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Microbiological resistance of sand-bitumen concrete

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Bitumen concrete; Strength; Hardness; Resistance; Filamentous fungi; Modulus of deformation; Linear interpolation; Hermite interpolation; Mean square error

Abstract:

The object of research is the biological resistance of twenty-two samples of asphalt concrete with different bitumen content. **Method.** Laboratory testing of samples of asphalt concrete mixtures for fungal resistance and the presence of antifungal properties. Determination of changes in strength and elastic-plastic properties of materials. **Results**. Based on the conducted studies of biostability and the proposed methods for monitoring changes in hardness and modulus of deformation, the most preferable compositions were deter-mined with respect to their resistance to the effects of filamentous fungi. For each group of samples and mixtures of bitumen concrete under study, their ranking according to the degree of the resistance to the effects of the external microbiological medium is provided.

1 Introduction

The issue of damage to various materials in operational conditions is very multifaceted and related to all types of industry, including space, aviation, shipbuilding, defense and construction industries, which indicates the importance and topicality of the problem of increasing their durability and, of course, is of great scientific and practical interest [1]-[5].

Articles [6]-[15] are devoted to the urgent problem of biocorrosion of ships. The physical and biological roughness of the ship's hull increases the resistance to friction of ships, increases fuel consumption and carbon emissions to the environment.

It is known that one of the most significant industries where corrosion processes should be taken into account is the construction industry [17]. Considerable attention has been paid to the processes of biocorrosion in buildings and structures. Biocorrosion of mineral building materials as a rule includes a number of various factors: microbiological (forming colonies of microorganisms), physiochemical (temperature, humidity, chemically aggressive environments), mechanical (formation and development of microcracks in materials), etc. [18]. In this regard, the issue of identifying relatively simple, reliable and inexpensive quantitative methods for assessing the bio-damage of construction materials is extremely topical.

Experiments for studying the behavior of materials under the influence of microorganisms and field surveys of buildings and structures indicate a decrease in strength indices, deterioration of concrete and brick products, lifting of plaster coatings, discoloration or formation of pigmented spots on paint coatings, dissolution of glass, swelling of putties [19]. Cellulose-containing materials are most vulnerable to biodegradation. For example, fungi can destroy structures made of wood materials in a few months [1]. It is estimated that the damage caused to buildings and structures as a result of biological deterioration amounts to tens of billions dollars annually [2].

A survey of buildings and structures operated in biologically aggressive media showed the presence of a significant amount of mold fungi on the surface of building materials. The largest number of biodegraders of building materials belongs to the class of Deuteromycetes. They are represented by such genera as Geotrichum, Scopulariopsis, Alternaria, Cladosporium, Aspergillus, Fusarium, Paecilomyces, Penicillium, Trichoderma, Trichosporiella [20].

It should be noted that currently the existing range of bio-damaged materials has significantly expanded. This is obviously due to the fact that with the expansion of the range of manufactured building materials and products, biological agents adapt to new conditions and damage almost everything that man has created: building materials, paint coatings, adhesives, rubbers, glass, as well as metals.

In the field of corrosion protection and biocorrosion in Russia, a series of state standards are being developed and are already in effect, united by the common name "Unified System of Corrosion and Aging Protection".

The standards contain testing methods that consist in holing products or materials infected with mold spores in conditions optimal for their development, followed by an assessment of fungiresistance and fungicidity. The methods reveal whether the tested materials are a source of nutrition for the development of mold fungi, as well as the presence or absence of fungicidal properties in the materials and the influence of external pollutants on the fungiresistance of materials and products. It is important to establish the effect of biologically active media on the physical and mechanical properties of materials [21].

The biostability of cement, polymer building materials in biological media has been studied to a greater extent. The biostability of materials based on bitumen binders - bitumen concrete has been studied to a lesser extent [22,23].

The purpose of the work was to study the microbiological resistance of bitumen concrete of various compositions.

