Influence of genesis of mineral components of asphalt concrete for its durability in aggressive environments

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Abstract. The results of determining the durability of asphalt concrete are presented by the method developed at the Department of Technology of Road-Building Materials and Chemistry of KhNADU. The features of the resistance of asphalt concrete on various rocks by the influence of liquid aggressive environments are shown. The coefficients of stability of asphalt concrete to the action of liquid aggressive media on asphalt concrete from mixtures of monomineral compositions made from various rocks are determined. Thus, despite the difference in the origin of the rocks that make up the asphalt concrete, a long service life of road coatings based on them can be ensured, which in turn can ensure high profitability of using these coatings even on roads with heavy traffic and difficult conditions exploitation.

1. Introduction

The wide variety of crystalline rocks of the deposits of Ukraine gives the possibility of a large number of options for selection and use in a wide range of mineral materials of different origin as constituents of asphalt concrete mixtures. And the study of this possibility in terms of its impact on the durability of asphalt concrete is becoming more and more urgent every year. Particularly urgent is the study of the durability of asphalt concrete with the simultaneous action of stress and a liquid aggressive environment. The use of local rocks, such as basalts, quartzites, limestones, sandstones, or other geological sites, whose deposits are much closer to the construction site than granite materials used for road construction, can significantly reduce the financial cost of transportation, and in some cases also for extraction, without losing the normative quality of asphalt concrete coating in which these mineral components can be used. In the first place, it is necessary to rely on the regulatory requirements for asphalt concrete, in National Standard of Ukraine DSTU B V.2.7-119: 2011 [1].

The main operational indicator of asphalt concrete, i.e. the material most used in road construction, is its durability. In the regulatory requirements for asphalt concrete [1] analog of its durability is the coefficient of long-term water resistance, which is determined by the degree of bending strength of its samples under the action of water during the normative time compared to samples aged in air at temperature (20±1) °C [2]. The constituents of this indicator are the strength of the bending specimens, which have been tested in a water-saturated and non-saturated state. But these strength indicators very roughly reflect the effect of the aquatic environment on the durability of asphalt concrete. A more sensitive indicator for predicting the durability of asphalt concrete may be the coefficient of resistance of asphalt concrete to the influence of liquid environments ($K_{l.e.}$) on its durability, which was used in previous works [3-6]. The components of this indicator were the time before the destruction of asphalt

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concrete samples, which were tested for bending in the aquatic environment \((t_{l,e})\) and the time before the destruction of asphalt concrete samples, which were tested for bending in air \((t_a)\) and which were used as the ratio (1) of the first to second:

\[
K_{l,e} = \frac{t_{l,e}}{t_a} \tag{1}
\]

Measurements of time before the destruction of asphalt concrete beams were carried out in seconds and the results ranged from 10 s to \(10^5\) s. Such a large range demonstrates the greater sensitivity method of measurement the time before the destruction to that of other methods. The numerical value of the coefficient of resistance of asphalt concrete to the influence of liquid environment is less than 1, since \(t_{l,e}\) always below \(t_a\) as a result of the adverse effect of the aquatic environment.

Mineral components of asphalt mixes in different territorial regions of Ukraine may be different in origin and mineral composition, but the main thing is so that they do not reduce the inter-service life of asphalt concrete pavement of roads in which they are used. To avoid reducing the durability of asphalt concrete, it was hypothesized that rocks, most of which include minerals of the silicate and carbonate class, can be used as components of asphalt mixtures [7]. And these rocks are present throughout the massif of the Ukrainian Crystal Shield, the Carpathians and the Crimea.

2. Geological survey of rock-forming minerals of Ukraine

Along with granites, as traditional mineral materials used in the production of asphalt mixtures, the northwestern and central parts of the Ukrainian Shield are composed of such rocks as basalts, gabbro, diorites, diabases, pegmatites, amphibolites, migmatites, labradorites, syenites, quartzites, gneisses, shales and marbles [8]. The south-eastern and Azov parts of the Ukrainian Shield are mostly represented by such rocks as basalts, gabbro and sandstones [8, 9]. The Carpathian region consists mostly of limestone, but there are granites, diorites, gneisses, andesites and sandstones [8]. The Crimean region is mostly represented by limestones and shale rocks of various origins [8].

