ГЕОМЕХАНИКА. РАЗРУШЕНИЕ ГОРНЫХ ПОРОД. ФИЗИЧЕСКИЕ И ХИМИЧЕСКИЕ ПРОЦЕССЫ ГОРНОГО ПРОИЗВОДСТВА

DOI: 10.21440/0536-1028-2021-1-27-35

The effect made by the interaction between rock and fibrous polymeric materials on the geotechnological processes

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Abstract

Introduction. When mining by opencast, mining enterprises use dams and dikes to create circulating water settling basins. The settling basins are equipped with layer drainages carrying groundwater off and ensuring stability of structures. Fibrous polymeric materials (geotextiles) can be used as drainages serving as protective and drainage layers in the bases of heaps in the process of metals leaching from rocks.

Research methodology. Geotextile drainages are calculated taking into account the uniform pressure from the overlying rock mass. Local deformation of fibrous materials caused by the force action of coarse rocks is not taken into account. Experimental studies of rock pressure on fibrous polymer materials have been carried out. The force measurement system creates the required force, the depth of the cone penetration into the fibrous material is measured using a dial indicator. The materials with a bulk density of 70, 110, 130 kg/m³ were used.

Results. Analysis and discussion. The above theoretical studies allow to consider the probable cases of macrocontacts between rock and fibrous media and determine the ratio of local deformation in order to clarify fibrous media sizes and characteristics in future function as drainage and protective materials.

Conclusions. Local deformations of fibrous media at the contact points may amount to 30–40% locally reducing the drainage capacity of fibrous material. Therefore, when designing structures made of rock, such as dikes, dams, leaching heaps, it is required to increase the design height of fibrous drainage by 10–30% taking into account macrocontacts with rocks.

Key words: mining enterprises; dam; leaching heaps; drainage; fibrous materials; rock; macrocontacts.

Introduction. Mining industry keeps developing well-known technologies of opencast and underground mining as well as valuable components extraction. The number of enterprises has risen, which apply the technology of underground and heap leaching of metals. Modern technologies are based on the indicators of resource efficiency, investment and operating costs reduction, and physical-technological processes effectiveness improvement.

Innovation technologies apply scientific and technological achievements and unconventional materials. Such materials include artificial fibrous polymeric materials (geotextiles) based on the polyester, polyamide, and polypropylene fibers. Geotextiles are processable, durable, and cost-efficient, being successfully applied in rail and motor roads foundation construction in order to control the processes of draining, reinforcing, hardening, and deformation reduction [1, 2].

Table 1. Basic physical and mechanical characteristics of geotextile materials
Таблица 1. Основные физико-механические характеристики геотекстильных материалов

Name	Country of origin	Fiber	Type of material	Width, m	Material thickness, mm	Surface density, kg/m ²	Transmission constant, m/day	Tensile strength, N/m	Specific elongation, %
Dornit F-1	Russia	polyester	needle-punched	2.5	4	0.4–0.6	70–120	90–100	60–80
F-2				2.5	4	0.4–0.5	80–150	50–70	80–100
Svteks	Russia	polyamide	needle-punched	2.5	4	0.6	120	90–120	70–100
Bidim	France	polyester	needle-punched	4.0	3–4	0.34; 0.55	80–100	80–90	70–100
Typar	USA	polypropylene	heat-treated needle-punched	5.0	2–3	0.2	More than 50	100–120	60
Armodor	Russia	polypropylene	heat-treated needle-punched	4.0	1	0.16	3–40	50–60	110–130
Polyfelt	Austria	polypropylene	needle-punched	5.0	3	0.35	More than 50	120–130	–
Terfil	Hungary	polyester	heat-treated needle-punched	4.0	3–5	0.35–0.5	More than 50	150–200	–
Heidelberg	Germany	polyester	heat-treated needle-punched	4.0	1–3	0.07–0.28	More than 50	30–120	40–60
Terram	England	polypropylene; polyamide	heat-treated needle-punched	3.0	1–2	0.07–0.14	More than 50	30–50	70
Stratum	Italy	polypropylene	needle-punched	3.0	3–6	0.3–0.8	More than 50	60–200	50–100

