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Experimental research of stress-strain properties of sandy soil when strengthened with polyurethane compounds

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Abstract
In a number of cases during construction and operation of engineering facilities, development of mineral deposits it is necessary to improve the properties of sandy soils by strengthening them with polymer compounds. Analysis of current research shows that the effect of flow rate and method of treatment with polyurethanes on the acquired properties of loose rocks is poorly understood. The paper presents the results of laboratory research of chemical strengthening of sandy soil with polyurethane compounds. Geomaterials typically produced by strengthening loose rock with highly elastic polymers have low strength properties and are stable under only minor loads. To improve the strength, a two-binder sandy soil treatment process is proposed, which includes sequential mixing of the soil with a two-component highly elastic slow-reacting compound and a small volume of a fast-curing one-component resin. The aim of the work is to experimentally investigate the dependence of strain and strength properties of sandy soil on the method of mixing with polyurethane compounds and the polymer volume flow rate. A standard one-component method of mixing samples with highly elastic resin at the resin-to-sand volume ratio from 0.05 to 0.4 and a two-component method including additional treatment with fast-curing one-component resin in the volume of 5% of the strengthened soil were experimentally tested. The effect of polyurethane resins on rock properties was evaluated by triaxial compression strength tests. Electron scanning microscopy was used to determine the content and distribution of cured polymers in the loose rock structure. It was found that the addition of a fast-curing polyurethane compound in the two-component mixing method leads to the formation of aggregates of cured polymer, binding mineral grains without continuous filling of intergranular voids. The presence of such aggregates improves the strength characteristics of sand up to 5 times that is 1.3–3 times more than at the standard one-component mixing with highly elastic resin at a resin-to-rock to be strengthened volume ratio up to 0.3. It was found that under triaxial compression conditions, the geomaterial obtained by the two-component mixing method withstands higher axial stresses. In case the volume ratio of resin to rock is more than 0.3, the strength of the produced geomaterial does not depend on the addition of the fast-curing compound. The study findings practical significance consists in increasing the strength of a sandy soil due to its low-volume strengthening with highly elastic polyurethanes.

Keywords
soil, sand, properties, strength, strengthening, technology, treatment, polyurethane, resin, geomaterial, testing, triaxial compression, failure, strain

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СВОЙСТВА ГОРНЫХ ПОРОД. ГЕОМЕХАНИКА И ГЕОФИЗИКА

Научная статья

Экспериментальные исследования деформационно-прочностных свойств песчаного грунта при его укреплении полиуретановыми составами

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Аннотация
При возведении и эксплуатации инженерных объектов, разработке месторождений твердых полезных ископаемых в ряде случаев необходимо улучшать свойства песчаных грунтов за счет их армирования полимерными составами. Анализ современных исследований показывает, что влияние расхода и

способа обработки полиуретанами на приобретенные свойства рыхлых пород слабо изучено. В работе представлены результаты лабораторных исследований химического закрепления песчаного грунта полиуретановыми составами. Геоматериалы, обычно получаемые при армировании рыхлых пород высокоэластичными полимерами, имеют низкие прочностные свойства и стабильны лишь при незначительных нагрузках. Для повышения прочности предложена технология двухрастворной обработки песчаного грунта, включающая последовательное смешение породы с двухкомпонентным высокоэластичным медленно реагирующим составом и малым объемом быстротвердеющей однокомпонентной смолы. Цель работы – экспериментальное исследование зависимости деформационно-прочностных свойств песчаного грунта от способа смешения с полиуретановыми составами и объемного расхода полимера. Экспериментально протестированы стандартный однорастворный способ смешения образцов с высокоэластичной смолой в соотношении объемов с песком от 0,05 до 0,4 и двухрастворный, включающий дополнительную обработку быстротвердеющей однокомпонентной смолой в объеме 5 % от укрепляемого грунта. Влияние полиуретановых смол на свойства породы оценивали по результатам прочностных испытаний методом трехосного сжатия. Для определения содержания и распределения отвержденных полимеров в структуре рыхлой породы использовался метод электронно-сканирующей микроскопии. Установлено, что добавление быстротвердеющего полиуретанового состава в двухрастворном способе смешения приводит к формированию агрегатов отвержденного полимера, связывающих минеральные зерна без сплошного заполнения межзерновых пустот. Наличие таких агрегатов повышает прочностные характеристики песка до 5 раз, что в 1,3–3 раза больше, чем при стандартном однорастворном смешении с высокоэластичной смолой в объемном соотношении с укрепляемой породой до 0,3. Установлено, что в условиях трехосного сжатия геоматериал, полученный при двухрастворном способе смешения, выдерживает более значительные осевые деформации. В случае объемного соотношения смолы и породы более 0,3 прочность получаемого геоматериала не зависит от добавки быстродействующего состава. Практическая значимость полученных результатов состоит в повышении прочности песчаного грунта при его малообъемном укреплении высокоэластичными полиуретанами.