Such a wide range of these rocks by origin causes a significant amount of rock-forming minerals [10-16]. But in turn, the properties of minerals depend on the chemical composition, building of the crystal lattice and many of their physical properties [11, 12, 17-21]. Depending on these properties, the structure and texture of the asphalt concrete is formed, which includes selected mineral components and in which the durability of asphalt concrete pavement of roads depends.

The choice of mineral components was based on three principles: first - rocks must have a brand beyond the strength of not less than M800; secondly, most rock-forming minerals must be of silicate or carbonate origin; third, the deposits of the selected rocks should be represented by the largest number in the respective region. Effective study of the durability of asphalt concrete was based on the initial physical and mechanical properties, chemical composition and the influence of the origin of selected rocks as components of the asphalt mixture, the interaction with organic petroleum binders [9-11, 22-27]. Based on this knowledge, four types of rocks were accepted for testing: basalt (Rafalivske deposit of Rivne region), limestone (Old Crimean deposit of the Autonomous Republic of Crimea), sandstone (Vilyanivske deposit of Luhansk region) and granite (Redutskoe deposit of Poltava region). selected as a comparative reference rock, which is traditionally used for the production of asphalt mixtures.

For all mineral materials accepted for testing, as potential components of the asphalt concrete mixture, the main physical and mechanical properties were determined, which are presented in table 1. The mineralogical composition of basalt consists of: silica (40-52 %); microliths of plagioclase; clinopyroxene (augite); titanomagnetite; hornblende and as an igneous rock belongs to the class of "basic". The chemical composition of basalt includes the following compounds: SiO\(_2\); K\(_2\)O; Al\(_2\)O\(_3\); Fe\(_2\)O\(_3\); TiO\(_2\); FeO; MnO; MgO; CaO; P\(_2\)O\(_5\) [10, 11], this causes their effect on the unsatisfactory interaction with organic petroleum binders and the adhesion of bitumen to the mineral surface of acid rocks is significantly reduced [23-27].


Table 1. The main physical and mechanical properties of the original rocks.

| Indicator                        | Test results | Requirements of DSTU B V.2.7-119: 2011 for asphalt concrete type "V" I brand |
|----------------------------------|--------------|--------------------------------------------------------------------------------|
| True density, kg/m³              | granite 2720 | -                                                                              |
|                                  | basalt 2870  |                                                                                 |
|                                  | limestone 2850 |                                                                                 |
|                                  | sandstone 2690 |                                                                                 |
| Average density, kg/m³           | granite 2700 | -                                                                              |
|                                  | basalt 2850  |                                                                                 |
|                                  | limestone 2690 |                                                                                 |
|                                  | sandstone 2470 |                                                                                 |
| Porosity, %                      | granite 0.7 | -                                                                              |
|                                  | basalt 0.7   |                                                                                 |
|                                  | limestone 3.3 |                                                                                 |
|                                  | sandstone 8.2 |                                                                                 |
| Grade of initial rock by crushability | M1200       | not less than M800                                                              |
|                                  | M1200       |                                                                                 |
|                                  | M800        |                                                                                 |
|                                  | M800        |                                                                                 |

Dense marble-like limestone has the following mineralogical composition: calcite; dolomite. The chemical formula of limestone includes the following compounds: CaCO₃; MgCO₃ [10, 11]. The interaction of these compounds has a satisfactory effect on the adhesion of bitumen to the mineral surface of alkaline rocks [23-27].

The mineralogical composition of sandstones as sedimentary rock fragments is due to the largest amount of quartz with some inclusions of feldspars and mica. The sandstone tested had iron oxide cementation and, accordingly, the chemical formula included the following compounds: SiO₂ and Fe₂O₃ [10, 11]. As is known from many sources [23-27], such a set of chemical compounds is not very conducive to good adhesion of bitumen to the mineral surface of acid rocks.