Due to high filtration coefficient ($5 \cdot 10^{-4}$ – $5 \cdot 10^{-3}$ m/s), fibrous polymeric materials may be widely used as drainage and reinforcing layers in embankment dams and dikes aimed at creating circulating water settling basins in mining enterprises [3, 4]. Promising is the trend of using geotextiles as protective and drainage layers in the heap bottoms when leaching gold [5].

Geotextile application in the foundation of open pit motor roads of Yakutalmaz industrial association allowed to reduce the destruction of the backfilled breakstone and gravel, make the road surface more even, ensure groundwater and rainfall drainage, producing the economic effect of 1534 thousand rubles per 1 km [6]. Open pit motor roads are overpressed by 230–250 t capacity dump trucks, at this rate being under hard operating conditions. Layers made of Dornit geotextile laid in the foundation of the open pit railroad of the Upper Kama phosphorite mine ensured gradual settlement of the railroad and groundwater drainage with the economic effect of 28 thousand rubles per 1 km [7]. The studies prove high drainage capacity of the fibrous materials for capillary water retention and transportation when constructing motor roads [8, 9].

The largest amount of fibrous polymeric materials applied in geotechnology has been obtained by manufacturing in the needlepuncher machines with extra thermal bonding [10].

Main physical and mechanical characteristics of geotextiles have been presented in table 1 [5].

Geotextiles possess high biological, chemical, and light resistance. Water saturated samples testing after 300 cycles of freezing down to -50 °C and thawing out have shown almost 100% of tensile strength. The longevity of such materials make up 30–50 years of continuous operation [11]. Fibrous polymeric materials possess high tensile strength retaining elastic properties when strained up to 14%; when compressed the elastic properties retain when strained up to 75%, when increasing medium density by a factor of 4 [5].

Experience of building dams and dikes in the East Siberia, Transbaikal and the Far East, which make up a cascade of settling basins at hydraulic polygons when mining valuable components by opencast, has shown that hydraulic structures up to 10 m high are made of local rock consisting of dry loamy sand, loam soil and fragmentary lumps of various sizes. The dam has the shape of a trapezia with a crest not less than 3 m wide. Here, the filtration flow from the settling basin generates a curvilinear depression with an access to the downstream slope. Drainages made of geotextile at the base of the dam ensure filtration flow drainage retaining the stability of the downstream slope and preventing from filtration deformations [3].

Research methodology. In gold and rare-earth minerals leaching, layer drainage made of geotextile laid in the foundation of the heap serves a dual purpose, carrying off the process solution to the gathering pipeline and protecting waterproof membrane foundation from disruption and destruction [12].

Layer drainage made of geotextile is calculated based on a certain equation by A. Darcy and the system of equations by academician N. N. Pavlovsky [3].

In this calculation, even pressure of rock mass on the drainage layer is taken into account. However, the effect made by some individual very coarse lumps of rock on the geotextile drainage should be taken into account.

The size of rock particles widely ranges from sand-clay grains to boulders. There are lumps of angular shape as well as rounded particles of various size.

Elastic modulus of rock material is 10^4 times as high as elastic modulus of fibrous media, therefore only the fibrous layer becomes deformed in contacts. Considering that there is a variety of shapes and sizes of pebbles, breakstone, and rock detritus, their interaction with fibrous materials has been classified as micro- and macrocontact.

The structure of geotextile represents a three-dimensional system of random synthetic fibers 10–30 μm in diameter, which form 40–120 μm pores in a layer. Due to a large number of layers and their firm adherence, transverse pores are overlapped by the fibers. So the microcontacts are possible provided that the sharp plane of the solid rock is able to draw the fibers apart and penetrate deep into the fibrous media punching through holes. Such state is likely if the diameter of the rock plane is commensurate with the diameters of the pores.

