Polyurethane composite mortar for expansion joints on road bridge structures

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Abstract. The article analyzes the main reasons for the low durability of road pavement in the zone of expansion joints. The main prerequisites for the use of polymer-based compounds for filling the transition zone between the asphalt concrete pavement and the metal profile of the expansion joint are considered. The results of the study of physical, mechanical, and operational properties of the polyurethane-based compound are given, and the increased durability of the proposed solution is justified compared to traditional solutions. A feasibility study of the above solution has been completed. A technical solution for the design of an expansion joint transition zone is proposed.

1. Introduction
Currently, one of the important aspects of extending the service life of highways is the issue of arranging a junction between asphalt concrete and expansion joints in bridge structures. This area is subjected to maximum impact-dynamic loads from the wheels of vehicles in the places of tracing ruts formation in asphalt concrete. This leads to the separation of asphalt concrete from the metal profile of the joint, destruction of the junction zone, and deformation of the profiles [1-3]. The problem is especially acute in megalopolises. Premature destruction of the zone of an expansion joint naturally results in costly repairs with full or partial blocking of traffic and a decrease in the comfort and safety of the passage of vehicles over the expansion joints [4].

![Figure 1. Destruction of asphalt concrete and profile of an expansion joint.](image-url)
This problem may be solved by creating a transition zone between the asphalt concrete and the metal profile of the joint using the material capable of withstanding these loads over a long period of time [5, 6]. The transition zone of the expansion joint provides a more uniform transfer of loads from the road pavement area to the steel elements of the expansion joint, which results in combined operation of the asphalt pavement and the metal bordering of the joint. In turn, the high wear resistance of the transition zone material significantly reduces the rate of tracing ruts formation.

2. Problem statement
Mastic-crushed-stone mixtures based on bituminous binder are traditionally used for filling the transition zone of expansion joints [7]. However, such compounds have limited durability and low performance, and require the use of a thermal mixer to heat the binder to a temperature of 170–190 °C and a special boiler with forced mixing or a perforated gravity-type drum for heating the crushed stone to a temperature of 150–190 °C. Thus, this material can only be installed by specialized contractors, which incurs additional costs.

Using the polymer resins in a compound with high-strength mineral aggregate seems to be the most promising way for arranging the transition zone [8, 9].

For this purpose, a polyurethane resin-based three-component compound Manopur 336 was developed. The advantages of this compound are its high resistance to abrasion, shock loads in a wide range of operating temperatures, high adhesion to the concrete base, asphalt concrete and metal surfaces, resistance to aggressive media: fuels and lubricants, anti-icing agents, high frost resistance, resistance to ozone and UV radiation.

3. Results and discussion
To confirm the effectiveness of the Manopur 336 material, research of the basic operation properties of the compound was conducted in the National Research Moscow State University of Civil Engineering (MGSU) (Test Report No. 02-06/K.483-18 dated 11/22/2018 from Research and Testing Laboratory No. 2 for Building composites of mortars and concretes).

All tests were performed on 7 day aged samples. The compressive strength and bending tensile strength were tested on the beam samples with dimensions of 160x40x40 mm according to GOST 30744. The average value of compressive strength was 19.9 MPa, bending tensile strength — 13.2 MPa.

The strength of the compound adhesion to a concrete base was determined according to GOST 31356. The adhesion of samples to concrete base was tested by pull-off method, the average value of adhesion strength was 3.6 MPa.

The water absorption of the compound by weight was determined according to GOST 5802 on sample-cubes with dimensions of 100x100x100 mm and amounted to 0.1 % by weight of the samples.

The test to determine the resistance of Manopur 336 to rutting was carried out according to the ARA method (AASHTO TP 63) at a temperature of +25 °C. The samples before the tests (left) and after the tests (right) are shown in Fig. 2. According to the test results, the Manopur 336 material was found to have a 10 time higher resistance to rutting by the ARA method than cast asphalt concrete. For one, after 8,000 wheel passes, the rut depth in the Manopur 336 samples tested at 25 °C was 0.16 mm, the same indicator for samples of cast asphalt concrete was 2.5 mm.
Figure 2. Test to determine the resistance of Manopur 336 to rutting by the ARA method (AASTHO TP 63). Samples before the tests (left) and after the tests (right).