Ключевые слова

грунт, песок, свойства, прочность, укрепление, технология, обработка, полиуретан, смола, геоматериал, испытание, трехосное сжатие, разрушение, деформация

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Introduction

The design, construction, and operation of engineering facilities, drifting and the sinking for mineral deposit development depend on the properties of soils and the surrounding loose rocks. The most problematic soils include sandy soils with loose structure, high hydraulic conductivity, and poor grading. These features contribute to the intensive manifestation of various negative physical processes, such as liquefaction, subsidence, and soil erosion. In complicated geotechnical conditions, strengthening with polymer compounds, chemical reagents interacting with each other and/or with groundwater is used to improve the properties of loose rocks [1–3]. Such methods are widely used in tunnel construction, underground space development, design of footings and foundations of structures[1] [4]. Various methods of injection strengthening, mixing and tamping with cements, polymer resins are used [5–7]. Technical requirements and regulatory documents, GOST R 59706–2022, have been developed for a number of technologies, such as soil consolidation with cement and sodium silicate based mortars used in construction, reconstruction, and repair of engineering facilities

The advantage of polymer resins is their ability to diffuse into rocks and strengthen them during the polymerization process. This increases the stability of loose soils by binding the individual particles into a single matrix. One type of such compounds is polyurethane resins, which are used not only to strengthen loose rocks, but also to reduce their permeability and prevent fluid filtration [8–10]. Depending on a geotechnical problem to be solved, one-component or two-component polyurethane systems are used. In one-component systems, polymerization occurs by interaction with stratal water. As a rule, such a compound intensively foams, its volume increases several times. An additional advantage is relatively simple

[1] SP 22.13330.2016. Footings of Buildings and Structures. Updated version of SNiP 2.02.01–83. URL: https://lentisiz.ru/wp-content/uploads/2019/01/11_SP-22.133330.2016-Osnovaniya-zdanij-i-sooruzhenij.pdf

pumping equipment for injection into rocks, while the disadvantages are limited storage time, difficulty in controlling the duration of polymerization, high sensitivity to water saturation of rocks and atmospheric moisture.

In two-component polyurethane systems, foamed polyurethane formation occurs as a result of interaction between isocyanate (component B) and polyester compound (component A), a mixture of polyfunctional hydroxyl-containing polyols with a foaming agent and a catalyst [11, 12]. Curing of such resins strongly depends on the uniformity of mixing and distribution of reagent molecules in the volume of the finished compound. The heterogeneity of the mixture impairs the interaction of substances, especially for fast-curing systems. Only resins with low viscosity and long curing time penetrate well into a rock pores. After diffusion and curing of a resin, the particles are "glued" together by the polymer with lesser residual porosity remained [13, 14]. In practice, the use of fast-curing compounds for rock and soil strengthening is complicated by the increase in viscosity due to the short reaction time. This limits the injection volume of a compound, depth and uniformity of its penetration into a rock [15–17]. The use of two-component slow-reacting, highly elastic polyurethane resins solves this problem. They are effective in the construction of cutoff curtains, waterproofing of soils, provide the level of permeability of sandy soil after strengthening corresponding to the values of practically impermeable rocks, about 10^{-4}–10^{-3} μm^2 [18, 19]. At the same time, geomaterials obtained by strengthening rocks with highly elastic polyurethanes have low mechanical strength and are stable only under minor loads [20, 21].