Research objectives:

1. Conducting research on the biostability of bitumen concrete containing mineral fillers of various types.

2. Identification of changes in the hardness and modulus of deformation of bitumen concrete mixtures after holding in a biological medium.

2 Materials and Methods

To determine the biological resistance of bitumen concrete mixtures, there were formed samples - beams with dimensions of 1.0x1.0x3.0 cm. Twenty-two samples of bitumen concrete mixtures were prepared.

The content of components in bitumen concrete samples are presented in Table 1.

Table 1. The content of components in bitumen concrete mixtures

Samples	Components						
	Natural sand	Crushing dust	Mineral powder	Flour	Waste glass	Bitumen BND 60/90, over 100%	Polymer-bitumen binders, over 100 %
No. 1	87	-	13	-	-	12	-
No. 2	87	-	13	-	-	8	-
No. 3	60	34	6	-	-	10	-
No. 4	60	34	6	-	-	6	-
No. 5	25	69	6	-	-	6	-
No. 6	25	69	6	-	-	10	-
No. 7	87	-	-	13	-	8	-
No. 8	87	-	-	13	-	12	-
No. 9	87	-	13	-	-	-	8
No. 10	87	-	13	-	-	-	12
No. 11	60	34	6	-	-	-	10
No. 12	60	34	6	-	-	-	6
No. 13	25	69	6	-	-	-	6
No. 14	25	69	6	-	-	-	10
No. 15	87	-	-	-	13	8	-
No. 16	87	-	-	-	13	12	-
No. 17	60	34	-	-	6	10	-
No. 18	60	34	-	-	6	6	-
No. 19	25	69	-	-	6	6	-
No. 20	25	69	-	-	6	10	-
No. 21	87	-	13	-	-	8	-
No. 22	87	-	13	-	-	12	-

The different content of petroleum bitumen was taken to determine the influence of the structure of bitumen concrete on the change of its properties in the process of biocorrosion.

Samples of materials were placed in Petri dishes. The surface of the samples was infected with a dispersion of fungal spores by steady spraying, preventing the merging of droplets. The tests were carried out at a temperature of (29 ± 2) ˚C and a relative humidity of more than 90%. The duration of the tests for assessing the fungi resistance of materials according to the degree of fungi development is 28 days with an intermediate inspection after 14 days. Laboratory tests for resistance to mold fungi were carried out in accordance with GOST 9.049-91" Unified system of corrosion and ageing protection. Polymer materials and their components. Methods of laboratory tests for mould resistance" [24]: tests of materials for fungal resistance and the presence of anti-fungal properties. The following types of micromycetes were used as test-organisms: Aspergillus niger van Tieghem, Aspergillus terreus Thorn, Aspergillus oryzae (Ahlburg) Cohn, Chaetomium globosum Kunze, Paecilomyces varioti Bainier, Penicillium funiculosuin Thorn, Penicillium chrysogenum Thorn, Penicillium cyclopium Westllng, Trichoderma viride Pens, ex Fr. The essence of the methods is to hold materials infected with fungal spores in conditions optimal for fungi development, followed by the assessment of fungal resistance according to the degree of the development of mold fungi and (or) in terms of changing the characteristic parameters of the materials properties. The methods determine: 1 fungi resistance of materials and their components in the absence of mineral and organic contaminants. 3 presence of fungicidal and fungistatic properties and fungal resistance of materials and their components in conditions simulating mineral and organic contamination. Along with the assessment of fungal resistance and fungicidity, it is important to determine changes in the strength and elastic-plastic properties of materials and, first of all, hardness and modulus of deformation [25].

The degree of fungal fouling (fungal resistance and fungicidity) and changes in physical and mechanical properties (hardness and modulus of deformation) were considered as characteristics for assessing the microbiological resistance of materials.