Table 1. The depth of the rut after exposure to cyclic load according to the ARA method at a temperature of 25 °C

| Number of cycles | Rut depth in samples of Manopur 336, mm | Rut depth in samples of cast asphalt concrete, mm |
|------------------|----------------------------------------|-------------------------------------------------|
| 100              | 0.02                                   | 0.38                                            |
| 200              | 0.03                                   | 0.62                                            |
| 300              | 0.04                                   | 0.72                                            |
| 400              | 0.04                                   | 0.80                                            |
| 500              | 0.05                                   | 0.85                                            |
| 600              | 0.06                                   | 1.03                                            |
| 700              | 0.06                                   | 1.04                                            |
| 800              | 0.07                                   | 1.08                                            |
| 900              | 0.08                                   | 1.12                                            |
| 1,000            | 0.09                                   | 1.21                                            |
| 2,000            | 0.10                                   | 1.53                                            |
| 3,000            | 0.11                                   | 1.78                                            |
| 4,000            | 0.14                                   | 1.94                                            |
| 5,000            | 0.15                                   | 2.08                                            |
| 6,000            | 0.15                                   | 2.15                                            |
| 7,000            | 0.16                                   | 2.30                                            |
| 8,000            | 0.16                                   | 2.45                                            |

Figure 3. The dependence of the rut depth on the number of wheel passes according to the ARA method (AASTHO TP 63) at a temperature of 25 °C: 1 — Manopur 336; 2 — cast asphalt concrete.
The frost resistance of the Manopur 336 compound was determined according to GOST in two media — standard medium and that of a 20% ICEMELT MIX road de-icing agent. In both environments, the composition showed frost resistance of at least F2500.

Table 2 shows the technical and economic comparison of the developed composition with foreign and domestic counterparts.

**Table 2.** The depth of the rut after exposure to cyclic load according to the ARA method at a temperature of 25 °C

| Parameter                      | Manopur 336, Gidrozo (Russia) | Betoflex, Maurer (Germany) | WaboCrete II, BASF (China/USA) | Mastic-crushed-stone mixture (Russia) |
|-------------------------------|-------------------------------|---------------------------|-------------------------------|------------------------------------|
| Compressive strength, N/mm²   | 17.9                          | 20                        | 15.17                         | 4.77                               |
| Bending strength, N/mm²       | 13.2                          | N/A                       | N/A                           | N/A                                |
| Adhesion to the substrate, MPa| 3.9                           | 1.5                       | 2.76                          | N/A                                |
| Water absorption, %           | 0.1                           | N/A                       | ≤ 3                           | N/A                                |
| Self-leveling during installation | Yes                           | No                        | Yes                           | No                                 |

**Technical parameters**

**Economic parameters**

| Parameter                                      | Material cost (retail), rub/kg | Estimated cost of material per linear meter (width of installation area 300 mm, depth 70 mm), rub | Durability (period of time before overhaul) | Average cost of operation year, rub |
|------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------------------|--------------------------------------------|------------------------------------|
| Material cost (retail), rub/kg                 | 800                           | 33,600                                                                                       | Up to 10 years and more                    | 3,360                             |
| Estimated cost of material per linear meter (width of installation area 300 mm, depth 70 mm), rub | 1,370                         | 57,540                                                                                       | N/A                                       | N/A                               |
| Durability (period of time before overhaul)    | 1,201                         | 50,442                                                                                       | Up to 10 years and more                    | 5,044                             |
| Average cost of operation year, rub            | 600                           | 25,200                                                                                       | 5–7 years                                  | 4,200                             |

The method for application of Manopur 336 is given in the STO 14171589-050-2018 "Waterproofing and protective materials for bridges and other artificial structures" and approved by the leading industry research institute of transport construction JSC TsNIIS.

The preparation of the Manopur 336 compound consists of mixing three components, a resin, a hardener and a mineral aggregate, using a construction mixer or a forced-action mixing station. After mixing, the compound is poured into a prepared transition zone between the asphalt concrete and the joint profile, as shown in Fig. 4. The absence of the need to heat the components of the material, the need for special equipment for the preparation of the mixture, as well as the ability of the compound to self-level during installation allows to create the transition zone in short time and by means of any construction contractor.
Figure 4. Technical solution for creating the transition zone of an expansion joint using the Manopur 336 compound.

4. Conclusions
The problem of ensuring the reliability and durability of the coupling of expansion joints and surface considered in the article is of immediate interest and requires an integrated approach to the choice of materials and technologies for transport construction. Reducing the period between scheduled preventive repairs and ensuring the safety of the passage of transport should be considered the main criterion.

The developed material Manopur 336 has high physical and mechanical and operational characteristics, significant expected durability during operation. According to the technical and economic comparison with similar solutions, the use of the compound can significantly reduce the average annual cost of the facilities operation. The compound can be used both for new construction, and for repair of bridges, overhead roads, overpasses already in service.

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