Comparative (reference) granite material, as an acidic igneous rock, in mineral composition was represented by: quartz (>50 %); plagioclase; feldspars; mica. Chemical composition of granite: SiO₂; K₂O; Al₂O₃; Fe₂O₃; TiO₂; FeO [10, 11]. Since granite is an acid rock, the adhesion of bitumen to its mineral surface is not very satisfactory.

3. Materials

Samples of all rocks accepted for testing were crushed and scattered into fractions starting from 10÷15 mm and ending with a fraction <0,071 mm. Subsequently, asphalt concrete mixtures were formed in fractions and each of them included only one rock, ie all mixtures were single-rock. The particle size distribution for all mixtures was the same, which is presented in table 2.

Table 2. Granulometric composition of asphalt concrete mixtures on granite, basalt, limestone and sandstone stone materials

| Leftovers | Content by weight, % of mineral grains larger than this size, mm: 0.63 0.315 0.14 0.071 <0.071 | Bitumen content, % |
|-----------|----------------------------------------------------------|-------------------|
| Partial   | 10 15 12 18 6 11 10 3 15                                  | 6,0               |
| Full      | 10 25 37 55 61 72 82 8 3                                  |                   |
| Requirements to grading (full leftovers) DSTU B V.2.7-119 | 0 25 36 48 60 71 80 84 100 | 6,0               |
| V type    | 10 35 49 63 75 84 89 91 100                               | 7,5               |

BND 60/90 bitumen was used as an organic petroleum binder for testing. The content of bitumen in all asphalt mixtures was 6.0 %, which corresponded to the optimal content of bitumen in the asphalt mixture, which consisted of one rock using granite.

To determine the structuring properties of the asphalt-binding component of asphalt concrete, several tests of mineral powders from the previously listed rocks were performed, the results of which are presented in Table 3. According to the results of tests of powders of different genesis, obvious facts attract attention: the highest bitumen content of limestone mineral powder is most likely due to the most
developed surface of grains and probably corresponds to its largest specific surface area, which allows optimal packaging of mineral particles completely covered with bitumen; the minimum porosity at consolidation allows to reach the minimum water saturation that in turn allows to increase coefficient of long water resistance as a guarantee of durability.

### Table 3. Normative properties of mineral powders of source rocks.

| Indicator                                | Test results | Requirements of DSTU B V.2.7-121-2003 |
|------------------------------------------|--------------|--------------------------------------|
| Grain content, % by weight:              |              |                                      |
| smaller than 1.25 mm                     | 100          | 100                                  |
| smaller than 0.071 mm                    | 73           | 72                                   |
| Porosity when compacted, %               | 29.0         | 31.9                                 |
| Swelling of the mixture of powder and bitumen, % by volume | 2.05         | 2.03                                 |
| Bitumen capacity, g                      | 51.2         | 52.4                                 |
| Average density of asphalt binder, kg/m³ | 2140         | 2230                                 |

Cylindrical specimens with a diameter of 71.4 mm were made of asphalt concrete mixtures, which consisted of one rock, which were tested in order to obtain their physical and mechanical properties. The test results are shown in table 4.

### Table 4. Physical and mechanical properties of asphalt concrete on granite, basalt, limestone and sandstone mineral materials.

| Indicator                                | Test results | Requirements of DSTU B V.2.7-119: 2011 for asphalt concrete type "V" I brand |
|------------------------------------------|--------------|--------------------------------------------------------------------------------|
| Average density, kg/m³                   | 2325         | 2453 | 2394 | 2298 | -                                |
| Water saturation, %                      | 3.0          | 2.5  | 1.9  | 3.0  | not more than 3.0                |
| Swelling, %                              | 0            | 0    | 0    | 0    | -                                |
| Limit compressive strength, MPa, at temperature, °C: | 0| 9.6 | 10.8 | 10.7 | 9.2 | not more than 12.0 |
|                                          | 20           | 4.8  | 5.5  | 5.8  | 5.7 | not less than 2.7               |
|                                          | 50           | 1.8  | 1.9  | 2.6  | 2.1 | not less than 1.3               |
| Coefficient of water resistance at long water saturation (on the 15th day) | 0.90 | 0.92 | 0.93 | 0.90 | not less than 0.90/0.86<sup>a</sup> |