When conducting research, bitumen concretes related in terms of the structure to dense and highly porous materials were considered as the objects of the research. The materials were tested using a Hoppler consistometer [26]. The change in the elastic-plastic properties of bitumen concrete after exposure to filamentous fungi compared with reference samples of the same composition was evaluated in terms of hardness and modulus of deformation of the material 15 minutes after the application of the T15 load. Taking into account the specific conditions used in the study of materials for biostability, a special form was developed for the manufacture of samples [27].

3 Results and Discussion

Indicators of biological resistance of bitumen concrete of various compositions are given in Table 2.

Table 2. Resistance of bitumen concrete samples to microorganisms

Sample	Degree of fungal growth in points according to method		Characteristics according to GOST 9.049-91 [13]
No.	1	3	
1	2,3,2	5	Non-fungus resistant, non-fungicidal
2	3	5	
3	3,3,2	5	
4	3,2,3	5	
5	3,2,3	5	
6	3,2,2	5	
7	5	5	
8	5	5	
9	3	5	
10	2	5	Fungus-resistant, non-fungicidal
11	2	5	
12	2	5	
13	4	5	Non-fungus resistant, non-fungicidal
14	3,2,3	5	
15	3,4,4	5	
16	3,2,3	5	
17	3,2,3	5	
18	3,2,3	5	
19	3,2,2	5	
20	3,3,2,2	5	
21	5	5	
22	5	5	

During the tests, it was found out that almost all the samples of the tested bitumen concrete showed their fungal non-resistance and non-fungicidity. The research results show that bitumen concrete mixtures are subject to microbiological deterioration, which requires taking measures to increase their biostability. The exception were samples with a polymer-bitumen binder. In dense bitumen-concrete mixtures, biological resistance indicators are usually higher than in porous ones. It also follows from the research results that the problem of bio-damage of building materials, products and structures is very far from being resolved and the need for research in this area is becoming more topical and essential.

Further, the results of the study of the hardness and deformative properties of bitumen concrete before and after exposure in biological media were obtained (Table 3).

Table 3. Hardness and modulus of deformation of dense and highly porous bitumen concrete mixtures

Sample	Hardness, MPa				Modulus of deformation, MPa				Note
	Reference sample	Time of exposure to biomedium, months			Reference sample	Time of exposure to biomedium, months			
		1 month	3 months	6 months		1 month	3 months	6 months	
1	1.48	0.61	1.36	1.6	0.66	0.18	0.58	1.69	Dense bitumen-concrete mix of D type
8	0.84	0.45	0.56	0.32	0.6	0.24	0.32	0.14	
10	1.48	0.8	2.16	2.77	1.42	0.59	2.48	3.61	
16	1.27	1.44	0.83	1.55	1.16	1.34	0.59	1.85	
22	0.28	0.62	0.61	0.38	0.12	0.38	0.39	0.18	
2	0.33	0.48	2.01	1.03	0.15	0.27	2.26	0.82	High is porous sand bitumen-concrete mix
7	0.05	0.14	0.4	0.05	0.01	0.05	0.24	0.01	
9	0.05	0.44	2.16	0.69	0.01	0.24	2.53	0.44	
15	0.57	1.09	0.72	0.4	0.34	0.89	0.48	0.2	
21	0.05	0.44	0.36	0.49	0.01	0.24	0.19	0.28	
3	0.05	1.1	1.19	1.4	0.01	0.93	1.01	1.29	Dense bitumen-concrete mix of G type
11	3.4	1.09	3.26	5.12	4.93	0.95	5.83	9.2	
17	0.99	3.97	0.67	2.37	1.05	6.93	0.46	3.61	
4	0.05	6.66	1.62	3.21	0.01	16.04	1.62	4.51	High is porous sand bitumen-concrete mix
12	0.05	0.15	14.98	2.74	0.01	0.06	65.74	3.98	
18	1.09	1.34	2.06	1.14	0.99	1.53	2.4	0.98	
5	0.37	11.77	1.75	12.19	0.23	32.7	2.02	12.05	High is porous sand bitumen-concrete mix
13	0.05	6.76	1.72	26.18	0.01	18.6	2.97	130.62	
19	4.32	4.03	3.91	2.73	7.96	6.63	6.2	3.99	
6	1.06	0.76	6.99	7.35	0.85	0.53	15.8	17.6	Dense bitumen-concrete mix of G type
14	3.35	12.21	1.45	8.82	4.78	36.08	1.4	24.75	
20	0.05	3.75	3.68	2.61	0.01	5.66	6.0	3.34	

