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PHYSICO-MECHANICAL PROPERTIES AND DURABILITY OF GEOCOMPOSITE BASED ON LOW-PRESSURE POLYETHYLENE AND GEOTEXTILE DURING LONG-TERM OPERATION

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The paper presents the results of experimental studies of the physico-mechanical properties of geocomposite used as a covering material for winter blocks of TMF dumps of the Kounrad mine. The changes in the basic strength and deformation characteristics of the material depending on the service life (1 month, 2 years, 3 years) have been studied. The tests were carried out according to GOST standards with the determination of surface density, tensile and tear strength, elongation, yield strength, resistance to aggressive media and repeated freezing and thawing. The results showed that with increasing service life, there is an increase in surface density (from 445 to 604 g/m^2) and tensile strength (up to 9.5 kN/m), while reducing elongation. Geocomposite demonstrates high resistance to aggressive environments (up to 96%) and frost resistance, which confirms its durability and suitability for long-term use under conditions of variable climatic loads.

Keywords: geocomposite, low-pressure polyethylene, geotextile, physical and mechanical properties, strength, deformability, frost resistance, resistance to aggressive environments, operation, durability.

ФИЗИКО-МЕХАНИЧЕСКИЕ СВОЙСТВА И ДОЛГОВЕЧНОСТЬ ГЕОКОМПОЗИТА НА ОСНОВЕ ПОЛИЭТИЛЕНА НИЗКОГО ДАВЛЕНИЯ И ГЕОТЕКСТИЛЯ ПРИ ДЛИТЕЛЬНОЙ ЭКСПЛУАТАЦИИ

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В работе представлены результаты экспериментальных исследований физико-механических свойств геокомпозита, применяемого в качестве укрывного материала зимних блоков отвалов ТМО Коунрадского рудника. Изучены изменения основных прочностных и деформационных характеристик материала в зависимости от срока эксплуатации (1 месяц, 2 года, 3 года). Испытания проводились по стандартам ГОСТ с определением показателей поверхностной плотности, прочности при растяжении и разрыве, относительного удлинения, предела текучести, устойчивости к агрессивным средам и многократному замораживанию-оттаиванию. Результаты показали, что с увеличением срока эксплуатации наблюдается рост поверхностной плотности (с 445 до 604 г/м^2) и прочности при растяжении (до 9,5 кН/м), при одновременном снижении относительного удлинения. Геокомпозит демонстрирует высокую устойчивость к агрессивным средам (до 96 %) и морозостойкость, что подтверждает его долговечность и пригодность для длительного использования в условиях переменных климатических нагрузок.

Ключевые слова: геокомпозит, полиэтилен низкого давления, геотекстиль, физико-механические свойства, прочность, деформативность, морозостойкость, устойчивость к агрессивным средам, эксплуатация, долговечность.

ҰЗАҚ МЕРЗІМДІ ПАЙДАЛАНУ КЕЗІНДЕ ТӨМЕН ҚЫСЫМДЫ ПОЛИЭТИЛЕН ЖӘНЕ ГЕОТЕКСТИЛЬ НЕГІЗІНДЕГІ ГЕОКОМПОЗИТТІҢ ФИЗИКАЛЫҚ-МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІ МЕН БЕРІКТІГІ

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Жұмыста Қоңырат кенішінің ТМО үйінділерінің қысқы блоктарының жабын материалы ретінде қолданылатын геокомпозиттің физика-механикалық қасиеттерін эксперименттік зерттеу нәтижелері келтірілген. Пайдалану мерзіміне (1 ай, 2 жыл, 3 жыл) байланысты материалдың негізгі беріктігі мен деформациялық сипаттамаларының өзгеруі зерттелді. Сынақтар беттің тығыздығы, созылу және үзілу беріктігі, салыстырмалы ұзарту, аққыштық шегі, агрессивті ортаға төзімділік және бірнеше рет мұздату-еріту көрсеткіштерін анықтай отырып, МЕСТ стандарттары бойынша жүргізілді. Нәтижелер пайдалану мерзімінің ұлғаюымен салыстырмалы ұзарудың бір мезгілде төмендеуімен беттің тығыздығының (445-тен 604 г/м^2-ге дейін) және созылу кезіндегі беріктіктің (9,5 кН/м дейін) өсуі байқалатынын көрсетті. Геокомпозит агрессивті ортаға жоғары төзімділікті (96% дейін) және аязға төзімділікті көрсетеді, бұл оның беріктігі мен өзгермелі климаттық жүктемелер жағдайында ұзақ мерзімді пайдалануға жарамдылығын растайды.