Laboratory testing on rock strengthening with subsequent determination of physical-mechanical, filtration properties of the produced geomaterials allow predicting the results of corresponding field works[2] [22, 23]. The analysis of known studies shows poor understanding of the effect of flow rate and method of polymer treatment on the acquired strength properties of loose and fractured rocks. The present work deals with a two-component method for increasing the mechanical strength of the produced geomaterials, involving sequential mixing of sandy soil specimens with a two-component highly elastic polyurethane compound and a small volume of a fast-acting one-component resin. The aim of the work is to determine the peculiarities of changes in the strength properties of sandy soil depending on the mixing method and polymer volume flow rate based on the results of laboratory testing. The following tasks were set: to investigate the structure, strain and strength properties of geomaterials produced by the one-component and two-component methods of mixing sandy soil with polyurethane compounds and their different volume flow rates; to determine the relationship between the internal structure and strength characteristics of geomaterials, the effect of adding fast-acting polyurethane compound on the mechanical strength of the sand to be strengthened.

Research Materials and Methods

Materials

In the tests, a two-component slow-reacting highly elastic polyurethane resin (hereinafter SR compound) was used, which was designed for consolidation and waterproofing of soils, creation of cut-off curtains. The SR compound is produced by mixing components A and B in a volume ratio of 1:1 to a homogeneous consistency. Component A is a mixture of castor oil (40–41 vol. %), phenoxypropanol (20 vol. %), and low molecular weight polypropylene glycol (40–41 vol. %). Component B is a mixture of methylene diphenyl di-isocyanate (66–67 vol. %), polypropylene glycol (10 vol. %), propylene carbonate (21–23 vol. %). After mixing components A and B, the viscosity of the SR compound is about 95–120 MPa·s and remains low for a long time (tens of minutes). This promotes penetration of the ready-made compound into thin joints, fine-porous soils, increases the effect on a rock, reduces its filtration properties. Full curing time is about 3 h. Meanwhile, the mixture foams and increases in volume. When cured, the SR compound is an impermeable, elastic material, stable at small strains. Technical characteristics are given in Table 1.

To increase the rock strength, in the tests, a one-component fast-acting polyurethane resin (hereinafter, FR compound) was used to strengthen loose, unstable rocks in the course of the construction of underground structures, filling microcracks in concrete and stone structures. The polymerization reaction occurs when the polyurethane compound is mixed with water to a homogeneous consistency in a ratio of 1:1 to 9:1 (resin : water). A 5:1 ratio was used in the tests. Curing time is 90–180 s at a temperature of 25 °C. At the same time foaming occurs due to the release of carbon dioxide, which is a product of the interaction between isocyanate and water. In cured form, the FR compound is a fine-porous foam capable of withstanding significant dynamic and static loads. High viscosity of the compound, 800-1,000 MPa.s at 20 °C, reduces the zone of impregnation of rocks, especially in low-permeable soils, rocks containing thin cracks, etc. Technical characteristics of the FR resin are given in Table 1.

[2] Ortiz R.C. Mechanical behavior of grouted sands. [Master's dissertation]. Kentucky: University of Kentucky; 2015. 117 p.

Table 1

Properties of two-component polyurethane compounds

Indicator	SR compound	FR compound
Purpose	Waterproofing, creation of cutoff curtains, etc.	Strengthening of loose, unstable rocks, etc.
Volume ratio of components A to B	1:1	–
Resin : water volume ratio	–	1:1–9:1
Density (components A/B), g/cm^3	1,01/1,21 at 23 °C	1,614 at 20 °C
Viscosity (components A/B/mixture), MPa·s	115/40/80 at 23 °C	800–1,000 at 20 °C
Curing time, s	about 10,800	90–180
Surface tension at 23 °C, mN/m	35.7	–

Laboratory studies were carried out with sand samples taken from a quarry in the Novosibirsk district of the Novosibirsk region. For the tests we used fine sand, in which 90% by mass belonged to 0.2–0.25 mm particle size fraction. The rock was pre-dried to constant weight, the density of mineral particles and bulk density were determined, and the porosity factor was estimated from the obtained values. The particle and skeletal densities of the dry soil averaged 2.64 g/cm^3 and 1.66 g/cm^3, respectively, and the estimated porosity coefficient was 0.65.