Further, the proposed method for assessing the resistance of samples was applied for the ratio of hardness and modulus of deformation of composites on the surface of samples, k=T/E before and after exposure to the biological medium. We consider this ratio as a complex indicator that characterizes both the strength and elastic-plastic properties of the material. The calculation results are provided in Table 4.

Table 4. Index (coefficient) of the ratio of hardness to modulus of deformation (k=T/E) of dense and highly porous bitumen concrete mixtures before and after exposure to biomedia

Sample	Coefficient k=T/E				Note
	Reference sample	Time of exposure to biomedium, months			
		1 month	3 months	6 months	
1	2.24	3.39	2.34	0.95	Dense bitumen-concrete mix of D type
8	1.40	1.88	1.75	2.29	

10	1.04	1.36	0.87	0.77	
16	1.09	1.07	1.41	0.84	
22	2.33	1.63	1.56	2.11	
2	2.20	1.78	0.89	1.26	High-porous sand bitumen-concrete mix
7	5.00	2.80	1.67	5.00	
9	5.00	1.83	0.85	1.57	
15	1.68	1.22	1.50	2.00	
21	5.00	1.83	1.89	1.75	
3	5.00	1.18	1.18	1.09	Dense bitumen-concrete mix of G type
11	0.69	1.15	0.56	0.56	
17	0.94	0.57	1.46	0.66	
4	5.00	0.42	1.00	0.71	High-porous sand bitumen-concrete mix
12	5.00	2.50	0.23	0.69	
18	1.10	0.88	0.86	1.16	
5	1.61	0.36	0.87	1.01	High-porous sand bitumen-concrete mix
13	5.00	0.36	0.58	0.20	
19	0.54	0.61	0.63	0.68	
6	1.25	1.43	0.44	0.42	Dense bitumen-concrete mix of G type
14	0.70	0.34	1.04	0.36	
20	5.00	0.66	0.61	0.78	

According to Table 4, the samples were ranked according to the metric proposed by the authors. The algorithm for obtaining metrics consists of the following steps [17].

Step 1. Bringing the data of each column to its maximum value.

Step 2. Determination of the Mean values of the values of each column.

Step 3. Calculation of the Metric of each sample by the expression:

Metric = 0;

dtemp = Rtab is Mean;

Metric = Metric + dtemp.

The ranking result is as follows:

Samples Metric
sample №19 => -0.947734
sample №14 => -0.884166
sample №11 => -0.812356
sample №6 => -0.697043
sample №5 => -0.638916
sample №18 => -0.561797
sample №17 => -0.528832
sample №10 => -0.505931
sample №16 => -0.336707
sample №13 => -0.246848
sample №2 => -0.043490
sample №20 => -0.029532
sample №4 => 0.052339
sample №15 => 0.096002
sample №12 => 0.332848
sample №22 => 0.394587
sample №8 => 0.399530
sample №3 => 0.429450
sample №9 => 0.576165
sample №1 => 0.997094
sample №21 => 1.056610
sample №7 => 1.898728

According to this result, sample number 7 from Table 4 is considered to be the preferable one. Accordingly, the less preferable sample is sample number 19 from Table. 4. Calculated metrics can vary from negative values of an arbitrary value to positive values of an arbitrary value as well. To clarify the performed calculations, Fig. 1 is provided.