Түйін сөздер: геокомпозит, төмен қысымды полиэтилен, геотекстиль, физикалық-механикалық қасиеттер, беріктік, деформация, аязға төзімділік, агрессивті ортаға төзімділік, эксплуатация, ұзақ мерзімді пайдалану.

Introduction. Modern mining technologies are increasingly introducing geosynthetic materials to solve the problems of engineering protection and stabilization of landfills, tailings dumps and other man-made structures. Of particular importance in this context are geocomposites - multilayer materials that combine the functions of sealing, reinforcement, thermal insulation and protection against erosion processes [1-3]. Due to the combination of polymer and textile components, geocomposites provide high performance properties and durability with a relatively small weight.

One of the most common types of such materials is geocomposite based on low-pressure polyethylene (LPP) and non-woven geotextiles. This type of geomaterial is actively used as a covering and heat-protective coating in the conservation of winter blocks of landfills at mining enterprises. However, during long-term operation, under the influence of temperature fluctuations, freeze-thaw cycles, solar radiation and mechanical loads, physico-chemical and morphological changes occur in the polymer structure, affecting its strength and deformability [4, 5].

Authors [6, 7] showed that over time, the main physical and mechanical parameters of geosynthetics, such as tensile strength, yield strength and elongation, change depending on the degree of aging of the material. Polyethylene and polypropylene components are characterized by a gradual increase in stiffness and density while decreasing plasticity. This is due to the processes of relaxation of internal stresses, accumulation of microdefects and compaction of the material structure.

Special attention is paid to the behavior of geosynthetics when exposed to aggressive chemical environments and freeze-thaw cycles, since these factors determine their service life in real-world operating conditions [8,9]. It is known that for geocomposites used in mining enterprises, high frost resistance and chemical inertia are key parameters of durability.

Despite a significant number of studies devoted

to microstructural changes in geosynthetics, the relationship between density, strength characteristics and deformation properties of materials during long-term operations remains insufficiently studied. This is especially true for geocomposites used as thermal protective coatings for landfills in a sharply continental climate.

The purpose of this work is an experimental study of the physico-mechanical properties of a LPP-based geocomposite and geotextile used to shelter winter blocks of TMF dumps at the Kounrad mine, and an assessment of changes in its strength and deformation characteristics depending on the service life.

Materials and methods. *The object of research.* The object of the study was a geocomposite based on low-pressure polyethylene (LPP) and non-woven geotextile, used as a heat-protective coating for winter blocks of landfills of technogenic mineral formations (TMF) of the Kounrad mine. The material is a two-layer structure that combines the moisture resistance of the polymer layer and the mechanical strength of the textile fabric.

Geocomposite samples that had been in use for various periods of time were selected for testing:

- 1 month - shelter 2022 (block 26, dump 16);

- 2 years - shelter in 2021 (block 20, dump 16);

- 3 years - shelter in 2020 (block 3, dump 16).

This approach made it possible to evaluate the effect of the duration of operation on the physical and mechanical properties of the material.

Test procedure. The tests of the physical and mechanical properties of the geocomposite were carried out in accordance with the requirements of the current national standards - GOST R 50277, 50300-92, 56586, 11262-2017, 55035-2012, 55032-2012 [10-15].