Study of shapes and sizes of 10 to 200 mm rock lumps has suggested that the planes of polyhedrons have the appearance of planar and curved surfaces. There have been no sharp planes of less than 1 mm, consequently, no microcontacts with through holes punched by the rocks in the fibrous media are observed.

The process of microcontact interaction may be pictured consisting of two stages: the development of a crater from the point effect of force and fibrous medium compression by the surface of the polyhedron.

Due to a large number of rock lump planes the with various angles γ_i , it is possible to use the method of reducing the surface of the polyhedron contacting with the fibrous medium to the surface of a cone the base edge of which should be presented in the shape of a disk with a diameter of $2R$ (fig. 1, *a*).

In order to ensure the reliability of the results when substituting the polyhedron with a cone, the surface of the truncated cone should be calculated according to the formula:

$$A_k = \frac{\pi w (\text{tg} \gamma_{\text{mean}} + 2R)}{\cos \gamma_{\text{mean}}},$$

where R is the radius of the base edge of the cone, m; w is the displacement, m;

$\gamma_{\text{mean}} = \frac{1}{\pi} \sum_{i=1}^n \gamma_i$ – is the mean value of the angle.

Displacement of a cone in the process of fibrous medium deformation by the base edge with the diameter of $2R$ can be determined according to the formula:

$$w = \frac{2(1-\mu^2)qR}{E},$$

where μ is the Poisson's ration of the fibrous medium; q is the intensity of load on the area of the cone's base edge, MPa; E is the elastic modulus under fibrous medium compression, MPa.

The second stage of interaction is connected with rock deepening into the fibrous medium and contact surface extend. Polyhedrons with apex angles less than 90° experience lateral pressure σ and fibers friction against the rock surface $f \cdot \sigma$ (fig. 1, *a*). The force of resistance against the fibrous medium deformation P and load intensity q for such polyhedrons are connected with the dependence

$$P = \pi q R^2 + 3.4 \pi c q^3 R^3 \frac{(1-\mu^2)^3 \text{tg}^2 \gamma_{\text{mean}} (\sin \gamma_{\text{mean}} + f \cos \gamma_{\text{mean}})}{E^3 \cos^2 \gamma_{\text{mean}}}, \quad (1)$$

where c is the spatial compressive stiffness of fibrous medium, N/m^3 ; f is the constant of friction.

The analysis of formula (1) shows that the resistance against rock displacement into the fibrous medium grows nonlinearly as soon the depth of penetration increases.

In case the rock polyhedron with cone apex angles of more than 90° interacts with the fibrous media, there is no fiber gliding (fig. 1, *b*). The vertical component of stress at the lateral surface of the cone is found from the equation

$$\sigma \sin \gamma_{\text{mean}} = \frac{15 \cdot 10^4 k \Delta g w^{2.5}}{t_0^{1.5}}, \quad (2)$$

where k is the correction factor; Δ is the density of the fibrous medium, kg/m^3 ; g – gravitational acceleration, m/s^2 ; t_0 – initial thickness of the fibrous material, m .

Fig. 1. Interaction of rocks and fibrous polymeric materials at macrocontacts
Рис. 1. Взаимодействие горных пород и волокнистых полимерных материалов при макроконтактах

After transformation and simultaneous solution of (1) and (2) the following formula is obtained:

$$P = \pi q R^2 + 21 \cdot 10^4 \frac{k \Delta g}{\sqrt{t_0^3}} \operatorname{tg} \gamma_{\text{mean}} \sqrt{1 + \operatorname{tg}^2 \gamma_{\text{mean}}} W_{\text{max}}^{4.5}. \quad (3)$$

Results. Analysis and discussion. As can be seen from above, it is possible to determine the maximum displacement W_{max} of cone lateral surface according to formula (3) knowing the parameters of the fibrous material, R and γ of rock under the known force P .