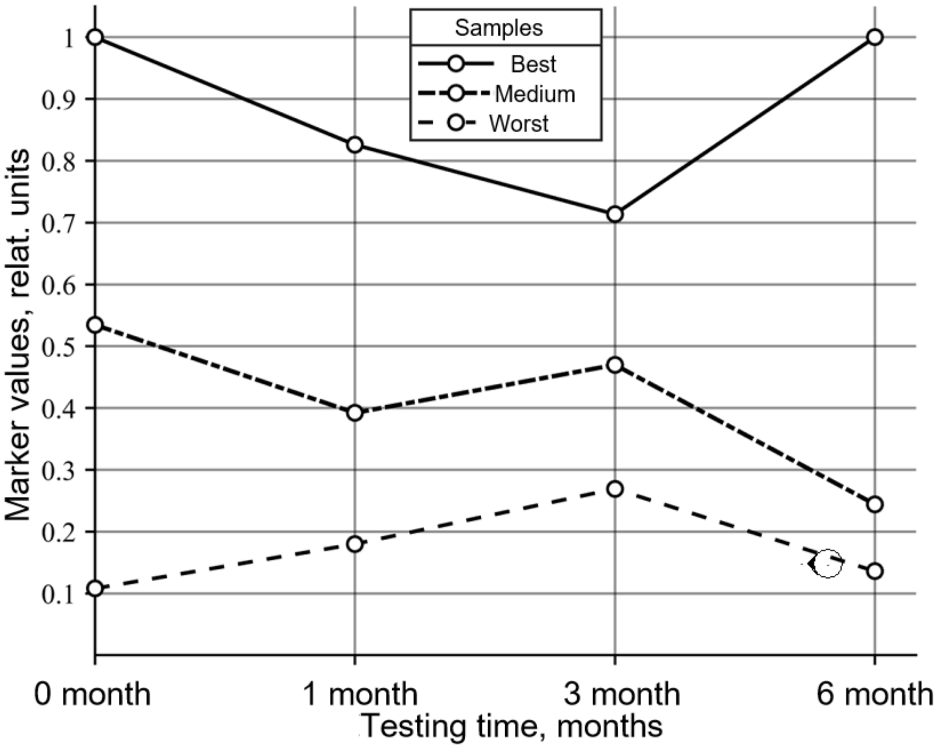

Fig. 1. - Comparative graphs of the best and worst samples relative to the average values of the metric

Linear interpolation of the data was performed at one-month interval. Since this operation is applied to all studied samples, possible interpolation errors can be considered as some instrumental error that refers to all the samples.

Table 4 presents the findings of the conducted experiments with monthly data sampling for the period of six months.

Findings presented in Table 3 allow us to perform a programme estimation of the dependence of deformation modulus of bitumen concrete samples as a result of their exposure in the biomedium.