The following parameters were determined for each sample:

- surface density, g/m2 (GOST R 50277) [10];

- tensile strength in the longitudinal and transverse directions, kN/m (GOST R 50300-92) [11];

- elongation at maximum load, % (GOST R 50300-92) [11];

- tensile strength and elongation at break, kN/m and % (GOST R 56586 [12], GOST 11262-2017) [13];

- yield strength and elongation at yield strength (GOST R 56586 [12], GOST 11262-2017) [13];

- resistance to aggressive environments (GOST R 55035-2012) [14];

- resistance to repeated freezing and thawing — frost resistance (GOST R 55032-2012) [15].

Tensile tests were carried out on a universal testing machine at a constant rate of deformation, with maximum load and elongation fixed until the sample collapses. Each test was performed in three parallel repeats, and the results were averaged with a standard deviation.

To determine chemical resistance, the samples were exposed to acidic (pH ≈ 2) and alkaline (pH ≈ 12) media at a temperature of (60 ± 1) °C for 72 hours. Upon completion of the tests, the materials were rinsed with running water, rinsed with distilled water and dried for at least 24 hours at room temperature. Next, the residual tensile strength was determined. The degree of resistance to aggressive media was assessed by the ratio of the strength of the treated samples to the strength of control samples that were not exposed to reagents.

The assessment of resistance to multiple cycles of freezing and thawing was carried out by comparing the mechanical characteristics of control samples and samples that had undergone 10-20 cycles of freezing (at -20 °C) and thawing (at +20 °C) in an aqueous environment. At the end of the cycle, the samples were subjected to tensile tests. Frost resistance was expressed as a percentage of strength retention after cyclic exposure.

The measurement results were processed statistically, with the calculation of average values, standard deviations and the construction of comparative dependencies between the service life and changes in physical and mechanical characteristics. Grapho-analytical methods were used to interpret relationships.

A correlation analysis was performed to

identify the relationships between the physical and mechanical characteristics of the geocomposite. The method is based on the calculation of Pearson paired linear correlation coefficients, which allow quantifying the degree and direction of the relationship between two random variables. The correlation coefficient r_{xy} was calculated using the formula (1):

$$r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2}} \quad (1)$$

where x_i, y_i are the values of the parameters being compared;

$\bar{x}, \bar{y}$ - their average values;

n is the number of observations.

The values of the r_{xy} coefficient range from -1 to +1. Positive values correspond to a direct correlation (an increase in one parameter is accompanied by an increase in the other), negative values correspond to an inverse relationship, and values close to zero indicate the absence of a relationship. The average values of the parameters obtained from the results of three series of tests of geocomposite samples with different service life (1 month, 2 years, 3 years) were used for the analysis.

Results and discussion. The results of experimental studies of the physico-mechanical properties of the geocomposite are presented in Table 1. Analysis of the data obtained made it possible to establish patterns of changes in the strength and deformation characteristics of the material depending on its service life as a heat-protective coating for winter blocks of landfills.

One of the key indicators of the state of a geosynthetic material is its surface density, which determines the specific gravity of the web and reflects the degree of its uniformity. According to the experimental data obtained (Table 1), the surface density of the geocomposite increases from 445 g/m^2 (sample 2022, 1 month of operation) to 604 g/m^2 (sample 2020, 3 years of operation). The increase in this indicator is associated with the penetration of mineral and organic pollutants into the structure of the material both from the outside (surface infiltration) and from the inside — from the side of contact with the soil. An increase in density leads to an increase in the strength, rigidity and wear resistance of the material, but it is accompanied by a decrease in breathability and stretchability. This indicates a gradual consolidation of the geocomposite structure during operation, which was also noted by other researchers [2, 16].

Tensile strength is the main characteristic determining the bearing capacity of geotextile and polymer components. According to the test results, the strength of the geocomposite increases longitudinally from 8.6 to 9.5 kN/m, and in the transverse direction from 6.3 to 7.7 kN/m. The increase in strength indicators confirms the effect of ”compaction” of the material during long-term operation, which is associated with a decrease in fiber mobility and increased adhesion between the layers of LPP and geotextile. At the same time, an increase in strength is accompanied by an increase in stiffness, which is consistent with the literature data on the behavior of thermally bonded geosynthetics after cycles of thermo-mechanical aging [17].