Techniques

The effect of polymer resins on the properties of fine sand was investigated under laboratory conditions. The experiments included several stages: preparation of rock specimens mixed with polymers (geomaterial); strain-strength tests (triaxial compression strength tests); analysis of microstructure and porosity by scanning electron microscopy. Two methods of mixing sand with polyurethane resins were used in the experiments: one-component with ready mixture of components A and B (SR compound); two-component, sequentially with ready SR and FR compounds. In the case of the one-component method, the prepared mixture of components A and B (SR compound) was added to sand and mixed until a homogeneous mass was formed. In the case of the two-component method, sand was sequentially mixed with the prepared SR and FR compounds. Specimens (Fig. 1) were formed at the ratios of volumes of liquid resin and being strengthened loose rock of 0.05, 0.1, 0.2, 0.3 and 0.4 (Table 2). The produced mixture of sand with the reagents was placed into a steel cylindrical mold 50 mm in diameter and 120 mm high, compacted and aged for 24 h until complete curing of the polymers. The specimens were then extracted and machined at a stone-cutting machine, reducing the height to 100 mm.

Table 2

Polyurethane resin content in geomaterial specimens

Specimen No.	Mixing method	SR compound-to-rock volume ratio	FR compound-to-rock volume ratio
1.1	One-component	0.4	0
1.2	The same	0.3	0
1.3	The same	0.2	0
1.4	The same	0.1	0
1.5	The same	0.05	0
2.1	Two-component	0.4	0.05
2.2	The same	0.3	0.05
2.3	The same	0.2	0.05
2.4	The same	0.1	0.05
2.5	The same	0.05	0.05

The produced specimens of geomaterials were tested by triaxial compression testing method using GT 1.3.5 instrument[3]. Strength and strain characteristics were determined in accordance with GOST 12248.3–2020. The tests were performed at a lateral pressure of 100 kPa, axial strain rate of 0.5 mm/min with a vertical load limit of 5,000 kPa. Based on the tests results, the peculiarities of strain of the specimens and ultimate loads were identified, and the values of strain modulus were determined according to the technique recommended by GOST 12248.3–2020. Data recording and processing were carried out using the specialized software program Geotek Studio of SPE Geotek LLC.

[3] Automated triaxial compression instrument GT 1.3.5. URL: https://npp-geotek.com/upload/iblock/3d5/3d5b19682b34abeee1c6ee34f00e5d9d.pdf [Дата доступа: май 2024].

Fig. 1. Geomaterial specimens for triaxial compression strength tests

The produced geomaterials were examined by scanning electron microscopy (SEM). Mineral grains, aggregates of cured polymer were identified from the obtained SEM images, and their content in the volume of strengthened rock was quantitatively estimated [24]. The spatial distribution of heterogeneities and voids, structural features of the geomaterials in accordance with the classification of [25] were determined. The samples for the study were taken along the axis, from the top, middle, bottom of the cylindrical specimens. Data analysis and processing were performed using a Mineral S7 automated analyzer of solids microstructure fragments of SIAMS Company.

Findings and Discussion

The distribution features of cured polyurethane resins in fine sand samples were determined by SEM images. In the geomaterials produced by the one-component method of mixing rock with resin, the cured SR compound occupies a significant part of the void space. Residual porosity is due to voids located near the surface of mineral grains (Fig. 2). As the ratio of resin and rock volumes increases from 0.05 to 0.4, the void space filling with the cured SR compound increases from 43 to 75% or 1.7 times. The linear approximation of the relationship between the above parameters has a coefficient of determination R^2 = 0.83 Fig. 3).

In the specimens produced by the two-component method of mixing sand with polyurethane compounds, the aggregates of cured resins also occupy the majority of the pore space. The fast-curing FR compound occurs near the surface of mineral grains, binding them and forming aggregates with isolated pores in the polymer structure. In addition, residual voiding is due to pores located in the intergranular space (see Figure 2). Studies of samples from the middle and bottom parts of the specimens showed that as the ratio of the volumes of SR resin and FR resin to the being strengthened sand increased from 0.1 to 0.45, the filling of the void space with cured polymers increased from 40 to 72 %, or 1.8 times (see Figs. 2, 3). The formation of aggregates of FR compound with closed pores near the surface of mineral grains can prevent the penetration of low-viscosity SR resin into unfilled voids. The structure of the produced geomaterial depends on the volume ratio of resins and sandy soil. If this ratio is greater than 0.3, the filling of void space with cured compounds is more than 60%, and the geomaterial has a basal structure characterized by a uniform distribution of mineral particles in the mass of the binding material. As the volume ratio of resin and rock decreases to 0.05–0.15, the void space filling with cured compounds decreases to 40–50%, and the produced geomaterial acquires a “contact” structure, in which the binding material occurs mainly at the contacts of grains (see Fig. 2)[4].