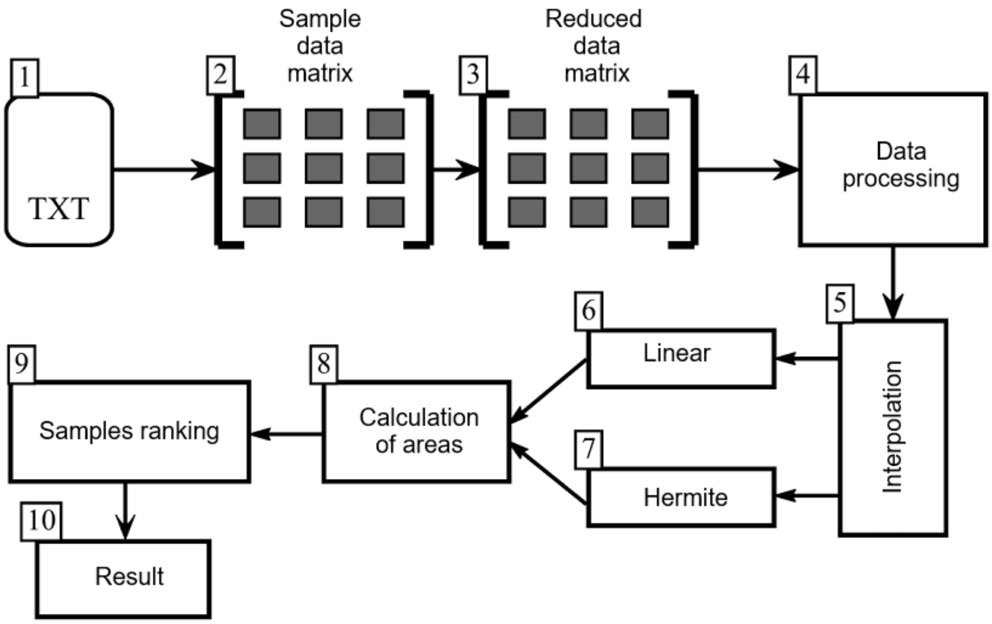

Fig. 2. - Diagram of modeling the process of assessing the change in the ratio of hardness to the modulus of deformation

The numerical symbols in Fig. 2 indicate the following operations:

1 is file system with text files containing numeric data;

2 is forming a matrix of numeric data of the samples under study;

3 is matrix of reduction of numeric data to relative units regarding numeric data of reference samples;

4 is the initial stage of processing numerical data of the studied samples for interpolation of experimental data;

5 is interpolation of experimental data;

6 is linear interpolation with an increase in the number of interpolation points by N times (for example, N = 100) relative to the size of the experimental data;

7 is cubic Hermite interpolation with the number of interpolation points equal to linear interpolation;

8 is calculation of areas (Sk, Si) relative to the exposure time of a polyline figure with linear interpolation and a smooth Hermite interpolation curve;

9 is ranking of samples on the basis of the absolute difference between the area of the rectangle S and the largest of Sk, Si areas, attributed to the base area S. The smaller the found relative value (metric) is, the more stable the deformation modulus will be in the results of the tests in the biological media;

10 is the result of s ranking indicating the sample number and its numeric metric.

The geometric interpretation of the values of the experimental data with the indication of the base area S is provided in Fig. 3.