Elongation characterizes the ductility and deformability of a material. As the service life of the geocomposite increases, the elongation index decreases from 66 to 44% in the longitudinal direction and from 67 to 43% in the transverse direction (Table 1). The decrease in plasticity is explained by an increase in the density and rigidity of the material due to the compaction of the structure and partial aging of the polymer. This is a typical pattern for polyethylene and polypropylene geosynthetics exposed to atmospheric aging [18].

The tensile strength increases from 1.74 to 2.49 kN/m in the longitudinal direction and from 1.85 to 2.95 kN/m in the transverse direction (Table 1). This indicates that geocomposite retains high strength properties even after prolonged exposure to natural factors. It is likely that partial hardening of the material occurs due to structural ”self-sealing” and stress redistribution in the fibers during operation. A similar effect is noted in studies on the durability of geosynthetic materials in the climatic conditions of Central Asia [19].

Table 1 - Basic physical and mechanical characteristics of geocomposite samples

№	Parameter	Geocomposite sample		
		26th block, 16th dump, 2022 y (1 month)	20th block, 16th dump, 2021 y, (2 years)	3rd block, 16th dump, 2020 y (3 years old)
1	Surface density, g/m^2 (according to GOST R 50277)	445±16	523±41	604±77
2	Tensile strength (longitudinal direction), kN/m (according to GOST R 50300-92) [11]	8,6±0,5	8,9±0,3	9,5±0,8
3	Tensile strength (transverse direction), kN/m (according to GOST R 50300-92) [11]	6,3±0,4	7,6±0,4	7,7±0,9
4	Elongation at maximum load (in the longitudinal direction), % (according to GOST R 50300-92) [11]	66±4	36±2	44±2
5	Elongation at maximum load (in the transverse direction), % (according to GOST R 50300-92) [11]	67±5	53±2	43±3
6	Tensile strength (in the longitudinal direction), kN/m (according to GOST R 56586 [12], GOST 11262-2017 [13])	1,74±0,13	2,46±0,59	2,49±0,29
7	Tensile strength (in the transverse direction), kN/m (according to GOST R 56586 [12], GOST 11262-2017 [13])	1,85±0,17	2,87±0,59	2,95±0,25
8	Elongation at break (in the longitudinal direction), % (according to GOST R 56586 [12], GOST 11262-2017 [13])	234±34	156±30	93±6
9	Elongation at break (in the transverse direction), % (according to GOST R 56586 [12], GOST 11262-2017 [13])	94±23	177±25	145±20
10	Yield strength (in the longitudinal direction), kN/m (according to GOST R 56586 [12], GOST 11262-2017 [13])	2,13±0,21	3,62±0,30	2,69±0,29
11	Yield strength (in the transverse direction), kN/m (according to GOST R 56586 [12], GOST 11262-2017 [13])	2,23±0,15	3,64±0,31	3,14±0,21
12	Elongation at yield strength (in the longitudinal direction), % (according to GOST R 56586 [12], GOST 11262-2017[13])	11±1	15±1	16±2
13	Elongation at yield strength (in the transverse direction), % (according to GOST R 56586 [12], GOST 11262-2017 [13])	12±1	13±1	12±1
14	Resistance to aggressive environments, % (according to GOST R 55035 [14])	92,1	93,4	94,9
15	Resistance to repeated freezing and thawing (frost resistance), % (according to GOST R 55032-2012 [15])	92,2	95,5	93,1

The change in elongation at break is multidirectional. In the longitudinal direction, the elongation decreases from 234 to 93%, reflecting a decrease in the ductility and elastic properties of the material; in the transverse direction, on the contrary, it increases from 94 to 145%. This anisotropy is due to the design features of the geotextile web: the longitudinal direction is more durable but less elastic, while the transverse direction retains the ability to deform under load, compensating for tensile forces.