The strain and strength properties of the produced geomaterials depend on the internal structure formed as a result of mixing with the polyurethane resins. The mechanical properties of sand strengthened with polyurethane compounds were determined using the diagrams “axial stress σ_v – relative axial strain ε_1”, when the specimens were deformed at a rate of 0.5 mm/min to the value of relative strain ε_1 = 0.15 (15%). It was found that in case of the one-component mixing method with resin-to-rock volume ratios of 0.05, 0.1, 0.2, and 0.3, the produced geomaterial fails with a pronounced strength limit (maximum stress), while at 0.4 it behaves as an elastomer. Moreover, its yield strength in the investigated range of relative strains was not achieved (GOST 4651–2014).

[4] Ortiz R.C. Mechanical behavior of grouted sands. [Master’s dissertation]. Kentucky: University of Kentucky; 2015. 117 p.

The value of the axial stress maximum depends on the content of the highly elastic SR compound in the rock and increases by more than 2.5 times when the amount of the resin decreases 8 times. At ε_1 = 0.15, maximum strength was achieved at the resin-to-rock volume ratios of 0.2, 0.3, and minimum strength was achieved at 0.4. As the amount of the resin increases, the strain value corresponding to the ultimate strength limit of the geomaterial increases (Fig. 4). For the resin-to-rock volume ratios of 0.05, 0.1, 0.2, the ultimate strength limit of the geomaterial is achieved at $\varepsilon_1 \approx$ 0.025, 0.04, and 0.08, respectively (see Fig. 4).

In case of the two-component method of mixing sand with polyurethane resins with addition 5 vol. % of fast-acting resin FR, the pronounced strength limit of the geomaterials was observed when the SR+FR resins-to-loose rock volume ratios were 0.1, 0.15, 0.25. When the volume ratio reaches 0.35, 0.45, the geomaterial behaves similar to elastomers (Fig. 5).

