strength over a long-term operation. Thus, despite the increased cost of epoxy asphalt concrete, long service life of pavements on its basis (up to 30 years as predicted) ensures a high profitability of using this material, especially on the roads with heavy traffic and severe traffic conditions.

1. Introduction

Today in Ukraine, actual service life of asphalt pavements is 6-12 years instead of the design 15-20 years. Premature repairs and rehabilitation of pavements require millions of additional costs that could be directed to the construction of new and reconstruction of existing roads. One of the main reasons of rapid deterioration of pavements in conditions of heavy traffic is bitumen properties. Of all the road construction materials bitumen is the most sensitive to traffic loads and impact of weather and climate factors. Being a thermoplastic material, bitumen is softened at high summer temperatures and it becomes fragile at low temperatures in winter. Along with low adhesion of bitumen with stone materials this leads to the formation of ruts, cracks, potholes and pits on the pavement.

Due to the above, a targeted change of bitumen properties is the most effective way to increase efficiency and durability of road pavements.

Modification of bitumen and asphalt concrete by different additives, particularly by polymers, is widespread.

Today, great interest in the use of thermosetting polymers especially epoxy resins as modifiers have shown the countries of the Western Europe, the USA, China and Australia [1-5].

Epoxy resins are oligomers containing epoxy groups and can form cross-linked polymers under the hardeners impact. The most common epoxy resins are products of epichlorohydrin polycondensation with phenols, and with bisphenol A are the most widespread.

Materials having various properties from rubbery to rigid and solid that exceed steel by strength characteristics can be obtained by combining different resins and hardeners. Today, epoxy resin which properties exceed all other materials properties based on synthetic resins is used in all branches of industry.

Epoxy glue is considered as the most all-purpose and reliable glue. Thanks to its strength and good adhesion, this glue bonds equally well both shoes and the parts of the planes. Epoxy resin is used as an impregnating material for glass thread and fabrics to manufacture glass fiber plastics which are used in shipbuilding, construction, aircraft construction, manufacturing of the machines parts and others. Nowadays epoxy resins are used in road construction for preparation of asphalt mixtures. Different types of asphalt containing epoxy resins are called epoxy asphalt concrete.

2. Materials

The following materials are used for research of asphalt concrete based on epoxy resin:

- Bitumen of BND 60/90 grade and production of PJSC "Ukrtatnafta" that meets the requirements of DSTU 4044 [6] (Table 1);
- Crushed stone of 5 - 10 mm fractions from Malyn granite quarry that meets the requirements of DSTU B V.2.7-75 [7];
- Sand from crushing screenings that meets the requirements of DSTU B V.2.7-76 [8];
- Filler produced by PJSC "Asphalt Plant" that meets the requirements of DSTU B V.2.7-121 [9];
- Epoxy resin of CHS-EPOXY 525 grade produced by Spolchemie (Czech Republic);
- Hardener of TELALIT 410 grade produced by Spolchemie (Czech Republic).

Table 1. Bitumen properties used for the research purposes.

Indicator	Test results
Penetration, 0,1 mm	61
Softening point, °C	47.5
Brittleness temperature, °C	55

Grading of fine grain asphalt concrete of B type was designed according to the requirements of DSTU B V.2.7-119 [10] "Asphalt mixtures and road and airfield asphalt. Specifications" (Table 2).

The content of the epoxy component was 25% by weight of bitumen.

Table 2. Grading of asphalt concrete.

Materials	Content by weight, % of mineral grains smaller than this size, mm								
	15	10	5.0	2.5	1.25	0.63	0.315	0.14	0.071
Crushed stone of 5 - 10 mm fractions	100	88	3	0	0	0	0	0	0
Sand from crushing screenings	100	99	89	68	57	41	28	17	9
Filler	100	100	100	100	100	99	98	94	81
Designed grading (full passages)	100	100	60.42	46.8	40.2	30.54	22.68	15.84	10.26
Requirements to grading (full passages) DSTU B V.2.7-119 B type	100	100-90	65-55	53-43	43-33	33-23	25-16	18-11	14-8

3. Technology of asphalt mixtures and asphalt concrete preparation

Preparation of the original asphalt concrete was performed using traditional technology.

The procedure of epoxy asphalt concrete preparation included the following operations:

- batching and mixing of crushed stone, sand and filler according to the designed grading;
- heating of aggregate to the required temperature;
- introduction of the hardener into bitumen heated to the required temperature followed by mixing during (5 - 10) minutes;
- introduction of bitumen together with the hardener into a mixture of aggregate followed by mixing;
- introduction of epoxy resin into the mixture followed by mixing.