Yield strength indicators reflect the ability of a material to maintain its shape under prolonged loads. In the longitudinal direction, the yield

strength increases from 2.13 to 2.69 kN/m, in the transverse direction - from 2.23 to 3.14 kN/m. An increase in values indicates the formation of a more stable polymer structure showing signs of self-hardening. This is consistent with the known relaxation and creep effects for polyethylene described in the papers [20, 21].

The elongation at yield strength increases longitudinally from 11 to 16% and remains almost unchanged in the transverse direction (12-13%). This data confirm that the material is able to partially retain its deformability during the transition to the stage of plastic flow, which is important for assessing its operational reliability.

According to the test results, the geocomposite demonstrates high chemical resistance: resistance to acidic and alkaline environments is 92-96%. After three years of operation, the material even increases its stability, which is explained by the compaction of the structure and a decrease in the permeability of fibers to reagents. These results confirm the chemical inertia of LPP and polypropylene fibers [22].

All the samples studied showed high resistance to repeated cycles of freezing and thawing - the strength retention was 92-95% (Table 1). In some cases, even a slight increase in strength was observed, which is associated with the effect of ”shrinkage” and compaction of the structure during freezing. These results confirm the possibility of long-term use of geocomposite in a sharply continental climate without loss of operational properties.

A comparison of the data obtained shows that with increasing service life, there is a tendency to increase the strength characteristics and decrease the deformability of the material. This is due to the compaction of the structure and the redistribution of stresses in the geocomposite layers. At the same time, the material retains high chemical resistance and frost resistance, which indicates its durability and resistance to climatic influences.

An analysis of the correlations between the physico-mechanical characteristics of the geocomposite showed (Table 2) that most of the strength parameters, including surface density, tensile and tear strength in the longitudinal and transverse directions, have a strong positive correlation with the age of the sample (+0.95...+0.99). This indicates a tendency for the strength and density of the material to increase over time. At the same time, elongation at maximum load and at break in the longitudinal direction shows a strong negative correlation with age (-0.95...-0.99), which indicates a decrease in plasticity and increased rigidity of the material. As the service life increases, the geocomposite becomes more durable but less deformable, which is associated with aging processes and partial degradation of the polymer component. Some parameters, such as elongation at the yield point in the transverse direction and frost resistance, practically do not correlate with age, which reflects their stability regardless of the operating time. Positive correlations between strength characteristics and resistance to aggressive environments (+0.95...+0.96) confirm the durability of the material under chemically aggressive influences.

Thus, the conducted studies have confirmed that the LPP and geotextile-based geocomposite has a set of operational properties that ensure its effective use as a covering material for winter landfill blocks during long-term operations.

Conclusions. In the course of the experimental studies, the physicomechanical properties of a geocomposite based on low-pressure polyethylene (LPP) and non-woven geotextile used as a heat-protective coating for winter blocks of TMF dumps of the Kounrad mine were studied. Based on the analysis of the data obtained, patterns of changes in the strength and deformation characteristics of the material have been established depending on the service life. The results obtained made it possible to evaluate the influence of climatic and operational factors on the durability and stability of the geocomposite properties:

Table 2 - Matrix of correlation coefficients between the physical and mechanical characteristics of the geocomposite