The adduced theoretical research allows considering the probable instances of macrocontacts between rock and fibrous media and determine the ratio the local deformation in order to specify their dimensions and characteristics in future function as drainage-protective materials.

In order to assess the justification of the proposed model of macrocontacts between the rock polyhedrons and fibrous media, the experiments on power contact between conical solids and fibrous material of various density have been carried out. The hardwood with 60 MPa ultimate strength was use as solids material, which meets the characteristics of solid rock compressive strength. Truncated cones of various dimensions have been mechanically processed. Fibrous materials of Dornit F-1 with 70, 110, 130 kg/m^3 bulk density have been used as fibrous medium. With the weighing

device in an experimental device force P has been determined, while the penetration depth $W_{\max}$ has been determined with the help of the indicator. Cones of solid were produced with angles 2γ equal to 45° , 90° , 135° and the diameters of the base edges of 1, 3, 5 mm.

Cones dimensions were as follows: for angles $2\gamma = 45^\circ$ the height was 40 mm, the diameter of the base edge made up 35–40 mm; for angles $2\gamma = 90^\circ$ the height was 35–40 mm, the diameter of the base edge made up 65–70 mm; for angles $2\gamma = 135^\circ$ the height was 20 mm, the diameter of the base edge made up 85–90 mm.

Fig. 2. Installation diagram for testing the contact interaction of rocks and fibrous materials:

1 – case; 2 – movable plate; 3 – dynamometer DOS-0.1; 4 – fibrous polymeric material; 5 – conical body; 6 – displacement meters; 7 – fixed plate

Рис. 2. Схема установки для проведения испытаний на контактное взаимодействие твердых тел и волокнистых материалов:

1 – корпус; 2 – подвижная плита; 3 – динамометр ДОС-0,1; 4 – образец волокнистого материала; 5 – конусное тело; 6 – измерители перемещений; 7 – неподвижная плита

The experiments on the macrocontact interaction between the rock models and fibrous materials were carried out at the facility presented at fig. 2.

In order to achieve high accuracy of results, each series included 10 tests, statistical processing of the obtained data included mean values calculation, RMS deviations and coefficients of variation. According to the results, the graphs have been built of the contact force P dependence on relative deformation ε under fibrous material compression. Fig. 3 shows dependence graphs for P and ε for fibrous material with the density of $\Delta = 110 \text{ kg/m}^3$ during the point macrocontact.

It follows from the graphs that the growth of depth and degree of compression nonlinearly influence the growth of the contact force.

In the course of the experiment the value of the correction factor (4,5) has been specified: $k = 0.35$ under $\Delta = 70 \text{ kg/m}^3$, $k = 1.05$ under $\Delta = 110 \text{ kg/m}^3$, and $k = 1.4$ under $\Delta = 130 \text{ kg/m}^3$.

Test results testified that divergence between the theoretical calculations and experimental data do not exceed 15% at the penetration depth of 3–3.5 mm, while at the smaller depth such deviations made up 30%. The increase in the apex angles of solid

cones from 45° to 135° results in the growth of force P by 4–6 times depending on the density of the fibrous medium under equal penetration depths.

Nonlinear character of fibrous media deformations under higher loads has been confirmed on trials.