<sup>a</sup> The numerator contains the requirements for the coefficient of long-term water resistance for the upper layer of the coating, the denominator - for the lower layer of the coating.

### 4. Durability test results and their analysis

To determine the durability of asphalt concrete, which consisted of one rock, 4×4×16 cm beam specimens were made of single-rock asphalt concrete mixture, which were tested for bending in order to obtain time to their destruction at different stresses with simultaneous action of different of liquid aggressive environments. The test temperature was maintained close to 21 °C. Asphalt concrete beam samples were tested on a press, as shown in Figure 1, in the stress range from 0.75 MPa to 2.50 MPa. The obtained results of durability are presented graphically in Figures 2 and 3, as well as in the form of indicators of resistance of asphalt concrete against the action of liquid aggressive media in table 5.
Figure 1. Scheme of the test lever press to determine long-term tensile strength in bending: 1 - four-pressure press lever; 2 - counterweight; 3 - transmitting rod; 4 - limit switch; 5 - asphalt concrete beam; 6 - lower supporting cylinders Ø 10 mm; 7 - loading area; 8 - upper cylinders of the loading platform Ø 20 mm.

Figure 2. Dependence of the time before the destruction of asphalt concrete (type “V”) on limestone (a), granite (b), basalt (c) and sandstone (d) mineral material with 6.0 % BND 60/90 bitumen on stress, at a temperature of 21 °C in environments: ○ – air; ● – distilled water; △ – 5 % aqueous solution of NaCl.
Table 5. Resistance of asphalt concrete on various mineral components to action of liquid aggressive environments.

| Indicator                                                                 | granite | basalt | limestone | sandstone |
|---------------------------------------------------------------------------|---------|--------|-----------|-----------|
| Time before destruction in 5 % aqueous NaCl solution at a stress of 0.75 MPa, s | 54002   | 49011  | 56175     | 41320     |
| Time before destruction in distilled water at a stress of 0.75 MPa, s     | 69671   | 67712  | 71567     | 64010     |
| Time before destruction in air at a stress of 0.75 MPa, s                | 93335   | 90625  | 95625     | 88007     |
| Coefficient of resistance of asphalt concrete ($K_{l.e.}$) to the influence of 5% aqueous NaCl solution at a stress of 0.75 MPa | 0.57    | 0.54   | 0.59      | 0.47      |
| Coefficient of resistance of asphalt concrete ($K_{l.e.}$) to the influence of distilled water at a stress of 0.75 MPa | 0.75    | 0.75   | 0.75      | 0.73      |
| Time before destruction in 5 % aqueous NaCl solution at a stress of 2.51 MPa, s | 77      | 70     | 80        | 59        |
| Time before destruction in distilled water at a stress of 2.51 MPa, s     | 93      | 90     | 96        | 88        |
| Time before destruction in air at a stress of 2.51 MPa, s                 | 124     | 120    | 128       | 117       |
| Coefficient of resistance of asphalt concrete ($K_{l.e.}$) to the influence of 5% aqueous NaCl solution at a stress of 2.51 MPa | 0.62    | 0.58   | 0.63      | 0.50      |
| Coefficient of resistance of asphalt concrete ($K_{l.e.}$) to the influence of distilled water at a stress of 2.51 MPa | 0.75    | 0.75   | 0.75      | 0.75      |

All time dependences presented in Figure 2 for asphalt concrete on different mineral components are located in the same way - above all are the dependences of the time to failure of asphalt concrete tested in air, in the middle, tested in distilled water, and the lowest dependences relate to the test 5 % aqueous NaCl solution. This location corresponds to well-known ideas, because the operation of asphalt pavements in natural conditions under the action of air depends only on the value of the applied voltage, as well as its durability. However, as climatic conditions change, the action of stress can be accompanied by the action of liquid media, such as rain or melt water and chloride solutions, which are used to combat winter slipperiness. But some differences distinguish these dependencies. Closest to each other are these three dependences for the limestone filler, which indicates the best interaction of mineral components with bitumen, and this corresponds to well-known ideas and previously performed research [23-27].