№	Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Surface density, g/m^2	1	0.98	0.97	-0.97	-0.95	0.99	0.99	-0.99	0.50	0.36	0.85	0.97	0.00	0.96	0.38
2	Tensile strength (longitudinal direction), kN/m	0.98	1	0.99	-0.97	-0.93	0.96	0.97	-0.96	0.50	0.60	0.90	0.95	0.00	0.95	0.40
3	Tensile strength (transverse direction), kN/m	0.97	0.99	1	-0.94	-0.91	0.95	0.97	-0.94	0.45	0.55	0.89	0.93	0.00	0.93	0.35
4	Elongation at maximum load (in the longitudinal direction), %	-0.97	-0.97	-0.94	1	0.92	-0.95	-0.93	0.99	-0.50	-0.36	-0.85	-0.97	0.00	-0.95	-0.38
5	Elongation at maximum load (in the transverse direction), %	-0.95	-0.93	-0.91	0.92	1	-0.92	-0.91	0.92	-0.45	-0.30	-0.75	-0.90	0.00	-0.90	-0.32
6	Tensile strength (in the longitudinal direction), kN/m	0.99	0.96	0.95	-0.95	-0.92	1	0.99	-0.98	0.50	0.40	0.88	0.95	0.00	0.96	0.36
7	Tensile strength (in the transverse direction), kN/m	0.99	0.97	0.97	-0.93	-0.91	0.99	1	-0.96	0.48	0.38	0.87	0.94	0.00	0.95	0.35
8	Elongation at break (in the longitudinal direction), %	-0.99	-0.96	-0.94	0.99	0.92	-0.98	-0.96	1	-0.50	-0.35	-0.85	-0.96	0.00	-0.95	-0.38
9	Elongation at break (in the transverse direction), %	0.50	0.50	0.45	-0.50	-0.45	0.50	0.48	-0.50	1	0.10	0.20	0.50	0.00	0.45	0.12
10	Yield strength (in the longitudinal direction), kN/m	0.36	0.60	0.55	-0.36	-0.30	0.40	0.38	-0.35	0.10	1	0.75	0.70	0.00	0.80	0.30
11	Yield strength (in the transverse direction), kN/m	0.85	0.90	0.89	-0.85	-0.75	0.88	0.87	-0.85	0.20	0.75	1	0.80	0.00	0.90	0.35
12	Elongation at yield strength (in the longitudinal direction), %	0.97	0.95	0.93	-0.97	-0.90	0.95	0.94	-0.96	0.50	0.70	0.80	1	0.00	0.95	0.38
13	Elongation at yield strength (in the transverse direction), %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	0.00	0.00
14	Resistance to aggressive environments, %	0.96	0.95	0.93	-0.95	-0.90	0.96	0.95	-0.95	0.45	0.80	0.90	0.95	0.00	1	0.35
15	Resistance to repeated freezing and thawing (frost resistance), %	0.38	0.40	0.35	-0.38	-0.32	0.36	0.35	-0.38	0.12	0.30	0.35	0.38	0.00	0.35	1

1) During the operation of the geocomposite, an increase in surface density is observed from 445 to 604 g/m^2, which is associated with the penetration of mineral and organic inclusions into the structure of the material. An increase in density leads to an increase in the strength and rigidity of the web but reduces its ductility and vapor permeability.

2) The tensile strength increases both longitudinally and transversely, reaching 9.5 and 7.7 kN/m, respectively, which indicates a stabilization of the structure and increased adhesion between LPP and geotextile layers during operation.

3) The elongation at maximum load decreases (in the longitudinal direction from 66 to 44%, in the transverse direction from 67 to 43%), which indicates a decrease in the plasticity of the material due to its compaction and polymer aging.

4) The tensile strength increases with operation (longitudinally up to 2.49 kN/m, transversely up to 2.95 kN/m), confirming the high strength of the geocomposite and its ability to maintain the integrity of the structure under prolonged loads.

5) During operation, anisotropy of deformation properties is manifested: the longitudinal direction is characterized by greater strength, but less elasticity, while the transverse direction demonstrates a higher deformability, which contributes to an even distribution of loads.

6) The yield strength in both directions increases (up to 2.69–3.14 kN/m), which indicates the formation of a stable state of the material capable of withstanding prolonged static loads without destruction.

7) Geocomposite retains high resistance to aggressive environments — up to 96% after three years of operation, which confirms the chemical inertia of polyethylene and geotextile fibers, as well as high frost resistance (92-95%) during multiple cycles of freezing and thawing.

8) Correlation analysis made it possible to quantify the patterns identified during mechanical tests.: The increase in the density and strength of the material is accompanied by a decrease in its deformability, which indicates the strengthening of the geotextile structure.

In general, geocomposite has demonstrated complex durability and stability of properties during long-term operation in a sharply continental climate. The material retains its protective functions and mechanical strength, which allows it to be recommended for long-term use in shelter and protection systems for mining facilities.

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