Fig. 3. Graphs of the dependences of the contact force P on the compression ratio of the fibrous material $\Delta = 110 \text{ kg/m}^3$:

1, 4 – $2R = 1 \text{ mm}$; 2, 5 – $2R = 3 \text{ mm}$; 3, 6 – $2R = 5 \text{ mm}$

Рис. 3. Графики зависимостей контактной силы P от степени сжатия волокнистого материала $\Delta = 110 \text{ кг/м}^3$:

1, 4 – $2R = 1 \text{ мм}$; 2, 5 – $2R = 3 \text{ мм}$; 3, 6 – $2R = 5 \text{ мм}$

Summary. The analysis of theoretical and experimental research has shown that at macrocontacts between rock and fibrous polymeric materials used as drainage and drainage-protective layers in the structures made of rock, the local impact of individual rock lumps on the fibrous medium should be taken into account. Local deformations of fibrous media at contacts may amount to 30–40%, which decreases the draining capacity of the fibrous material in this area. For this reason, the design height of drainage made of fibrous material should be increased by 10–30% taking into account macrocontacts with rock, when designing structures made of rocks, such as dams, dikes, and heap leaching heaps.

REFERENCES

1. Kelech U. P., Okeke O. C. Geotextiles and geomembranes: properties, production and engineering applications. *International Journal of Advanced Academic Research*. 2018; 4: 17–32.
2. Wu H. et al. Review of application and innovation of geotextiles in geotechnical engineering. *Materials*. 2020; 7: 2–21. Available from: <https://doi.org/10.3390/ma13071774>
3. Gerasimov V. M., Nizhegorodtsev E. I. Calculation of bed drainages made of fibrous polymeric materials for hydraulic constructions at mining enterprises. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2015; 7: 19–23. (In Russ.)
4. Svalova K. V. *Geosynthetic materials in the processes of filtration and drainage: monograph*. Chita: TSU Publishing; 2016. (In Russ.)
5. Gerasimov V. M. *Fibrous polymeric materials in geotechnology: monograph*. Chita: ChitSU Publishing; 2010. (In Russ.)

6. Shtein V. D. *The experience of applying geotextile materials when constructing mining and conveyor service lines*. Moscow: NIITsVETMET ekonomiki i informatsii Publishing; 1988. (In Russ.)

7. Pevzner M. E., Belenkii P. G., Iliina N. G. The method of reinforcing pit roads with the help of the synthetic fabric. *Gornyi zhurnal = Mining Journal*. 1984; 10: 39–42. (In Russ.)

8. Lin C., Zhang X., Han J. Comprehensive material characterizations of pavement structure installed with wicking fabrics. *Journal of Materials in Civil Engineering*. 2019; 31: 04018372.

9. Wang F., Han J., Zhang X., Guo J. Laboratory tests to evaluate effectiveness of wicking geotextile in soil moisture reduction. *Geotextiles and Geomembranes*. 2017; 45: 8–13.

10. Rawal A., Shah T., Anand S. Geotextiles in civil engineering. Handbook of Technical Textiles. Woodhead Publishing; 2016. P. 111–133.

11. Shcherbina E. V. *Geosynthetic materials in construction: monograph*. Moscow: ASV Publishing; 2004. (In Russ.)

12. Gerasimov V. M. Innovative methods of application of fibrous media in the technologies of mining production. *Actual Science*. 2016; 1(2): 40–41.

Received 7 October 2020

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УДК 622.271:627.824(073)

DOI: 10.21440/0536-1028-2021-1-27-35

Влияние взаимодействия горных пород и волокнистых полимерных материалов на геотехнологические процессы

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Реферат

Введение. На горных предприятиях при разработке месторождений полезных ископаемых открытым способом используются плотины и дамбы для создания отстойников оборотной воды, которые снабжены пластовыми дренажами, обеспечивающими отвод грунтовых вод и устойчивость сооружений. В качестве дренажей могут быть использованы волокнистые полимерные материалы (геотекстилы). В основаниях штабелей кучного выщелачивания металлов из горных пород такие материалы выполняют роль защитно-дренажных прослоек.

Методика исследования. Расчеты дренажей из геотекстильных материалов проводятся при учете равномерного давления от вышележащего массива горных пород. При этом не учитываются локальные деформации волокнистой среды от силового воздействия крупнообломочных горных пород. Проведены экспериментальные исследования давления горных пород на волокнистые полимерные материалы. Силоизмерительная установка создает необходимое усилие, с помощью индикатора часового типа измеряется глубина проникновения конуса в волокнистый материал. Используются материалы объемной плотностью 70, 110, 130 кг/м³.