The resistance of asphalt concrete on the limestone components of the aggressive action of liquid environment is the highest, as evidenced by the coefficient of resistance of asphalt concrete to liquid environment ($K_{l.e.}$), which was at a stress of 0.75 MPa for 5% aqueous salt solution 0.59 (table 5). The duration of the aggressive environment at the lowest stress of 0.75 MPa was more than 11 hours, which allowed for such a long time to penetrate the aggressive environment between the bituminous film and the mineral surface and contribute to the destruction of asphalt concrete, so $K_{l.e.}$ for all single-breed asphalt concrete samples the smallest. The action of the aqueous medium is less aggressive, which is also confirmed by the values of $K_{l.e.}$, which for almost all samples was 0.75 at all stresses. However, if we consider the location of the lines of dependence of durability of all monomineral asphalt concrete samples accepted for testing in Figure 3, they are very close to each other, and some even merge, which indicates the overall high stability of asphalt concrete on all accepted rocks.
Figure 3. Dependence of the time before the destruction of asphalt concrete (type “V”) on various mineral materials with 6.0 % BND 60/90 bitumen on stress, at a temperature of 21 °C in environment:

- ○ – limestone air;
- ● – limestone distilled water;
- × – limestone 5 % aqueous solution of NaCl;
- + – granite air;
- ● – granite distilled water;
- * – granite 5 % aqueous solution of NaCl;
- ◇ – basalt air;
- ◼ – basalt distilled water;
- ■ – basalt 5 % aqueous solution of NaCl;
- ▲ – sandstone air;
- □ – sandstone distilled water;
- ▲ – sandstone 5 % aqueous solution of NaCl.

5. Conclusions

Analyzing the test results, we can assume that for all asphalt concretes accepted for testing with the use of mineral materials of different rocks in general, satisfactory durability indicators were obtained, indicating a sufficiently high resistance to liquid aggressive media. However, it should be noted that asphalt concrete, in which the limestone mineral component was used, may have the longest service life in road surface, because its coefficient of resistance of asphalt concrete to the influence of liquid media (K_{l.e}) is the highest at all stress levels. This is explained and corresponds to the well-known laws [23÷27] of better interaction of alkaline mineral surfaces with bitumen in comparison with acidic ones. The predominant surface interaction with alkaline mineral surfaces allows to obtain the best bitumen coating of limestone grains, which in turn allowed to obtain the highest durability, given that the tensile strength of the original rock in terms of fragmentation is not the highest.

Against the background of high normative test results of asphalt concrete on limestone, other results are also quite high and they all meet the requirements of DSTU B V.2.7-119:2011 [1] for asphalt concrete type "V" I brand, as well as it is characteristic and for durability. Compared with the obtained normative coefficient of water resistance at long water saturation on the 15th day (K_{w,l}) for asphalt concrete on granite, the same indicator for asphalt concrete on basalt is higher, which is explained by higher density and strength of the original basalt rock in turn, it was possible to obtain a higher density and strength of asphalt concrete on its basis, but the coefficient of resistance of asphalt concrete on basalt to the influence of liquid media (K_{l.e}) is lower, because its mineral composition contains more augite, hornblende and Labrador than granite, which adversely affects its durability. In general, it can be argued that the results allow the use of dense basalt, dense marble-like limestone and fine-grained sandstone with iron oxide cementation for the production of asphalt mixtures to replace granite rocks.

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