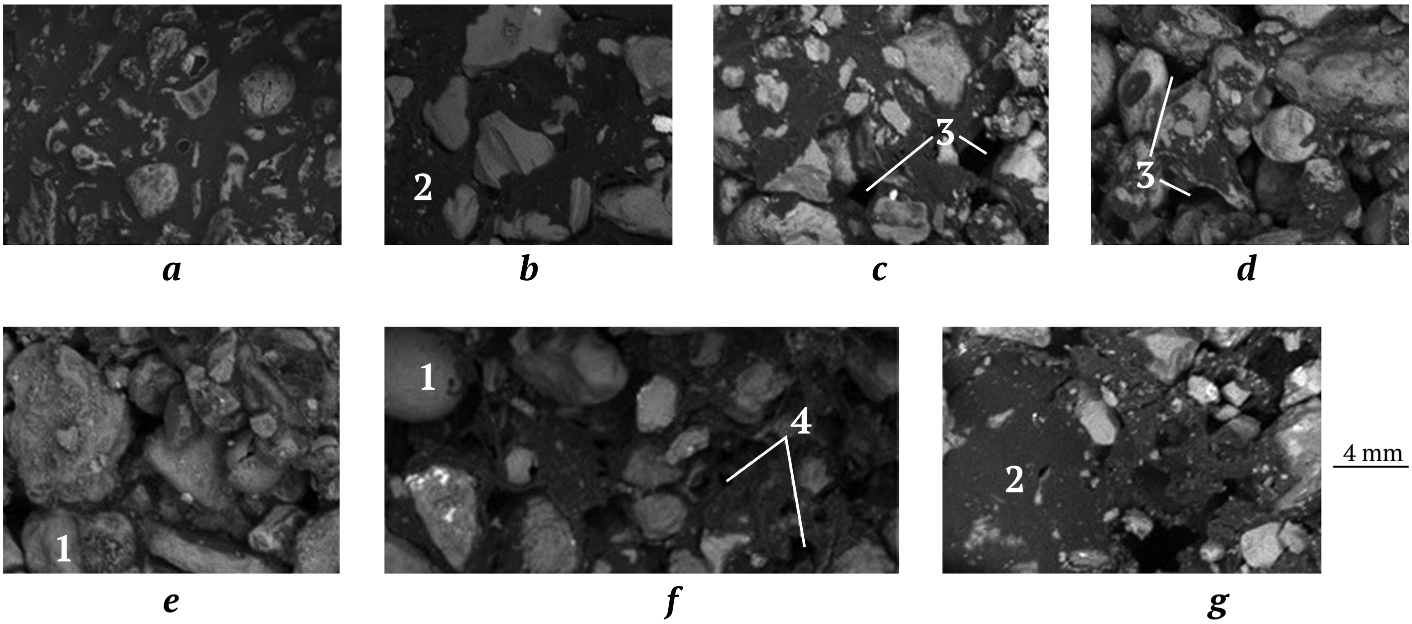

Fig. 2. Fragments of SEM images of geomaterials produced by mixing sand with polyurethane resins. One-component mixing method with a highly elastic SR compound at a volume ratio of resin to rock: *a* – 0.4; *b* – 0.3; *c* – 0.2; *d* – 0.1; *e* – 0.05. Two-component method of mixing with SR and FR compounds at the ratio of volumes of FR compound and strengthened rock of 0.05, SR compound and the rock: *f* – 0.2; *g* – 0.3. Legend: *1* – mineral grains; *2* – cured polymer; *3* – intergranular voids; *4* – closed pores in the structure of cured polymer

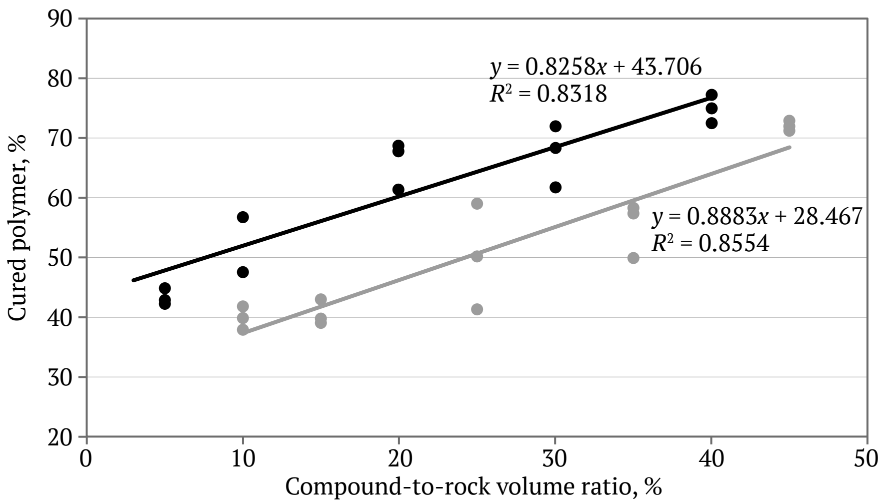

Fig. 3. Cured polymer content in the void volume as a function of the polyurethane resin-to-being strengthened rock (sand) volume ratio based on SEM image analysis. Black and gray circles are data of experimental studies of samples produced by one-component method of mixing sand with SR compound and by two-component method of mixing sand with SR and FR compounds, respectively. Black and gray lines are linear approximations of the experimental data

When the content of the resin compounds decreases 4.5 times, the strength limit increases by more than 9 times. For ε_1 = 0.15, the strength reaches peak at a SR resin-to-rock volume ratio of 0.05, and is minimum at that of 0.4. For the SR+FR compounds-to-rock volume ratios of 0.1, 0.15, and 0.25, the strength limit of the geomaterial is observed at $\varepsilon_1 \approx 0.03$, 0.05 and 0.07, respectively (see Fig. 5, 6).