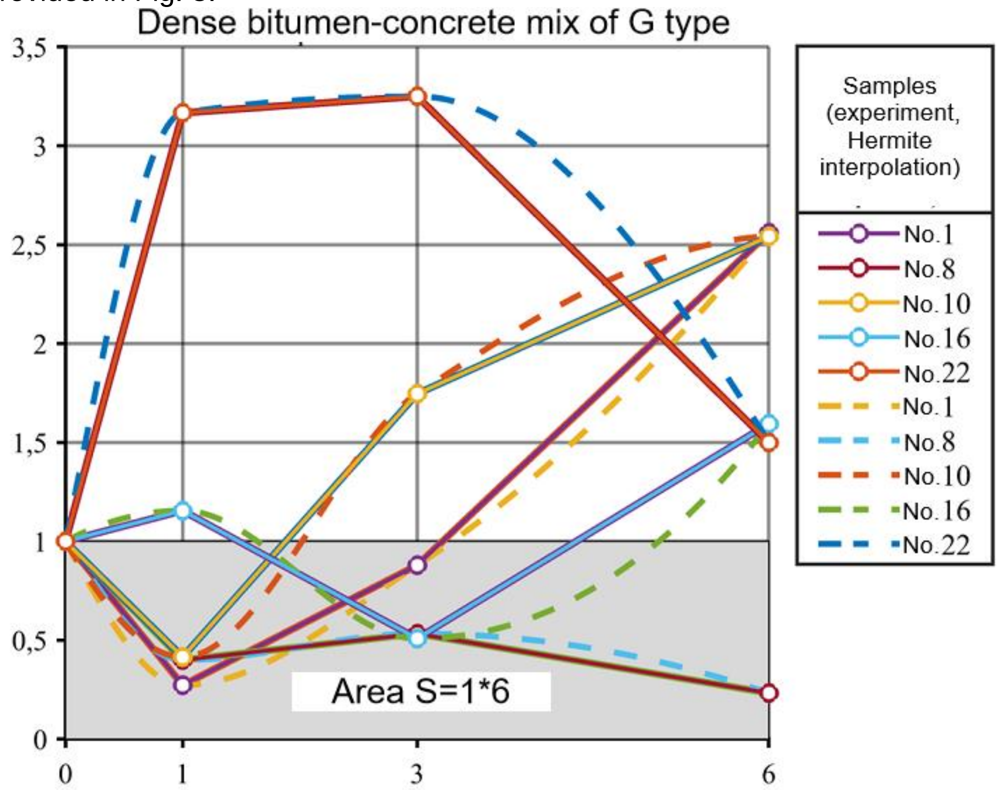

Fig. 3. - Example of data reduction and determination of the base area S

In Fig. 3. the curves of the experimental data coincide with their linear interpolation. The task is to programmatically determine the minimum absolute difference between the value of the base area S and the area of either Sk (formed by a linear interpolation curve) or Si (a smooth curve by cubic Hermite interpolation).

Having the numbering of the samples and their numeric data of the deformation modulus in accordance with Table 3, according to the explanations in Fig. 2 and in Fig. 3, a program was created that in an automated mode made it possible to rank the samples under study. The result is provided in Table 5; the following mixture designations are used:

Mix1 is a dense bitumen concrete mixture of type G,

Mix2 is a highly porous sand bitumen concrete mix,

Mix3 is a dense bitumen concrete mixture of type D.

Table 5. Results of ranking samples according to the metric

№	Samples	Metric, relat.units	Mixture type
1	2	3	4
1	№16	0.017240	Mixture1
2	№1	0.080356	Mixture1
3	№17	0.087299	Mixture1
4	№6	0.249978	Mixture3
5	№21	0.473030	Mixture2
6	№8	0.522529	Mixture1
7	№10	0.550473	Mixture1
8	№5	0.727268	Mixture2
9	№4	1.518347	Mixture2
10	№22	1.604154	Mixture1
11	№20	1.927161	Mixture3
12	№7	7.177759	Mixture2
13	№9	10.583278	Mixture2
14	№14	12.160789	Mixture3
15	№3	19.649921	Mixture1
16	№13	48.855555	Mixture2
17	№11	96.666277	Mixture1
18	№15	121.499563	Mixture2
19	№12	577.224922	Mixture2
20	№18	2839.240278	Mixture2
21	№19	2981.779066	Mixture2

The results presented in Table 5 allow us to make a decision about the quality of the studied samples in the form of the stability of a complex indicator equal to the ratio of hardness to the modulus of deformation in the biological medium. In accordance with the described algorithm for assessing the quality of the studied samples and the data from Table 5, it is clear that the sample number 16 (No. 16) should be considered to be more preferable compared to the other samples. Accordingly, sample No. 19 is less preferable in relation to the other samples in terms of resistance as a result of the tests in the biological medium.

4 Conclusions

The analysis of the literature sources shows that bitumen concrete is early deteriorated due to the insufficient stability of its physical and technical properties. Quite often, the change in the elastic-plastic properties of bitumen concrete occurs as a result of its exposure to the microbiological media and, in particular, filamentous fungi.

This paper presents studies of changes in elastic-plastic properties on the surface of samples of bitumen concrete of various types in a standard filamentous fungus medium. Sand bitumen concrete of dense and high-density structure were considered as objects of the research.

The results are obtained on the basis of empirical analytical calculations. The main result is the determination of the most preferable sample that is most resistant to changes in elastic-plastic properties during the specified 6-month tests in the biological medium.

The proposed method allows for a software-automated assessment of the quality of a group of samples by changing the elastic-plastic properties in the biological medium.

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