Temperature of the components heating at asphalt mixes preparation shown in Table 3.

Table 3. Temperature of the components heating at asphalt mixes preparation.

Mixture components	Temperature of the components heating, °C	
	Original asphalt concrete	Epoxy asphalt concrete
Bitumen	150	130
Aggregate	170	140
Epoxy resin	-	80
Hardener	-	80

Preparation and testing of asphalt concrete and epoxy asphalt concrete samples were performed according to the standard DSTU B V.2.7-89 (GOST 12801) [11].

Given that the actual content of crushed stone aggregate in mixtures was more than 35%, the samples obtained compacted mixture under the pressure of 30 MPa for 3 minutes. The temperature of original asphalt concrete samples at the beginning of compaction was 160 °C, and at the end of compaction - 150 °C. For epoxy asphalt concrete it was 130 °C and 100 °C, respectively. The temperature of asphalt concrete preparation was taken in accordance with section 2 of DSTU B V.2.7-89 (GOST 12801) [11]. Due to the plasticization of bitumen as a result of the epoxy components introduction, as well as to reduce the speed of hardening of epoxy components, the temperature of the epoxy asphalt concrete preparation was reduced.

To study changes in the properties of epoxy asphalt concrete dependent on the structure formation stage of the material under the impact of thermal-oxidative processes in the epoxy components, epoxy asphalt concrete samples were cured for 1, 14 and 28 days at 20 °C.

4. Test metods

For prepared asphalt concrete the following was determined: porosity of the mineral skeleton, residual porosity, water saturation, swelling, limit compressive strength, rut resistance.

4.1. Determination of the mineral skeleton porosity

Porosity of the mineral skeleton was determined in accordance with section 11 of DSTU B V.2.7-89 (GOST 12801) [11]. The main point of the method is to determine the volume of pores contained in the mineral skeleton of asphalt concrete.

4.2. Determination of residual porosity

The residual porosity was determined in accordance with section 12 of DSTU B V.2.7-89 (GOST 12801) [11]. The main point of the method for determining the residual porosity is to determine the volume of pores contained in asphalt concrete.

4.3. Determination of water saturation
Water saturation was determined in accordance with section 13 of DSTU B V.2.7-89 (GOST 12801) [11]. The main point of the method is to determine the amount of water absorbed by the sample at the given saturation mode.

4.4. Determination of swelling
Swelling was determined in accordance with section 14 DSTU B V.2.7-89 (GOST 12801) [11]. The main point of the method is to determine the increment in the volume of the sample after its saturation with water.

4.5. Determination of compression strength limit
The compression strength limit was determined in accordance with section 15 DSTU B V.2.7-89 (GOST 12801) [11]. The main point of the method is to determine the limit stress which leads to the destruction of the sample under the given conditions of the test.

4.6. Determination of rut resistance
The main point of the method is to determine the total value of residual deformations at the cyclic loading of asphalt concrete.

Test procedure is shown in Figure 1.

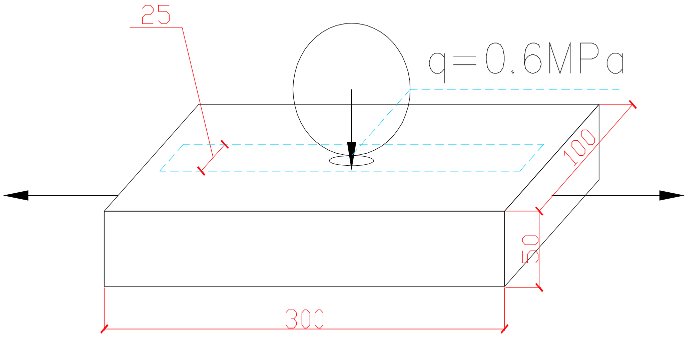

Figure 1. Rutting test procedure.

The tests were conducted at a temperature of 45 °C for the original asphalt concrete after 1 day of curing, for epoxy asphalt concrete – after 14, 28, 36 and 42 days of curing. The samples were cured at 20 °C. The sample size was 300 × 100 × 50 mm, wheel diameter - 120 ± 5 mm, track width - 25 ± 5 mm, track length - 250 mm. Test loading was 0.6 MPa. The results were recorded after 1; 2.5; 5; 7.5; 20; 25 days of curing and after 30.000 wheel passages.

5. Test results and their analysis
The results of asphalt concrete tests are shown in Table 4.

According to Table 4, the values of porosity, water saturation, swelling and strength at temperatures of 0 °C of epoxy asphalt concrete were the same as for original asphalt concrete and within the requirements range of DSTU B V.2.7-119 [10].