The specimens strain-strength tests data made it possible to determine the values of strain modulus of the geomaterials. The technique recommended by GOST 12248.3–2020 was used. It was found that when using the one-component mixing method, an eightfold increase in the amount of SR resin reduces the strain modulus of the produced geomaterials by more than 10 times. The largest increase in the strain modulus was achieved when the resin-to-rock volume ratio decreased from 0.2 to 0.1.

The two-component mixing method with the addition of the fast-acting FR polyurethane compound leads to an increase in the geomaterial strain modulus when the SR resin-to-rock volume ratio is 0.05, 0.1, 0.2. If the value of this ratio is higher, the addition of the FR compound has little effect (Table 3).

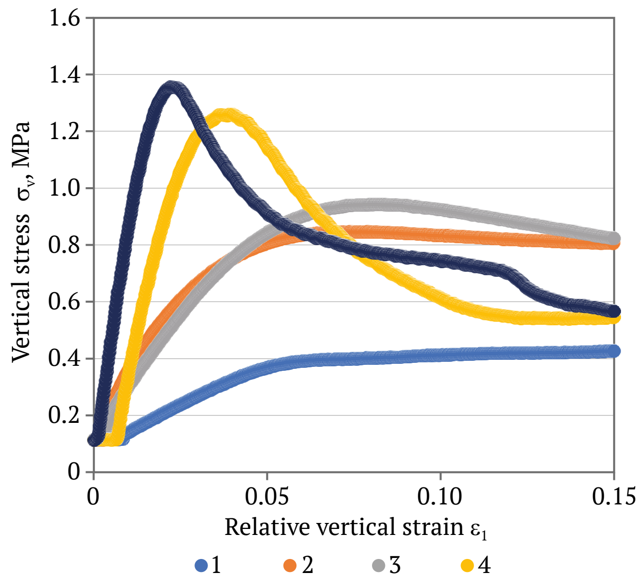

Fig. 4. Axial stress – relative axial strain" graphs of geomaterial specimens produced by the one-component method of mixing sand with highly elastic polyurethane resin SR. Resin-to-rock volume ratio (and cured polymer content determined by the graphs in Fig. 3): *1* – 0.4 (77%); *2* – 0.3 (68%); *3* – 0.2 (60%); *4* – 0.1 (52%); *5* – 0.05 (48%)

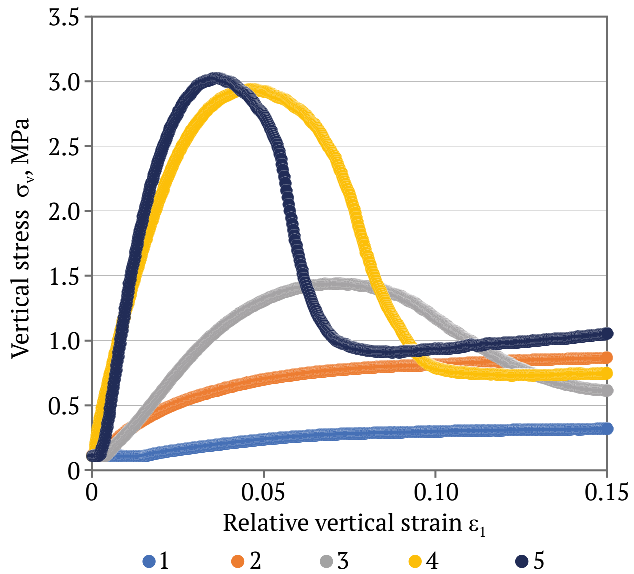

Fig. 5. Axial stress – relative axial strain" graphs of geomaterial specimens produced by the two-component method of mixing sand with highly elastic polyurethane resins SR and FR. Resin-to-rock volume ratio (and cured polymer content determined by the graphs in Fig. 3): *1* – 0.45 (68%); *2* – 0.35 (60%); *3* – 0.25 (51%); *4* – 0.15 (42%); *5* – 0.05 (37%)

a ***b***

Fig. 6. Examples of broken down and deformed geomaterials after triaxial compression tests at SR+FR resin-to-rock volume ratios of: *a* – 0.35, 0.45; *b* – 0.1, 0.15, 0.25