Результаты. Анализ и обсуждение. Приведенные теоретические исследования позволяют рассмотреть вероятные случаи макроконтрактов горных пород с волокнистыми средами и определить степень локального деформирования для уточнения размеров и характеристик последних в будущей работе в качестве дренажно-защитных материалов.

Выводы. Локальные деформации волокнистых сред в местах контактов могут составить 30–40 %, что уменьшает дренирующую способность волокнистого материала в этой зоне. Поэтому при проектировании сооружений из горных пород: плотин, дамб, штабелей кучного выщелачивания – следует увеличивать проектную высоту дренажа из волокнистого материала на 10–30 % с учетом макроконтрактов с горными породами.

Ключевые слова: горнодобывающие предприятия; плотины; штабели кучного выщелачивания; дренажи; волокнистые материалы; горные породы; макроконтракты.

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Kelechi U. P., Okeke O. C. Geotextiles and geomembranes: properties, production and engineering applications // *International Journal of Advanced Academic Research*. 2018. No. 4. P. 17–32.

2. Wu H. et al. Review of application and innovation of geotextiles in geotechnical engineering // *Materials*. 2020. No. 7. P. 2–21. <https://doi.org/10.3390/ma13071774>

3. Герасимов В. М., Нижегородцев Е. И. Расчет пластовых дренажей из волокнистых полимерных материалов для гидротехнических сооружений горнодобывающих предприятий // Известия вузов. Горный журнал. 2015. № 7. С. 19–23.
4. Свалова К. В. Геосинтетические материалы в процессах фильтрования и дренирования: монография. Чита: ЗабГУ, 2016. 222 с.
5. Герасимов В. М. Волокнистые полимерные материалы в геотехнологии: монография. Чита: ЧитГУ, 2010. 207 с.
6. Штейн В. Д. Опыт применения геотекстильных материалов в строительстве горнотранспортных коммуникаций. М.: НИИЦВЕТМЕТ экономики и информации, 1988. 56 с.
7. Певзнер М. Е., Беленький П. Г., Ильина Н. Г. Метод укрепления карьерных дорог с помощью синтетического полотна // Горный журнал. 1984. № 10. С. 39–42.
8. Lin C., Zhang X., Han J. Comprehensive material characterizations of pavement structure installed with wicking fabrics // Journal of Materials in Civil Engineering. 2019. No. 31. P. 04018372.
9. Wang F., Han J., Zhang X., Guo J. Laboratory tests to evaluate effectiveness of wicking geotextile in soil moisture reduction // Geotextiles and Geomembranes. 2017. No. 45. P. 8–13.
10. Rawal A., Shah T., Anand S. Geotextiles in civil engineering // Handbook of Technical Textiles. Woodhead Publishing; 2016. P. 111–133.
11. Щербина Е. В. Геосинтетические материалы в строительстве: монография. М.: АСВ, 2004. 112 с.
12. Герасимов В. М. Инновационные методы применения волокнистых сред в технологиях горного производства // Научный журнал Actual Science. 2016. № 1, том 2. С. 40–41.

Поступила в редакцию 7 октября 2020 года

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Для цитирования: Герасимов В. М., Нижегородцев Е. И., Воронов Е. Т. Влияние взаимодействия горных пород и волокнистых полимерных материалов на геотехнологические процессы // Известия вузов. Горный журнал. 2021. № 1. С. 27–35 (In Eng.). DOI: 10.21440/0536-1028-2021-1-27-35

For citation: Gerasimov V. M., Nizhegorodtsev E. I., Voronov E. T. The effect made by the interaction between rock and fibrous polymeric materials on the geotechnological processes. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2021; 1: 27–35. DOI: 10.21440/0536-1028-2021-1-27-35