Compressive strength of a newly compacted epoxy asphalt concrete sample of CHS-EPOXY 525 at 20 °C (R_{20}) and 50 °C (R_{50}) is slightly lower than of the original asphalt concrete (0.5 MPa and 0.2 MPa, respectively). Strength of epoxy asphalt concrete samples increases with increasing the curing period. Particularly intense increase in strength takes place from 7 to 14 days of curing. After 28 days the strength of epoxy asphalt at 20 °C reaches 5.4 MPa versus 3.3 MPa of the original asphalt concrete and at 50 °C it reaches 2.9 MPa versus 1.4 MPa. Thus, the strength at 20 °C is increased by 64%, and at 50 °C - in 2 times.

Table 4. Test results of asphalt concrete.

Indicator		Test results: Original asphalt concrete	Test results: Epoxy asphalt concrete	Requirements of DSTU B V.2.7-119
Porosity of the mineral skeleton, % by volume		15	15	from 15 to 18
Residual porosity, % by volume		2	2	from 2 to 4
Water saturation, % by volume		1.0	1.2	from 1.0 to 2.5
Swelling, % by volume		0.2	0.2	0.5, not more
Limit compressive strength, MPa, at temperature:				
0 °C	1 day	8.0	–	12, not more
	14 days	8.0	–	-
	28 days	8.0	9.0	-
20 °C	1 day	3.3	2.8	2.5, not less
	7 days	3.3	3.0	-
	14 days	3.3	5.0	-
	28 days	3.3	5.4	-
50 °C	1 day	1.4	1.2	1.2, not less
	7 days	1.4	1.6	-
	14 days	1.4	2.6	-
	28 days	1.4	2.9	-

An important property of asphalt concrete is its ability to retain strength at higher temperatures which can be characterized by the coefficient of temperature sensitivity. The higher the ratio of the limit strength of asphalt concrete at a temperature of 50 ° C to the limit strength of asphalt concrete at the temperature of 20 ° C, the less the properties of asphalt concrete change under increasing temperature.The coefficient of temperature sensitivity is calculated by the formula:

$$R_T = \frac{R_{50}}{R_{20}} \tag{1}$$

Where R_{50} is limit compressive strength at 50 °C, MPa and R_{20} is limit compressive strength at 20 °C, MPa. The coefficient of temperature sensitivity for the original asphalt concrete is 0.42, and for epoxy asphalt concrete it is 0.54.

Given the fact that the introduction of epoxy component increases the strength and heat resistance of asphalt concrete, its impact on rutting resistance of pavements at high summer temperatures was investigated. The results of testing rutting intensity depending on the number of passages of a wheel are shown in Table 5.

According to test data, after 14 days of epoxy asphalt concrete samples curing rutting intensity was almost the same as of the original asphalt concrete (after 30.000 passages the rut depth on both pavements was 4.6 mm).

After curing for more than 28 days, the intensity of rutting on epoxy asphalt pavements was significantly reduced. If the rut depth on the original asphalt concrete after 1000 wheel passages was 1.7 mm and it was 4.6 mm after 30.000 of wheel passages – then on epoxy asphalt pavements after 42 days of curing it was 0.3 and 1.7 mm respectively. Thus, as the structure of epoxy asphalt concrete is formed, rutting resistance of pavements increases. After 42 days of curing it grows almost in 3 times.

Table 5. Depth of rut in asphalt concrete

Number of cycles, wheel passages	Intensity of rutting at the temperature 45 °C, mm				
	For original asphalt concrete	For epoxy asphalt concrete			
	1 day	14 days	28 days	36 days	42 days
1000	1.7	1.3	1.1	0.9	0.3
2500	1.9	1.9	1.5	1.2	0.6
5000	2.6	2.5	2.1	1.6	0.8
7500	2.9	2.9	2.3	1.8	1.0
20000	3.7	3.8	3.2	2.5	1.4
25000	4.3	4.4	3.4	2.7	1.6
30000	4.6	4.6	3.6	2.9	1.7

6. Conclusions

When introducing epoxy component to asphalt concrete, the trend of improving its strength characteristics at elevated temperatures can be clearly observed.

Epoxy asphalt concrete is characterized by high rutting and shear resistance. When applying EPOXY 525, the rut depth on epoxy asphalt after 42 days of curing was 3 times lower than that on the original asphalt concrete.

Low temperature characteristics of asphalt concrete can deteriorate as a result of hardening of epoxy components, so the further studies should be aimed at establishing the crack resistance properties of epoxy asphalt concrete.

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