Table 3

Strain modulus of geomaterials as a function of SR compound-to-rock volume ratio

Sample number	SR compound-to-rock volume ratio	FR compound-to-rock volume ratio	Strain modulus, MPA
1.1	0.4	0	5.6
1.2	0.3	0	18.3
1.3	0.2	0	16.1
1.4	0.1	0	53.3
1.5	0.05	0	70.6
2.1	0.4	0.05	5.2
2.2	0.3	0.05	14.1
2.3	0.2	0.05	29.9
2.4	0.1	0.05	101.5
2.5	0.05	0.05	132.7

Comparing the results of the sand mechanical tests before and after strengthening with polyurethane resins, it can be noted that the application of the highly elastic resin at the resin-to-rock volume ratio no more than 0.3 increases the strength of the rock by 1.3–2.3 times. The addition of 5 vol. % of the fast-acting FR resin leads to an additional 1.6–2.2-fold increase in the strength. In the case of the highly elastic resin-to-rock volume ratios greater than 0.3, the nature of the geomaterial strain changes significantly. Compared to the loose rock not treated with the polymers, the strength decreases 1.3–1.7 times and is practically independent of the addition of the fast-acting resin. Such a geomaterial exhibits the properties of a composite elastomer. Its specimens deform without apparent failure and recover to nearly their original size after the load is removed (see Fig. 6).

The experimental studies have shown that under triaxial compression conditions the geomaterials produced by the two-component method of mixing sand with the SR and FR polyurethane compounds withstand higher mechanical loads than those produced by the one-component method of mixing with only one highly elastic resin. It is most pronounced at low resins-to-loose rock volume ratio (0.05, 0.1). At the volume ratios of 0.3, 0.4, the addition of the fast-acting resin has an insignificant effect on the value of the strain modulus of the produced geomaterial.

Conclusion

The method of mixing sand with polyurethane compounds, the resin-to-loose rock to be strengthened volume ratio have a significant effect on the distribution of mineral grains and binder in the produced geomaterial and its strain and strength properties. At the resins-to-rock volume ratio of 0.05–0.15 the filling of its void space with cured polymer is 40–50%. The produced geomaterial has a contact type of structure, in which a binding material is located in the places of contact between mineral grains. Specimens of such geomaterial withstand greater loads than the specimens with the highly elastic resin-to-rock volume ratio greater than 0.3, for which the filling of the void space with the binding polymer reaches 60% or more. As the geomaterial void space filling with cured highly elastic compound decreases from 75 to 43%, their mechanical strength increases more than 2.5 times. On the contrary, the strain value corresponding to the geomaterial strength limit increases with increasing the resin content.

Two-component method of sand mixing with addition of 5 vol. % of fast-curing polyurethane compound leads to intensive formation of aggregates of cured polymer in a loose rock, binding mineral grains without continuous filling of inter-grain voids that significantly increases the strength of the strengthened sand at relatively low consumption of the chemical reagents. The strength of the produced geomaterials increases 2–5 times in comparison with the loose rock before the chemical treatment and 1.3–2.3 times as compared to the one-component method of mixing with highly elastic resin at the resin-to-rock volume ratio less than 0.3. It was found that under triaxial compression conditions, the specimens produced by the two-component method of mixing with the resin compound withstand more significant loads than those produced by the one-component mixing with only one slowly reacting highly elastic resin. If the highly elastic resin-to-rock volume ratio was greater than 0.3, the geomaterials withstanding only low loads were formed, and the addition of the fast-acting compound is ineffective in this case.

The study findings practical significance consists in increasing the efficiency of using low-viscosity highly elastic polyurethane resins in solving problems of loose rock stabilization. The experimental studies have shown that the method of two-component mixing with the addition of fast-acting polyurethane resin significantly increases the rock strength. The pronounced nonlinear dependence of strain and strength properties of geomaterials on the method of mixing and polyurethane resins-to-rock volume ratio indicates the expediency of optimizing the modes of chemical treatment taking into account a geotechnical problem to be solved. This allows, on the one hand, reducing the consumption of expensive polymers per unit volume of a rock, and, on the other hand, improving the mechanical properties of the produced geomaterials. In the future it is planned to investigate the regularities of changes in physical-mechanical and filtration properties of loose rocks when using other types of polymers, in particular, organomineral resins, to solve the problems of stabilization of loose rocks under conditions of rock pressure and filtration of underground fluids.

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